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PHD THESIS

EVALUATION OF THE BIODIVERSITY IN SUSTAINABLE DEVELOPMENT USING GIS

BY

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TABLE OF CONTENTS

APPENDICES

ACRONYMS

Abbreviation	Description
CSDI	Composite Sustainable Development Index
EEA	European Environment Agency
IUCN	The World Conservation Union
SD	Sustainable development
“Three Es”	Environment, Economy and Equity
FL	Fuzzy Logic
SAT	Significance-Acceptability Transformation
FANP	Fuzzy Analytic Network Process
GIS	Geographic Information System
PSR	Pressure-State-Response
(S)	Social Indicators, i.e. Society
(EC)	Economic Indicators, i.e Economy
(EN)	Environmental Indicators, i.e. Environment
(S1)	Population Theme
(S6)	Transportation Theme
(EC3)	(Production & Consumption) – Agricultural Goods;.
(EC4)	(Agriculture) – Agriculture;
(EC5)	(Industry) – Industry;
(EC6)	(Tourism) – Tourism
Landsat TM and ETM	Landsat Thematic Mapper and European Themmatic Mapper
GCP points	Ground Control Points
$\text{RMS}_{\text{error}}$	Root-Mean-Square Error
ER Mapper	Software
FRAGSTATS:	Spatial Pattern Analysis Program for Quantifying Landscape Structure
(Class 1) (EN1)	Sparse Vegetation
(Class 2) (EN2)	Medium Vegetation
(Class 3) (EN3)	Dense Vegetation
(L) (EN4)	Landscape Level (Ecosystem)
AHP	Analytic Hierarchy Process
PDF Format	Acrobat Reader
CBA	Cost-Benefit Analysis
TEV	Total Economic Valuation
DMUV	Direct Market Use Value
DMNUV	Direct Market Non Use Value
IUV	Indirect Use Value
NUV	Non Use Value
CBD	The United Nations Convention on Biological Diversity
UNEP	United Nations Environment Program
OECD	Organisation for Economic Co-operation and Development

Abbreviation	Description
PCR	Polymerize Chain Reaction
ICN	Instituto de Conservacao da Natureza
CBVI	Comparative Biological Value Index
HI	Health Index
V	“Vigour”
O	“Organisation”
R	“Resilience”
AMOEBE	Algemene Methode voor OEcosysteembeschrijving en Beooordeling
COP	Conference of the Parties
WTP	Willingness-To-Pay
CA	Class Area
TA	Total landscape area
PLAND	Percentage of Land
GIS	Georgaphic Information System
ERDAS IMAGINE	Geospatial Imaging, LLC, Norcross, Georgia
NP	Number of patches
PD	Patch density
LPI	The largest patch index
LSI	Landscape Shape Index)
NLSI	Normalized Landscape Index
TE	Total edge
ED	Edge density
AREA_X	Patch Area Distribution
GYRATE_X	Radius of Gyration
PARFAC	Perimeter Area Fractal Dimension
PARA_X	Perimeter Area Ratio Distribution
SHAPE_X	Shape Index Distribution
FRAC_X	Fractal Dimension Index Distribution
CIRCLE_X	Related Circumscribing Circle Distribution
CONTIG_X	Contiguity Index Distribution
TCA	Total Core Area
NDCA	Number of Disjunct Core Areas
DCAD	Disjunct Core Area Density
CORE_X	Core Area Distribution
DCORE_X	Disjunct Core Area
CAI_X	Core Area Index
PLAND	Core Area Percent Of Land
PROX_X	Proximity Index Distribution
ENN_X	Euclidean Nearest Neighborhood Distance
COHESION	Patch Cohesion Index
CONNECT	Connectance Index
CLUMPY	Clumpiness
PLADJ	Proportion of Like Adjacencies
AI	Aggregation Index

Abbreviation	Description
IJI	Interspersion Juxtaposition Index
DIVISION	Landscape Division
SPLIT	Splitting Index
MESH	Effective Mesh Size
CONTAG	Contagion Index
PR	Patch Richness
PRD	Patch Richness Diversity
RPR	Relative Patch Richness
SHDI	Shanon Diversity Index
SIDI	Simpson Diversity Index
MSIDI	Modified Simpson Diversity Index
SHEI	Shanon Eveness Index
SIEI	Simpson Eveness Index
MSIEI	Modified Simpson Eveness Index
EF	Ecological Footprint
HDI	Human Development Index
ESI	Environmental Sustainability Index
ISEW	Index of Sustainable Economic Welfare
WI	Well Being Index
HWI	Human Well-being Index
EWI	Ecosystem Well-Being Index
GDP	Gross Domestic Product
GS	Genuine Savings Index
SPI	Sustainability Performance Index
SSI	Sustainable Society Index
SI	Sustainability Index
SDI	Sustainable Development Index
CSDI	Combined / Composite Sustainable Development Index
EFSM	Ecological Footprint Simulation Model
DI	Development Index
WEF	World Economic Forum
YCELP	Yale Centre for Environmental Law and Policy
CIESIN	Columbia University Centre for International Earth Science Information Network
CV	Contingent Valuation
CES	Centre for Environmental Strategy
NEF	New Economics Foundation
IDRC	International Development Research Centre
PPP	Purchase power parity
US	United States
DNI	Duurzaam Nationaal Inkomen, Sustainable National Income
CES	Constant Elasticity Substitution
SUE-MoT Project	Sustainable Urban Environment Metrics, Models and Toolkits Project

Abbreviation	Description
FFT	Fourier Filter Transformations
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
VHR	Very High Resolution
SAT	Significance-Acceptability Transformation
FANP	Fuzzy Analytic Network Process

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES FOR APPENDICES

LIST OF EQUATIONS

PART A

LITERATURE REVIEW

In Part A, Literature Review of the biodiversity concept to evince its levelness, role and measurements in environmental processes, to pertain it to the Mediterranean Forests and to sketch its and Forests' threats, and of its economic valuation techniques to expound Producer's Surplus, Marshallian Consumer's Surplus and the Hicksian Demand Curve means, to prominence to valuation perceptions, to propose provisions of Mediterranean forests and to assess total economic value, is introduced in the current dissertation. Furthermore, the literature of landscape metrics is pursued to gauge environmental indicators. The notion of indicators is purveyed to investigate the role of biodiversity towards the sustainability. Sustainability indices are dealt with estimation of social and economic indicators in the ongoing PhD thesis. Decisively, Composite Sustainable Development Index (CSDI) is ordained to appraise social, economic and environmental indicators in the sustainable development.

CHAPTER 1

INTRODUCTION

Biodiversity is considered to form the very basis of life on earth (Roosen et al., 2003). Representatives of 190 countries at the 2002 Johannesburg World Summit on Sustainable Development committed themselves to "… achieving by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional, and national level…". By adopting the Convention on Biological Diversity's 2010 target, governments are explicitly recognizing the value of biodiversity (Balmford et al., 2005; EEA, 2006 a; Strand et al., 2007).

Development needs biodiversity and the services it delivers in order to be sustainable. Biodiversity and development are so intrinsically interrelated that it makes no sense to suppose that progress can be achieved separately (IUCN, 2006).

According to Zhang et al. (2006), the aim of assessing and estimating the interactions within the ecosystem is to optimize the link between man and nature. Regrettably, the demands of socioeconomic development from time to time are not consistent with environmental protection. In the judgment of Feoli et al. (2002), to develop environmental protection strategies, it is essential to have a clear understanding of the interaction between the environmental variables, which manipulate and constrain the accessibility of natural goods and the pressure of human population in the rural system. Furthermore, Fresco and Kroonerberg (1992) describe sustainability as the "… dynamic equilibrium between the input and output."

Reducing the numerous diverse precise objectives to a small set of universal objectives resulted in a synthesis into five categories, which comprise a mixture of sustainable development objectives identified by stakeholders (Gustavson et al., 1999):

1. To maintain ecosystem integrity and diversity;
2. To meet basic human needs for social and economic development;
3. To maintain intergenerational distribution and options;
4. To improve intergenerational distribution and entitlements;
5. To improve local empowerment and decision-making.

There is a great attention has given to sustainability nowadays. Few people experience the logic of urgency with respect to sustainability in its more extensive viewpoint (Van de Kerk and Manuel, 2008). Adriaanse (1993) defines sustainability as either a “no-effect level” or a “no-major-effect level” of environmental impact. His approach involves combining measures of environmental stress as “theme equivalent units” for dissimilar environmental matters and normalizing these units of stress in terms of sustainability standard (Ekins and Simon, 2001).

Sustainable development (SD) is focused on developing a commonly valued relationship between society, economic development and the environment. In practice, the focal point of SD is to find the means to support development, which do not damage the environment or compromise future generations’ access to natural resources. A number of researchers suggest that ecologically sustainable economic development “calls for an economic development within the limits imposed by the natural system, or at least within the limits imposed by the maintenance on the biological basis of human beings” (Bithas and Nijkamp, 2006). According to Nijkamp and Vreeker (2000); Wiek and Binder (2005), a multidimensional sustainability assessment tool is desired to give attention to the issue. The tool includes the following dimensions:

(i) Normative dimension – a normative guiding concept operationalized in specific targets,
(ii) Systemic dimension – a target-related model of the system to be assessed,
(iii) Procedural dimension – an appropriate procedure to integrate the relevant stakeholders and to link normative and systemic aspects.

Moreover, graphic representation of sustainability is used by Necker (2004), which is another way of displaying results effectively.

“… A man who wishes to profess goodness at all times will come to ruin among so many who are not good. Hence it is necessary for a prince who wishes to maintain his position to learn how not to be good, and to use this knowledge or not to use it according to necessity” (Machiavelli, 1998; Hezri and Hasan, 2004).

Sustainability is not represented as the endpoint of a process; rather, it is represented as the process itself (Shearman, 1990). Gale and Cordray (1994) identified four questions for the classification into several types of resource sustainability. The four questions are as follows (Kelly, 1998):

1. What is sustained?
2. Why should it be sustained?
3. How is sustainability measured?
4. What are the politics?

Simultaneously, Macnaghten et al. (1997); Diamantis (1999) and Ford (2000) illustrate a three-stage process:

(i) The present unsustainable situation;
(ii) The new mechanism and relations based on the utilization of environmental indicators to maintain the current position;
(iii) The sustainable state, which can be achieved through the mechanism cited within the latter category.

The argument of Bagheri and Hjorth (2008) is pointing to sustainability, which is neither a state of the system to be increased or decreased, nor a static goal or target to be achieved. Sustainability is a complex concept because it can be never measured (Korhonen, 2003). Bossel (1999) referred to sustainability as "sustainable development".

Sustainable development is an umbrella concept that puts equal emphasis on economic vitality, protecting the environment, managing growth, building healthy communities and enhancing the well-being of residents. Different communities use sustainable development to mean different things. But the concepts are not the same, and it is valuable to take note of several aspects of sustainable development that differentiates it from sustainability (Mitra, 2003). In conclusion**,** recent studies evidently distinguish between the terms "sustainable development" and "sustainability" (Dovers and Handmer, 1993). Brundtland's commission report on sustainable development refers it as "the development, which meets the needs of the present without compromising the ability of future generations to meet their own needs". On the other hand, sustainability points to the "the ability of a human, natural, or mixed system to withstand or adapt to endogenous or exogenous changes indefinitely" (Prasad and Badarinath, 2005).

According to Holden (2006), learning from a case of failed consensus-building around a sustainable development initiative in Greece, Sapountzaki and Wassenhoven (2005) encapsulate the wicked problem within participation for sustainable development this way: "Sustainable development and planning's assumptions, objectives and content are not always understood by the public at large, especially their comprehensiveness and global nature. Inversely, the community of academics, researchers, government officials and professionals engaged in the study, planning and implementation of sustainable development . . . does not always have a satisfactory grasp of the view of the citizens, which, quite naturally, tends to focus on the level of everyday life and experience."

According to Gustavson et al. (1999); Spangenberg et al. (2002); Spangenberg (2004; 2008); Vera et al. (2005); Comim et al. (2007); Lee and Huang (2007), policies towards SD must attain by incorporating four dimensions, i.e. economic, social, environmental, and institutional objectives into an integrated approach guaranteeing the concerns of each dimension. The Mediterranean Action Plan (2008) concentrates on the Mediterranean strategy for Sustainable Development. Adams and

Ghaly (2007) confer current framework for sustainability where the desire is to join together the different parts of sustainability by taking into consideration indicators that offers a description of the systemic nature of the industry. It consists of two-dimensional indicators, instead of exclusively focusing on indicators that provide a one-dimensional, reductions evaluation of economic, environmental, social and institutional sustainability. Assessing the relationships at the boundaries of each area provides a more widespread understanding of the system.

The appropriate balance among what is frequently referred to as the "three Es" — environment, economy and equity — is fundamental to the attainment of a sustainable future (Owens and Cowell, 2002; Stimson et al., 2006; Sagoff, 2007). Lyytimaki and Rosenstrom (2008) represented a holistic illustration of a sustainable development framework. Levett (1998) examines the (proposed) "Russian dolls" model of sustainability. Krajnc and Glavic (2005 a,b) represent the basic hierarchy of composing indicators into the composite sustainable development index (CSDI).

1.1. MOTIVATION

It is obvious from above that there is no approach connecting the sustainable development and biodiversity using the Geographic Information System as a tool. The absence of such an approach leads to the following results:

- **Difficult approaches are applied to assess the sustainable development.** Cornelissen et al. (2001); Phillis and Andriantiatsaholiniaina (2001); Andriantiatsaholiniaina et al. (2004); Zavadskas and Antucheviciene (2006); Kangas et al. (2007); Nasiri and Huang (2007); Liu and Lai (2009) presented in their papers complicated approaches for the SD assessment as follows:

    (i) Fuzzy Logic (FL) to manipulate the subjectivity as decision makers do in appraising the facts and values.

    (ii) Significance-Acceptability Transformation (SAT) to incorporate standards and decision maker's risk attitude in the decision-making process.

    (iii) Fuzzy Analytic Network Process (FANP) to manage the dependencies among social, economic and environmental factors.

- **The concept of Biodiversity is approached mainly through valuation methods.** The economic valuation of natural resources, in general, and biodiversity, in particular, is among the most pressing and challenging issues confronting today's environmental economists. In the opinion of Nunes et al. (2000), economists value biodiversity because such a valuation technique allows a direct comparison of economic values with alternative options and facilitates. For example, cost-benefit analysis represents a crucial tool for the policy formulation. In addition, the monetary valuation of biodiversity allows economists to perform environmental accounting, to assess natural resource damage and to carry out proper pricing. Moreover, the valuation technique is shown to be essential in the research of individual consumer behavior and investigation of what the individual consumer thinks of certain biodiversity management objectives, or identification of individual consumers' motivations with respect to biodiversity conservation. Many people, however, do not accept placing monetary values of biodiversity. Arguments against it are rooted in the human preference orientation that "guides" consumer behavior with respect to biodiversity (Greenfeld, 1988, Lockwood, 1999).

- **Evaluation of biodiversity using GIS as a tool is not considered an easy task.** Generally, onsite data, which are observations taken on site in the field or data collected from actual onsite visits to the areas, or comprehensive technologies of remote sensing are implemented to evaluate biodiversity. Through a comprehensive literature review several thousand abstracts have been screened, and more than 820 Object Based Image Analysis -related articles comprising 145 journal papers, 84 book chapters and nearly 600 conference papers, were analyzed in detail by Blaschke (2010).

It is obvious from prior mentioned approaches that the following tools are necessary:

- **A comfortable approach is necessary to evaluate sustainable development.** The work of Krajnc and Glavic (2005a) presents the design of a composite sustainable development index (CSDI) that would assess performance as a function of time. The focus of the paper is on the consideration of how to integrate indicators in order to determine SD in relevant and useful manners for decision-making. It concentrates on sustainability and it tends to move from trying to define SD towards developing a concrete model for promoting and measuring sustainability achievements. The paper organizes sustainability assessment in terms of economic, environmental, and social performance.

- **The concept of Biodiversity from environmental economics is applied while retrieving and manipulating remote sensing data as an input of environmental indicators to the sustainable development model.**

1.2. AIM

The main goal of the current thesis is to evaluate Biodiversity in Sustainable Development using the Geographic Information Systems and Remote Sensing.

What is the problem?
Evaluation of Biodiversity in Sustainable Development using GIS and economic tools.

Why is it a problem?
Biodiversity needs our attention for two reasons:

- First, it offers a wide range of indirect benefits to humans.
- Second, human activities have contributed, and still contribute, to unprecedented rates of biodiversity loss, which threaten the permanence and continuity of ecosystems (Levin et al., 2007), as well as their stipulation of goods and services to humans (Pimm et al., 1995; Simon and Wildavsky, 1995). As a result, in current years many studies of biodiversity and its loss have been carried out.

Simple definition of Sustainable Development raises two main issues:
(a) How can we take a rational view of what future generations might need?
(b) How can we monitor our progress towards a sustainable future?

1.3. APPROACH

What is the approach to solve the aforementioned problem?
The approach to solve the aforementioned problem is to calculate Composite Sustainable Development Indices with a time series which constitute a sequence of observations in time of 10 years. The procedure of calculating the CSDI is divided into several parts: selecting, grouping, weighting, judging, normalizing indicators, calculating sub-indices and combining them into the CSDI. These procedural parts have the following structure:

1. & 2. Selecting and Grouping Indicators

Mainly, sustainable development (SD) is made up of three pillars or dimensions: social, economic and environmental. While constructing the current thesis, theoretical and practical approaches have been met and coincide the information pyramid (Hammond et al., 1995b) as follows:

- In theory, the information pyramid indicates that a very large set of primary data is needed to obtain certain analyzed data. Indicator sets can be defined based on this information and, by aggregation, a reduced number of indices obtained. For this reason, hundreds of articles have been reviewed. Several indicators have been recollected for six (6) themes of each dimension. Themes with their dimensions are introduced in *three dimensions of SD with Proposed Sub-Classified 6 Themes* (See *Table 6.1*) in **Chapter 6** – **Theoretical Framework**. Approximately, 350 derived indicators in accompany with their trend (increasing or decreasing), sustainability (positive impact), theme (captured theme from S1-S6, EC1-EC6 or EN1-EN6), pressure-state-response (PSR), authors and description are exposed in **Appendix 1** – **Social Indicators (S), Appendix 2** – **Economic Indicators (EC)** and **Appendix 3** – **Environmental Indicators (EN)**. Notwithstanding, the theoretical approach didn't fit to the practical one due to lack of existing statistical data.

- The truth is, however, that this pyramid is inverted: a large number of indicators and indices are in fact generated from limited data. The Social and Economic data are taken from the Hellenic Statistical Authorities and exhibited in Final Proposed Datasets (See *Table 8.7*) of **Chapter 8** – **Study Area and Datasets**. It is detectable from the subsistent social data, only S1 theme (population) corresponds to the input data of social indicators. Furthermore, a small research for Transportation (S6) theme is pursued in **Appendix 4** – **Indicators of Sustainable Transportation**. Economic data has better picture than social one. It is apparent from the contemporaneous economic data; four (4) themes (EC3-EC6) stand for the input data of economic indicators. Presenting differently, the defined themes of economic indicators coincide with the real statistical ones as follows:

  (i) EC3 (Production & Consumption) – Agricultural Goods;
  (ii) EC4 (Agriculture) – Agriculture;
  (iii) EC5 (Industry) – Industry;
  (iv) EC6 (Tourism) – Tourism.

  Arising from the nonexistence of environmental statistical data for the particular region of Athens, EN data were derived from the Remote Sensing data, a fortiori, Landsat TM and ETM images. Five (5) Landsat TM and two (2) Landsat ETM+ satellite extant images were co-registered while associated with 30 GCP points, which were distributed through the whole area of the Municipality of Nea Makri. The RMS_{error} for all images were between 0 and 1 and was accepted as a pass level. To remove noises from the images, automatic periodic noise removal was implemented in each image. Afterwards, georeferenced images to the map were carried out. The raw NDVI values were fractional real numbers that range between –0.32 to +0.35. An NDVI with the range of –0.32 to –0.10 meant no green vegetation and with the range of +0.12 to +0.35 indicated the highest possible density of green leaves. Classification of Landsat TM and ETM was exhibited using ER Mapper 7.0 software. Classified remotely sensed data were inputs to the Fragstat 3.3 program, where the outputs were a class or landscape metrics classified into 6 main groups: Area / Density / Edge, Shape, Isolation Proximity, Connectivity, Contagion Interspersion, Diversity.

The concept of Biodiversity is presented in the *General Model for Biodiversity* (See *Figure 6.7*) and an interesting interlink with the *Proposed Model with Dimensions, Themes and Indicators for Sustainable Development* (See *Figure 6.1*) of **Chapter 6** - **Theoretical Framework**, which has the following indication:

- Ecosystem= Dimensions (S; EC; EN)
- Species = Themes (S1-S6; EC1-EC6; EN1-EN6)
- Genes = Indicators organized by themes
- Functions = Interactions between Dimensions; Themes and Indicators

The same idea of Biodiversity is used by McGarigal and Marks (1995) in the Fragstat program as follows:

- Ecosystem= Landscape Level
- Species = Class Level
- Genes = Patch Level
- Functions = Interactions between Landscape, Class and Patch Levels

Indices for one (1) Landscape Level (Ecosystem) and three (3) Class Levels (Species) were admitted as inputs of Environmental Indicators. Class Levels stand for as follows:

- Class 1 = Sparse Vegetation = NDVI range [–0.32; –0.10]
- Class 2 = Medium Vegetation = NDVI range(–0.10;+0.12]
- Class 3 = Dense Vegetation = NDVI range (+0.12;+0.35]

3. Weighting and judging indicators

To derive the weights practically, the Analytic Hierarchy Process (AHP) was used in the model.

- The first step is setting the problem as a *hierarchy*, where the topmost node is the overall objective of the decision, while subsequent nodes at lower levels consist of the criteria used in arriving at this decision.

- The second step requires *pairwise comparisons* to make between each pair of indicators (of the given level of the hierarchy). This is done by pairwise comparisons between each pair of indicators, by giving to each indicator the values of 1 to 5, which shows the importance towards Sustainable Development.

These three (3) overtures were utilized for all values of indicators of each real theme of each dimension, where two (2) intriguing perceptions were applied:

(i) There are approximately 604 indicators for the S1 theme (Population). Due to the limitation of Microsoft Excel, the calculation of normalized weights was bestowed in a 3x3 matrix. Refer to *Division of Weightings in a Matrix* (See *Table 11.2*) in Chapter 11 **- A Model for Integrated Assessment of Sustainable Development**, for the procedures of the elements of the matrix and their detailed calculations.

(ii) There are approximately 1135 indicators for the EC6 theme (Tourism). Due to the limitation of Microsoft Excel, the calculation of normalized weights was executed by dividing each weighting value from 1 till 5 to the sum of all weights.

(iii) Finally, an engrossing investigation has been carried out to define weights for the EN dimension (Environmental). All indicators of EN dimension have been separated into 6 categories. 32 papers were expended to canvass the weight of each indicator. Fewer than 32 papers were adopted per each category and per each index separately. Then the sum of used papers per index is divided into the sum of expended papers per category. The highest value of the fraction is weighed as 5 and correspondingly the lowest value of the fraction is counted as 1. Differently, the more authors are dealing with the discerning index; the highest value has towards the sustainable development.

4. Normalizing Indicators

Normalization is utilized to avoid the redundancy, to achieve consistency, to reduce data size and to standardize values of each indicator. The normalization of each indicator is a fraction of its value minus the minimum value of the range to the maximum value of the range minus the minimum value of the range. The normalization of Indicators is further discussed in *Section 9.3 – Normalization* of Chapter 9 **– Data Preprocessing and Normalization.**

5. **Calculating the Sub-Indices**
The calculation of the CSDI is a step-by-step procedure of grouping versatile fundamental indicators into the sustainability sub-index for each group of sustainability indicators. There are three (3) sub-indices which exemplify three formerly cited dimensions, i.e. Social (S), Economic (EC) and Environmental (EN). Each sub-index summed up of the multiplication of each value of indicator with the weight correspondingly for the time series of 10 years as complied:

(i) The social sustainability sub-index is introduced as a population theme.

(ii) The economic sustainability sub-index is comprised of four extant themes, i.e. EC3 (Agricultural Goods); EC4 (Agriculture); EC5 (Industry) and EC6 (Tourism). This sub-index is the summation of four themes with the identical weights, i.e. ¼ values per each theme.
(iii) The environmental sustainability sub-index is constituted from one (1) Landscape Level and three (3) Class Levels, i.e., Class 1 (Sparse Vegetation), Class 2 (Medium Vegetation) and Class 3 (Dense Vegetation). This sub-index is the aggregation of four levels with the similar weights, i.e. ¼ values per each level.

6. **Combining the Sub-Indices into the CSDI**
Three sustainability aforesaid sub-indices with the resembling weights, i.e.,⅓ value per each dimension, are added up into the composite sustainable development index (CSDI).

1.4. STRUCTURE OF THE WORK

Chapter 2 – Economic Valuation of Biodiversity Loss portrays as an introduction to biodiversity notion, accentuates the affinities of Environmental or Ecological Economics with the biological diversity, explores an absorbing proffered conviction of evaluation of biodiversity in the Mediterranean forests and is composed of two (2) outstanding parts:

(i) The first part of the current chapter addresses to the environmental foundations of biodiversity. An important step in the analysis and valuation of biodiversity is the definition of the term “biodiversity”, which includes four levels, i.e. Genes, Species, Ecosystem and Functional. Some aspects of measurement of biodiversity are examined, distinguishing the same components of biodiversity as follows:

- Genetic Diversity (Allelic Frequencies, Phenotypic Traits and DNA sequences);
- Species Diversity (α-, β- and γ-diversities);
- Ecosystem Diversity (Large scale ecological systems, i.e. eco-regions or eco-zones).

Forests are centers of biodiversity and play a critical role in the livelihoods of humanity. Peculiarly, Mediterranean forests represent one of the planet's most important centers of plant diversity, with an estimated 25,000 species of which around half are endemic. The forests are fragile and under threats, i.e. intensive agricultural practices, climate change, grazing, forest fires, clearance and degradation, which affect to the regeneration of European Mediterranean forests and the maintenance of biodiversity richness and diversity.

(ii) The second part of the current chapter plows the Economic Foundations of Biodiversity. Economists value biodiversity because such a valuation technique allows a direct comparison of economic values with alternative options and facilities. Predominantly, three leading reasons for undertaking economic valuation of biodiversity and biological resources. These reasons are to assist the progress of cost-benefit analysis (CBA), to merge the systems of national accounts and to set up applicable pricing to the biological resources. The investigation attempts to value alterations in biodiversity, where the inquiry is proposing to review an abundant methodological issues united to environmental valuation approaches. A paramount distinction in the evaluation of the environmental components is assigned between intrinsic and instrumental values. Producer’s Surplus, Marshallian Consumer’s Surplus and the Hicksian Demand Curve are inspected as practical valuation techniques. On the other hand, the development of the Total Economic Valuation (TEV) framework should be perceived as a requisite guideline for the assessment of biodiversity. Ultimately, the concept of TEV for the Proposed “Provisions” of Mediterranean Forest is the sum of the following four major elements:

1. Direct Market Use Value (DMUV), i.e. Timber as Building Materials, Fuel, Food, Medicine and Dyes, Gums and Resins, Cork and Aromatic Plants;

2. Direct Market Non Use Value (DMNUV), i.e., Recreational Hunting, Bird Watching, Tourism, Sightseeing, Hiking or Camping and Photography;

3. Indirect Use Value (IUV), i.e. Biodiversity, Habitat Value, Nutrient Cycling, Flood Control, Climate Control and Erosion Avoidance;

4. Non Use Value (NUV), i.e., Scarcity, Option, Existence, Intrinsic, Bequest, Altruistic, Cultural or Historical and Philanthropic Values.

Later chapters show an opposed approach using the concept of Biodiversity in Sustainable Development.

Chapter 3 – Landscape Metrics based on Remote Sensing Data, converses about Landscape Metrics based on Remote Sensing Data to further appraisals of environmental indicators contemplated as inputs of EN dimension towards sustainability. The current chapter consists of six (6) primary categories:

1. Area / Density / Edge;
2. Shape;
3. Isolation Proximity;
4. Connectivity;
5. Contagion Interspersion
6. Diversity.

In the present chapter, an extensive investigation of the literature has been covered with:

(a) The collection of all the landscape metrics based on remote sensing data;

(b) The literature classification consistence with indices by previously alluded categories;

(c) Their estimation through their use.

Furthermore, the incidence of used papers is divided into five groups. The frequency of used papers equals to the number of used papers per subcategory over the number of used papers per main category. It has been found that min=1/17=0.059 and max=12/15=0.8. The range from min to max has been divided into five equal pieces accordingly representing five groups, i.e. from Group A till Group E. To have a better idea of each group appearance per subcategory and main categories according to the frequency of used papers per each index, the first three before-mentioned groups has the following order:

(a) Group A:

- ❖ Euclidean Nearest Neighbourhood (Isolation Proximity category);
- ❖ Shannon Diversity Index (Diversity category;
- ❖ Shape Index (Shape category);
- ❖ Patch Density (Area / Density / Edge category).

(b) Group B:

- ❖ Patch Cohesion Index (Connectivity category);
- ❖ Connectance Index (Connectivity category);
- ❖ Contagion Index (Contagion Interspersion category);
- ❖ Proximity Index Distribution (Isolation Proximity category);
- ❖ Number of Patches (Area / Density / Edge category);
- ❖ Interspersion Juxtaposition Index (Contagion Interspersion category).

(c) Group C:

- ❖ Largest Patch Index (Area / Density / Edge category);
- ❖ Edge Density (Area / Density / Edge category);
- ❖ Class Area (Area / Density / Edge category);
- ❖ Patch Richness (Diversity category).

An explanation of the aforementioned results is shown at the end of the present chapter, where only the four (4) proposed indices of group A and two (2) suggested indices from the group B are considered, viewed and explained.

Chapter 4 – The Sustainability Indices, refers to the Sustainability Indices, where the attention is given to twelve (12) sustainability indices, which play an important role to the sustainable development. These twelve indices will be discussed in order support their roles in the sustainable development.

1. Ecological Footprint (EF):

At the heart of the ecological footprint concept is the recognition that closed-loop ecological systems provide the productivity needed to support human society (Rees and Wackernagel, 1996). Whereas this indicator is appealing and widespread, it is not perfect. Nourry (2008) presents below three main limitations:

(1) The ecological footprint construction is problematic because heterogeneous data are transformed into land units. Conversion methods are criticized (Neumayer, 2004b).

(2) The ecological footprint can be seen as an indicator of weak sustainability whereas proponents present it as a measure of strong sustainability. Although this indicator focuses on the environmental constraint on development, it does not include irreversibility or threshold effects. Furthermore, it should not be regarded as an indicator of strong sustainability.

(3) The last but not the least limit, is the lack of specific policy proposals based on ecological footprint analysis. If the goal is to reduce the ecological footprint to fit within the carrying capacity of the land, advocates of this indicator do not propose detailed policy advice.

2. **Human Development Index (HDI)**:

United Nations (1990) developed an index called HDI which is a summary measure of human development in three basic dimensions:

- ❖ A long and healthy life;
- ❖ Knowledge;
- ❖ GDP per capita.

There are several limitations which are as follows:

- ❖ Dasgupta and Weale (1992); Hicks (1997); Sen (1997) are pointing to the idea that the HDI is not reflecting human development accurately;

- ❖ Mac Gillivray (1991); Srinivasan (1994); Noorbakhsh (1998) are critisizing the construction and technical properties of the index.

- ❖ Critics of Nourry (2008) also apply to the “green HDI”, which is an attempt to incorporate an ecological measure into the HDI (Desai, 1994; Lasso de la Vega and Urrutia, 2001; Costantini and Monni, 2004).
- ❖ Indeed, since economic and social variables are included, an environmental measure is missing in the HDI to be interpreted as a sustainable development indicator.

- ❖ HDI covers only a minor part of all aspects of sustainable development (Neumayer, 2001).

- ❖ Van de Kerk and Manuel (2008) concluded that HDI is very suitable for giving a rough idea of the level of development, though not on the sustainability of the development, particularly in developing countries.

3. **Environmental Sustainability Index (ESI)**:

As WEF (2002a) described that the core components of the ESI include:

- ❖ Environmental systems;
- ❖ Reducing stress;

- Reducing human vulnerability;
- Social and institutional capacity;
- Global stewardship.

Despite the ESI has advanced the debate and available information, at the level of measurement, it does not provide a complete picture of environmental sustainability. Perhaps the biggest challenge to global comparisons, and the most serious weakness of the ESI, is the existent of relevant data (Johnson, 2002).

4. **Index of Sustainable Economic Welfare (ISEW)**:

The Index of Sustainable Economic Welfare (ISEW) has been developed by C.W. Cobb (1989) to integrate environmental and social externalities in national welfare accounting. The ISEW is set to control the inflation-adjusted consumption of households. The time series of consumption values is adjusted by five categories to obtain a "GDP" which is more appropriate for measuring social welfare:

- Distribution of income;
- Economic activities not counted in the conventional gross national income;
- Time adjustments;
- Damage caused by economic activity;
- The consideration of net capital endowment of foreign investors.

Although the ISEW is calculated for some countries, these calculations were done by very different institutions and are hardly comparable (Cobb and Cobb, 1994; Cobb et al., 1995). Moreover, the ISEW is available for a limited number of countries only (Van de Kerk and Manuel, 2008).

5. **Well Being Index (WI)**:

The Well-Being Assessment by Prescott-Allen (2001) is based on the assumption that a healthy environment is necessary for healthy humans and is the arithmetic mean of two (2) indices:

(i) Human Well-being Index (HWI):

  - Population and Health;
  - Welfare;
  - Knowledge;
  - Culture and Society;
  - Equity Index

(ii) Ecosystem Well-Being Index (EWI):

- Index for the land deployment;
- Index for the water deployment;
- Index for the air deployment;
- Index for the species deployment;
- Index for the genes deployment.

The results and discussions of Distaso (2007) are that Greece, Ireland and Portugal present many values below the mean and are at the bottom of the range.

As a disadvantage, an excellent, therefore, rather comprehensive index was published only once to date (Van de Kerk and Manuel, 2008).

6. Gross Domestic Product (GDP):

The common usage of gross domestic product (GDP), which is suggested in the paper of Wilson et al. (2007), is for a broad measure of economic performance and progress. Very few people still consider GDP per capita to be a useful indicator for sustainable development. In that respect, other indicators, such as the ISEW (Daly and Cobb, 1989; Bleys, 2007) or the Dutch DNI (Duurzaam Nationaal Inkomen, Sustainable National Income) (Hueting, 1980), are far more indicative. Unfortunately, they cannot be used for the sustainable development, since these two indicators are available for no more than a couple of countries (Van de Kerk and Manuel, 2008).

7. Genuine Savings Index (GS):

Pearce and Atkinson (1993) put forward an index, which is based on the Hicksian income concept (see **Chapter 2 - Economic valuation of Biodiversity Loss** for the *Hicksian Demand Curve* and refer to *Figure 2.10*). In 1997 this index has been enhanced by Hamilton et al. (1997) using the Hartwick rule (Hartwick, 1977), which defines the level of re-investment from resource rents that are reinvested to assure that the societal capital stock will never decline. The societal capital stock includes:

- The capital produced in the industries;
- The capital of human skills and knowledge;
- The capital of natural resources.

However, the Genuine Savings (GS) Index is considered as an indicator for a weak Sustainable Development.

8. Sustainability Performance Index (SPI):

The Index of sustainable performance (SPI), as Singh et al. (2009) emphasized, is based on an operationalized form of the principle of sustainable development. Only process data is not used for the presumable unknown influence, but is used to know an early stage of planning and data of natural concentrations of the substances. The weakness of the present index is to evaluate the SPI from the underneath, i.e. to calculate the area needed to embed a process completely into the biosphere (Narodoslawsky and Krotscheck, 2004).

9. Sustainable Society Index (SSI):

For many people, the major concept of sustainable development focuses greatly on depletion of resources (Van de Kerk and Manuel, 2008). Others consider that sustainable development covers also irreversible pollution, conservation of nature and other environmental and ecological aspects. Some authors include the aspects of quality of human well-being and life. From an anthropocentric point of view, sustainability includes all three (3) elements:

1. The depletion of resources→ not to leave future generations empty-handed;
2. Environmental and ecological aspects→ to enable present and future generations to live in a clean and healthy environment;
3. The quality of life → to ensure present and future generations’ life.

The weakness of the current index covers the concept, based on papers of (Van de Kerk and Manuel, 2008), where the created indicator rationale per five existent categories for the sustainable society index gives more power to the society rather than to the environment/ecology or to the natural balance.

10. The Sustainability Index (SI):

The weakness of the sustainability index is that the concept of what is meant by sustainability varies considerably. Even among scientists there are numerous definitions of sustainable development (Pearce, 1996). To be able to support a sustainable way of our planet’s creatures, a clear definition of sustainable development is required. Moreover, one has to be able to measure the present level of sustainability and refer how deep is a need for the complete sustainable development (Lawn, 2004). Moreover, the concept of sustainability applies to integrated systems comprising humans and nature. The structures and operation of the human component (namely society, economy, government etc.) must be such that these reinforce or promote the persistence of the structures and operation of the natural component (namely ecosystem trophic linkages, biodiversity, biogeochemical cycles, etc.) and vice versa (Cabezas et al., 2005).

11. **The Sustainable Development Index (SDI):**
The deceptively simple definitions raise many issues, but the two of them are the followings (Escobar, 1996):

- How can we take a rational view of what future generations might need?
- How can we monitor our progress towards a sustainable future?

As Owens and Cowell (2002); Stimson et al. (2006); Sagoff (2007) mentioned that the proper balance among what is often referred to as the “three Es”:

- Environment;
- Equity—is central to the achievement of a sustainable future;
- Economy.

12. **The Combined / Composite Sustainable Development Index (CSDI):**
The paper of Krajnc and Glavic (2005a) presents a designing of a composite sustainable development index (CSDI) that would assess performance as a function of time. The focus of the paper is a consideration how to integrate indicators in order to determine SD in a relevant and useful manner for decision-making. It concentrates on sustainability and it tends to move from trying to define SD towards developing a concrete model for promoting and measuring sustainability achievements. The paper organizes sustainability assessment for:

- The social performance.
- The economic performance;
- The environmental performance.

All twelve indices were described in the **Chapter 4**. Each index separately has its own significant role in sustainable development. However, the last index, i.e. Combined / Composite Sustainable Development Index (CSDI), is the most important in the evaluation of Sustainable Development. The core idea of the current thesis is based on the Combined / Composite Sustainable Development Index (CSDI).

Chapter 5 – **The Indicators for the Sustainable Development,** represents as a preamble to the indicators for the sustainable development. Furthermore, the subsequent angles will be confabulated as:

1. **What are the aspects of indicators?**

   The surveys of Gallopin (1997) and Rigby et al. (2001) are on a wide range of literature and reports and are acknowledged as:

   - A parameter;
   - A variable;
   - A measuring instrument;
   - A fraction;
   - An index;
   - An empirical model;
   - A sign;
   - A statistical measure;
   - A meter;
   - A value;
   - A proxy;
   - A measure.

2. **What are the broad goals to account for the above adverted indicators' aspects?**

   Varma et al. (2000); Bell and Morse (2004); Simianer (2005) enhanced the three sub-goals as:

   - An aspect of sustainability that recognizes its ecological, economic and social underpinning, i.e. what is the objective?

   - To trove ways to measure sustainability with due regard to its spatial and temporal dimensions, i.e. what are the elected spaces?

   - The effects of the sustainability to acknowledge strategies to improve management, wherever needed, i.e. how the goals can be chosen?

3. **What is the Design Process for the Sustainable Development Indicator?**

   Boyd and Charles (2006) the overall process for the set of indicators of sustainable development for community-level is shown as:

   - To start the participant identification stage;

- To proceed through visioning;
- To specify a suitable framework;
- To specify the sustainability characteristics;
- To specify an iterative series of steps to develop;
- To classify and evaluate the indicators involved.

4. What are the Criteria for Sustainable development?

De Kruijf and Van Vuuren (1998); Ravetz (2000); Spangenberg et al. (2002); The Energy & Biodiversity Initiative (2002); Yuan and James (2002); Limoux et al. (2005) have developed a number of additional criteria to determine the quality of selected or proposed measurables as:

(1) Sole, so that each indicator must be meaningful;

(2) Declaratory, so that each indicator must be truly representable of the phenomenon to be earn-marked;

(3) General, so that not dependent on a concrete modes, society or culture, but be momentous for several concepts of truth;

(4) Robust, so that the behest should be safe and no severe changes in case of minor changes in the methodology or improvements in the data base;

(5) Sensitive, i.e. they have to react early and sensibly to changes in what they are observable, to allow and to observe the trends or the successes of methods.

5. What are the indicators to model the framework?

By the words of Potts (2006), the sustainable development indicator system encompasses an assortment of policy contexts, frameworks, dimensions, criteria, indicators, real strategies and targets. The conceptual model of the sustainable development indicator system displays the core processes that underline sustainability indicator systems. The current approach focuses on the core indicator system as dependent upon a series of inputs, so that involve updates to construct the indicators and to develop an apprehend structure for the policy need, and of outputs, so that involve to use the indicator results, to operate effectively. Hilden and Rosenstrom (2008) emphasize that the different uses and the indicators' development are thus abstrusely connected. To keep the connectance, one can ensure that the indicators of sustainable development stay observable, secure and lawful while the world is in a stage of changes. Some clear challenges related to the indicators use have been identified to develop indicators of sustainable development.

1. There has been a lack of clear and simple frameworks.

2. Developers of indicators often neglect to engage those who are earmarked to well advantages from the indicators in the process..

3. Many real indicators stay unknown to the atlantean users due to unsuccesses to make them accessible (Morrone and Hawley, 1998).

6. What are the types of Indicators Categories and Principles?

According to the UK Biodiversity Partnership (2007), the indicators for assessing the 2010 targets are grouped under focal areas based on those identified by the Convention on Biological Diversity and the European Council:

- Status and trends in the components of biodiversity;
- Sustainable use;
- Threats to biodiversity;
- Ecosystem integrity and ecosystem goods and services;
- Status of resource transfers and use;
- Public awareness and participation.

Moreover, Korhonen (2007b) mentioned the four sustainability principles which are as follows:

1. In the sustainable society, nature is not subject to systematically increasing concentrations of substances extracted from the Earth’s crust,

2. Concentrations of substances produced by society,

3. Degradation by physical means,

4. In a sustainable society, human needs are met worldwide in the short- and long-term.

The latter definition was not applicable in the literature survey of Palme and Tillman (2008), as the presence or lack of a connection between an indicator and a vision, target, or goal was not always evident in the texts studied. Furthermore, inconsistencies in the indicators in the micro-level do not help policy makers in formulating and implementing sustainable strategy at the macro-level. Therefore, standardization of indicators is the next step that may aid identification and comparison of options for more sustainable development (Azapagic and Perdan, 2000).

7. How top-down and bottom-up approaches are accorded in Sustainable Development?

The chosen indicators are expected to help political decision-makers evaluate alternatives, make policy choices, and adjust policies and objectives based on actual performance (Rosenstrom and Kyllonen, 2007).

Reed et al. (2006) has shown as a two methodological paradigms for developing and applying sustainability indicators at local scales and how each method approaches four basic steps (Blue Plan - Regional Activity Centre, 2006). Furthermore, Hartmuth et al. (2008) shows the linkage of the top-down (↓) and bottom-up (↑) approaches in the integrative concept of sustainable development.

8. How is the composite indicator construed?

The development of a sustainable development reference system involves five steps (Garcia et al., 2000):

1. Specifying the scope of the sustainable development reference system;
2. Developing a framework to agree on components within the system;
3. Specifying criteria, objectives, potential indicators and reference values;
4. Choosing the set of indicators and reference values;
5. Specifying the method of aggregation and visualization.

The composite indicator can be simply defined as an aggregation of different indicators under a well-developed and pre-determined methodology. Thus the composite indicator lies on the top of an “Information Pyramid” (Hammond et al., 1995b).

9. What are the arguments of the Pressure State Response (PSR) indicator framework?

Putting indicators in an appropriate context or framework can increase their usefulness (IISD, 1997). The driving force-pressure-state-impact-response (DPSIR) indicator framework is a general framework for organizing systems of indicators of sustainable development (Turner, 2000; Bellini, 2005; EEA, 2006b; Zavadskas and Antucheviciene, 2006; Nuissl et al., 2009). The framework assumes cause–effect relationships between

> interacting components of social, economic and environmental systems (Smeets and Weterings, 1999). The systems according Amajirionwu et al. (2008) proposes five types of indicators:
>
> (1) Driving force indicators, which refer to human activities, processes and patterns that impact on sustainable development.
>
> (2) Pressure indicators, which refer to activities having a direct effect on a given issue.
>
> (3) State indicators, which describe the observable changes as a result of the earlier mentioned pressures.
>
> (4) Impacts indicators, which show the effect of the impact on the population, economy, ecosystems.
>
> (5) Response indicators which show the actions taken by the society in response to the changes in the state of sustainable development.
>
> Although the DPSIR framework has been criticized for over-simplifying reality and ignoring many of the linkages between issues and feedbacks within the socio-ecological system, the framework is nevertheless a useful conceptual system (Smeets and Weterings, 1999).
>
> Pressure–State–Response (PSR) methodology was developed by the OECD, for the categorization of environmental indicators, and is based on the "stress–response" model (OECD, 1993).

The key point of the current chapter is the definition of a composite indicator, which can be simply defined as an aggregation of different indicators under a well-developed and pre-determined methodology. The current indicator system is proposed to interlink the current chapter with **Chapter 4 – The Sustainability Indices**, where the Composite Sustainable Development Index (CSDI) was proposed for the evaluation of sustainable development. To meet the challenges of sustainability, an approach to integrated assessment is required to provide a good guidance for decision-making. Decision-makers had a very difficult task for the assessment of sustainable development per region. Meanwhile, it is proposed that decision-makers combine indicators into one while referring to society. It is suggested that they merge into the other group of indicators while referring to the economy. In the same way, the environmental indicators are joined as another composite indicator. Therefore, three composite indicators, i.e. social, economic and environmental indicators, are proposed to highlight the concept of sustainable development. To review and define each composite indicator, refer to **Chapter 6 – Theoretical Framework**.

Chapter 6 – Theoretical Framework, reviewed approximately 350 indicators, which belong to three dimensions, i.e. Social Indicators (**Appendix 1** - **Social Indicators**); Economic Indicators (**Appendix 2** - **Economic Indicators**); Environmental Indicators (**Appendix 3** – **Environmental Indicators**). Each indicator is separately discussed taking into consideration the huge range of overviews of the authors on diverse topics of sustainable development. In general, the overviews of different authors were kept to show not only the precise opinions of the authors but also their diverse thoughts on the same indicator. Afterwards the Proposed Model with Dimensions, Themes and Indicators for Sustainable Development (see *Section 6.2*) is proffered in *Figure 6.1* of the current chapter.

Mainly two (2) themes, i.e. Population (S1) and Transportation (S6), out of six (6), namely, S1-S6, are discussed in *Sub-Section 6.2.1 – Social Indicators (S)* of *Section 6.2 – Proposed Themes and Indicators for Sustainable Development* in **Chapter 6 – Theoretical Framework**. These two (2) themes are chosen as they have an important role in Sustainable Development of Greece. By the words of Baldwin-Edwards (2006), migration at the borders of Turkey from S1 theme and Traffic especially in Athens from S6 theme are the main problems for social dimensions of sustainable development. In addition, the interlink of human security, well-being & sustainability to population is shown in *Figure 6.2* (Anand & Gasper, 2007) of **Chapter 6 – Theoretical Framework.** Furthermore, Population (S1) & Transportation (S6) somehow correlate to each other as shown by the conceptual model of land development in *Figure 6.3* (White et. Al, 2009) and represented in **Chapter 6 – Theoretical Framework**.

All six (6) themes of Economic (EC) dimension have a major impact on Sustainable Development of Greece (Hellenic Ministry for the Environment, 2002; Blue Plan – Regional Activity Centre, 2007; 2008). Primarily, two (2) main themes, Agriculture (EC4) & Tourism (EC6) interrelate with each other (*Figure 6.5 –The Derived System Graphs for "School" & "Agriculture" Groups* of **Chapter 6 – Theoretical Framework**).

Environmental Indicators (See **Appendix 3 – Environmental Indicators (EN)**) are categorized into six (6) themes, i.e. EC1-EC6, which have relation to the Environmental Footprint by Eaton et al. (2007) & Chambers et al. (2000B), whose approach is shown by the schematic representation of the environmental footprint & its land types in *Figure 6.6* of **Chapter 6 – Theoretical Framework**. "Ecological" or "Environmental" Footprints represent the indicators for the sustainable development. As it was shown by the Level of Biodiversity in *Table 2.1* of **Chapter 2 – Economic Valuation of Biodiversity Loss** of *Section 2.2 –Environmental Foundations for Biodiversity Analysis & Valuation*, the general model for biodiversity is shown in *Figure 6.7* of **Chapter 6 – Theoretical Framework**, where not only Economic & Environmental Evaluations are presented but also Evaluation of Biodiversity using GIS as a tool. Recently, the new technology has been developed that even for Gene level, a few evaluation can be performed using the Remote Sensing & Geographic Information System. The general model for biodiversity (*Figure 6.7*) of **Chapter 6** – **Theoretical Framework** with the proposed themes and indicators for sustainable development (see *Figure 6.1*) has an interesting interlink, which has the following indication:

1. Ecosystem = Dimension (S; EC; EN);
2. Species = Themes (S1 – S6; EC1 – EC6; EN1 – EN6);
3. Genes = Indicators organized by themes;
4. Functions = Interaction between Direction, Themes & Indicators.

There is another interesting point to be mentioned in the current thesis. If Ecosystem is taken at the level of themes, let say Agriculture (EC4), then the following indication of the general model for biodiversity will be:

1. Ecosystem = Agriculture (EC4);
2. Species = Agronomists; Lands; Plants; Trees; Animals; Water; Heats; Pesticides etc.;
3. Genes = Each Agronomist with His Own Land, Number of Plants; Trees and Animals; the Amount of Used Water; Heat & Pesticides;
4. Functions = Interaction Between Ecosystem; Species & Genes to Reach Optimal Needs & Solutions.

Finally, the concept of biodiversity presented as general model for biodiversity can be applied to different subjects and levels.

Chapter 7 - **Methodological Framework,** shows all the interrelationships between the chapters and represents the core model drafted from the theoretical framework. The proposed model has taken the roots from the concept of SD, i.e. Society, Economy and Environment (See *Figure 4.8* and *Figure 4.9* of the *Section 4.12 – Sustainable Development Index* of **Chapter 4** – **The Sustainability Indices**) and the Composite Sustainable Development Index (See *Section 4.13 – Composite Sustainable Development Index* of **Chapter 4** – **The Sustainability Indices**). The Core Proposed Model (See *Figure 7.1*) is driven from the proposed model with dimensions, themes and indicators for the sustainable development (See *Figure 6.1* of **Chapter 6** – **Theoretical Frameworks**) and has three (3) sub-models:

1. The first sub-model represents the first dimension, i.e. Society (S). The social indicators per social themes (S1-S6) are shown in **Appendix 1** – **Social Indicators (S)**. The theoretical approach to the Social dimension is overviewed in *Subsection 6.2.1 – Social Indicators* of **Chapter 6** – **Theoretical Framework**. The direct input of Social data is equal to the Population (S1) data (see *Figure 7.2*) is presented in *Section 7.2 – Social Indicators (S).*

2. The second sub-model represents the second dimension, i.e. Economy (EC). The economic indicators of economic themes (EC1-EC6) are shown in

Appendix 2 **– Economic Indicators (EC)**. The theoretical approach to the Economic dimension is overviewed in *Subsection 6.2.2 – Economic Indicators* of **Chapter 6 – Theoretical Framework**. The inputs of Economic data have the subsequent branches:

- EC3 (Production & Consumption) – Agricultural Goods;
- EC4 (Agriculture) – Agriculture;
- EC5 (Industry) – Industry;
- EC6 (Tourism) – Tourism.

These four (4) branches of Economic Data are depicted in *Section 7.3 – Economic Indicators (EC)* (see *Figure 7.3*).

3. The third sub-model represents the third dimension, i.e. Environment (EN). The environmental indicators of environmental themes (EN1-EN6) are shown in **Appendix 3 – Environmental Indicators (EN)**. Due to the lack of Greek statistical environmental data per municipality, an interesting approach has been applied to the proposed model. The only two (2) levels are retrieved from an idea of Biodiversity (See **Chapter 2 – Economic Valuation of Biodiversity Loss**) which is used by McGarigal and Marks (1995) in the Fragstat program, as follows:

- Ecosystem = Landscape Level
- Species = Class Level
    - Class 1 – Sparse Vegetation;
    - Class 2 – Medium Vegetation;
    - Class 3 – Dense Vegetation.

The detailed approach is provided in the branches of Environmental Data (See *Figure 7.4*) of *Section 7.4 – Environmental Indicators (EN)*.

The three (3) aforementioned sub-models are enlarged and are inputs to the of the Proposed Model (see *Figure 7.5*) presented at the final look of the current chapter.

Chapter 8 – Study Area and Datasets, describes the Environmental Conditions on the municipality of Nea Makri, Athens, Greece. There are two (2) types of data are used in the current dissertation and are as:

(1) GR stat data:

- Population Dataset (Society Branch) for the time series of ten (10) years;
- Agriculture Dataset (Economy Branch) for the time series of ten (10) years;
- Tourism Dataset (Economy Branch) for the time series of each year;
- Agricultural Dataset (Economy Branch) for the time series of each year;
- Industry Dataset (Economy Branch) for the time series of each year.

(2) RS data, i.e. Landsat TM and ETM images for the time series of three (3) years.

The first type of dataset, i.e. GR stat dataset, represents two (2) branches, i.e. Society and Economy. The existent GR stat dataset is shown in Available Statistical data (See *Table 8.2*). However, the used GR stat dataset is shown in Suggested Statistical data (See *Table 8.3*) is derived from the existent GR stat dataset because of the differences of the time series. The second type of dataset, i.e. RS dataset, where seven (7) Landsat TM and ETM RS images are used, is shown in Available Remote Sensing Data (See *Table 8.1*) of the current chapter. Due to the afore-marked differences of time series, the final suggested statistical data is given in the *Table 8.7* of the current chapter. The role of the current chapter in the PhD thesis is to introduce the existent and suggested data for the further usage.

Chapter 9 – Data Preprocessing and Normalization, presents the preprocessing of Landsat TM & +ETM data and Normalization of statistical data. The preprocessing of optical data includes Co-Registration and Noise Reduction using ERDAS Imagine software. The normalizing of each indicator or data is implemented in the current PhD thesis using *Equations 9.5 & 9.6* of the current chapter.

Chapter 10 – Processing and Results of Remote Sensing Data, presents Processing and Results of Remote Sensing Data. The complete methodology is presented in the flowchart of *Figure 10.1 – Flowchart of Methodology* in **Chapter 10 – Processing and Results of Remote Sensing Data**. Each part of the flowchart is discussed later in the current chapter, except the portion of Data Pre-processing (Co-Registration and Noise Reduction), which is highlighted with Red Quadrate and is discussed in **Chapter 9 – Data Pre-processing and Normalization**. In **Chapter 10 – Processing and Results of Remote Sensing Data**, an attempt is made to investigate the usefulness of spatial techniques like Remote Sensing and GIS and to assess land use change and the related biodiversity variations. The NDVI is calculated. Classification into three (3) classes is performed. Landscape metrics are computed. Finally, Discussions of Remote Sensing Data are given for Landscape Indicators at Class Level and Landscape Indicators at the Landscape Level.

Chapter 11 – A Model for Integrated Assessment of Sustainable Development, presents A Model for Integrated Assessment of Sustainable Development. Approximately 350 indicators, which were, classified into three dimensions, i.e. social (**Appendix 1 – Social Indicators (S)**), economic (**Appendix 2 – Economic Indicators (EC)**) and environmental (**Appendix 3 – Environmental Indicators (EN)**) dimensions. Each dimension is sub-classified into 6 themes. However, because of the enormous size of work and the lack of time and statistical data, background, implementations and results for Calculations and Results of Social Indicators (*Section 11.1 – Calculations and Results of Social Indicators*), Calculations and Results of Economic Indicators (*Section 11.2 – Calculations and Results of Economic Indicators*) and Calculations and Results of Environmental Indicators (*Section 11.3 – Calculations and Results of Environmental Indicators*) are implemented. Finally, background, implementation and results for An Integrated Assessment of Sustainable Development (*Section 11.4 – An Integrated Assessment of Sustainable Development*) are given by paying attention to Results of Calculation of the Sub-Indices (Sub-Section 11.4.1 – Background) and Results of the Combination of the sub-indices into the CSDI (Sub-Section 11.4.2 - Implementation).

Chapter 12 – General Conclusions and Recommendations, presents General Conclusions, i.e. Preferences and Recommendations, i.e. Future Works are proposed in the current chapter to make inferences and to suggest further works. The preferences are marked to calculate and perform the CSDI equals to sum of ⅓ Society Sub-Index, ⅓ Economy Sub -Index and⅓ Nature Sub -Index. Further on, three (3) recommendations, where the last one has four (4) further inferences, are suggested for the future works as:

1. Due to the hugeness of the work and time pressure, the CSDI are calculated based on the key concept for the time series of three (3) years rather than of ten (10) years.

2. Economic Assessment, i.e. TEV, is appraised to calculate the biodiversity for the Mediterranean Forest.

3. Further four (4) inferences are suggested as:

    - Fuzzy Set Theory;
    - Significance-Acceptability Transformation (SAT);
    - Fuzzy Mathematical Models;
    - Fuzzy Analytic Network Process (FANP).

The afore-marked three (3) targets are suggested for the future works.

Eventually, the following guides are demonstrated:

1. References are invoked in the current thesis with all specified authors with their papers.

2. DVD with all handouts and works has been requested:
    - Appendices, where all appendices are attached in the form of Excel and Doc Files;
    - Calculation, where two (2) approaches are provided. The first one is the current approach where three (3) periods are taken into consideration, i.e. 1981, 1991 & 2001. The second one is the future suggested approach where additional three (3) periods can be added, i.e. 1993, 1996 & 1999, for the future study.
    - Used Papers, containing 1427 papers used while doing the current thesis, which are contained in PDF format.

CHAPTER 2

ECONOMIC VALUATION OF BIODIVERSITY LOSS: THE CASE OF MEDITERRANEAN FOREST

The current chapter evokes as a prelude to biodiversity sentiment, foregrounds on the rapports of Environmental or Ecological Economics with the biological diversity, ascertains engrossing propounded creeds of appraisals on biodiversity in the Mediterranean forests and is comprised of two (2) terrific portions:

(i) The first portion of the ongoing chapter invokes to the environmental institutions of biodiversity. A meaningful action in the inspection and valuation of biodiversity is the denotation of the term “biodiversity”, which covers four levels, i.e. Genes, Species, Ecosystem and Functional. A few features of biodiversity assessment are scrutinized, differentiating the similar constituents of biodiversity as follows:

  - Genetic Diversity (Allelic Frequencies, Phenotypic Traits and DNA sequences);
  - Species Diversity (α-, β- and γ-diversities);
  - Ecosystem Diversity (Large scale ecological systems, i.e. eco-regions or eco-zones).

Forests are focal points of biodiversity and have an acute impact on the livelihoods of humanity. Remarkably, Mediterranean forests act for one of the planet's most imperative centers of plant diversity, with an appraised 25,000 species of which approximately half are endemic. The forests are brittle and under threats, i.e. concentrated agricultural lands, climate change, grazing, forest fires, clearance and degradation, which motivate on the regeneration of European Mediterranean forests and the preservation of biodiversity richness and diversity.

(ii) The second portion of the current chapter draws attention to the economic institutions of biodiversity. Economists value biodiversity because such a valuation technique permits a straight judgment of economic values with substitute possibilities and amenities. Principally, three prominent reasons for accomplishing economic valuation of biodiversity and biological resources. These reasons are to advance the cost-benefit analysis (CBA), to unite the organisms of national accounts and to inaugurate reasonable pricing to the biological resources. The scrutiny endeavors to value variations in biodiversity, where the study is recommended to appraise a plentiful procedural matter joint to environmental valuation methods. A domineering alteration in the evaluation of the environmental constituents is allocated between intrinsic and instrumental values. Producer’s Surplus, Marshallian Consumer’s Surplus and the Hicksian Demand Curve are perceived as practical valuation techniques. In a different way, the expansion of the valuation techniques is offered by Total Economic Valuation (TEV) structure which should be detected as obligatory counsels for the assessment of biodiversity. Eventually, the idea of TEV for the Proposed “Provisions” of Mediterranean Forest is the addition of the following four chief modules:

1. Direct Market Use Value (DMUV), i.e. Timber as Building Materials, Fuel, Food, Medicine and Dyes, Gums and Resins, Cork and Aromatic Plants;

2. Direct Market Non Use Value (DMNUV), i.e., Recreational Hunting, Bird Watching, Tourism, Sightseeing, Hiking or Camping and Photography;

3. Indirect Use Value (IUV), i.e. Biodiversity, Habitat Value, Nutrient Cycling, Flood Control, Climate Control and Erosion Avoidance;

4. Non Use Value (NUV), i.e., Scarcity, Option, Existence, Intrinsic, Bequest, Altruistic, Cultural or Historical and Philanthropic Values.

2.1. INTRODUCTION

Humanities rely on the natural resources for their endurances. Plants endow not only food to survive for more than 10,000 years, but also the majority of the raw materials to produce the goods which keep and enhance human life. While the twin processes of industrialization and urbanization have obscured our conventional reliance on natural production processes for existence–generalizing the faith in human being's discipline over its natural surroundings–contemporary society persists to widely depend on the products of nature. In some majors, modern developments underline this reliance more obviously than ever before. Perchance, this tendency is more dramatic than in biotechnology, where modern improvements have flashed a revitalization of curiosity in the local biodiversity and native knowledge of the Third World. The appearance of modern biotechnological techniques, which permit the movement of the genetic materials in the species, has mainly augmented the potential value of biodiversity (Zerbe, 2005).

Biodiversity requires our intentness for two motives. First, a wide range of indirect benefits for humans is purveyed to biodiversity. Second, human activities have conduced and still conduce to outstand rates of biodiversity loss, which menaced the constancy and continuity of ecosystems (Levin et al., 2007), as well as their potential provide goods and amenities to humans (Pimm et al., 1995; Simon and Wildavsky, 1995). Subsequently, in recent years innumerable studies of biodiversity and its loss have appeared.

This work will critically evaluate the notion of biodiversity value and the application of economic, monetary valuation techniques for its evaluation. The monetary values of changes in biodiversity admit a direct comparison of monetary values of substitute options, such as benefits of an investment project, thus enabling cost-benefit analysis of biodiversity policies. Furthermore, they permit economists to perform environmental accounting to assess damages and carry out appropriate pricing. This chapter inspects how the information provided by the available studies on biodiversity valuation should be interpreted. First of all, Producer's Surplus, Marshallian Consumer's Surplus and the Hicksian Demand Curve are observed as practical valuation techniques. Though, the other approach to the valuation techniques is tendered by Total Economic Valuation (TEV) structure. Lastly, the initiative of TEV for the Proposed "Provisions" of Mediterranean Forest is the sum of the following four paramount values: Direct Market Use Value (DMUV), Direct Market Non Use Value (DMNUV), Indirect Use Value (IUV) and Non Use Value (NUV).

2.2. ENVIRONMENTAL FOUNDATIONS FOR BIODIVERSITY ANALYSIS AND VALUATION

2.2.1. The Concept of Biodiversity and Multilevelness

An important step in the analysis and valuation of Biodiversity is the definition of the term “biodiversity”. This is certainly not an explicit notion. The United Nations Convention on Biological Diversity (CBD) describes biodiversity as “… the variability among living organisms from all sources, covering terrestrial, marine and other aquatic ecosystems and the ecological complexes of where they do belong…” (UNEP, 1992; article 2). Turner et al. (1999) showed that biodiversity includes four levels as shown in *Table 2.1*. These will be subsequently discussed.

Table 2.1: Levels of Biodiversity

Gene	**Genes, Nucleotides, Chromosomes, Individuals**
Species	**Kingdom, Phyla, Families, Genera, Subspecies, Species, Populations**
Ecosystem	**Bioregions, Landscapes, Habitats**
Functional	**Keystone process species, ecosystem resilience, and ecological services**

Source: Turner et al. (1999)

Another definition, easier and purer, but more demanding, is the totality of genes, species, and ecosystems of a region (Richerzhagen and Holm-Mueller, 2005). An advantage of this meaning is that it seems to describe most instances of its use (Barnes, 1999), and one possibly unified view of the traditional three levels at which biodiversity has been identified as in above portrayed table, namely:

- Gene Diversity;
- Species Diversity;
- Ecosystem Diversity;
- Functional Diversity.

2.2.1.1. Genetic Diversity

Genetic Diversity is the diversity of genes within a species. There exists a genetic variability among the populations and the individuals of the identical species. Genetic diversity is a feature of ecosystems and gene pools that illustrates an attribute which is commonly grasped to be advantageous for endurance and that many different types of otherwise similar organisms are existent. Unfortunately, according to Curtis (2004) the genetic diversity within species is declining rapidly.

The most basic level is genetic diversity, which matches to the degree of variability within species. Roughly speaking, it concerns the genetic information (DNA structure) contained in the genes of the individual plants and animals. Gene diversity provides the basis for biotechnological manipulation of genetic material. The extent to which biodiversity is lost depends on the extent to which genetic diversity is lost which, in turn, depends on the extent to which genetic information is disappeared. The value estimation of such information loss can be based on the conceptualization of "genetic difference" and "genetic distance" within species (Weitzman, 1995). In order to describe the diversity between species it is necessary to go one step further in the level of organization of living resources as referred species diversity.

2.2.1.2. Species Diversity

Species Diversity is the diversity between species. Species richness is perhaps the easiest measure of biodiversity. The greater the quantity, the more species are in an area. A strong inverse correlation appears in many groups between species richness and latitude - the further from the equator is located, the fewer species can be found, even during compensation of the reduced surface area of the globe in higher latitudes. Other estimations of biodiversity may also take into account the scarcity of the taxa, and the amount of evolutionary novelty they exemplify. As an estimation of biodiversity, species richness agonized from the absence of a good definition of "species", but it is easy to measure, and is well studied. Species richness has been discovered to be a good surrogate for other measures of biodiversity that would be hard to measure directly.

Species diversity refers to the variety of species on the earth, or in a given area. This is related to a large degree of certainty. In fact, estimates of the total number of species in the earth range from 5 – 300 million, of which about 1.5 million have been portrayed, and less than 0.5 million have been scrutinized for potential economic benefit properties (Miller et al., 1985; CBD, 2001b). The best-catalogued species groups include vertebrates and flowering plants, with other groups, namely lichens, bacteria, fungi and roundworms, comparatively under-researched (Pimm et al., 1995). Such a lack of information has important implications for defining priorities for cost-effective conservation. Scientists have long been proposing the notion of "biodiversity index" as an important tool in conservation policy. This index is dedicated to summarize information about the number of different species within a specified area, the implied endurance probability distribution functions, and the grade of variety in the relationships of species to each other (Margalef, 1996). Whatever is the most threatened should be preserved first, may not minimize the predictable level of diversity loss. Weitzman (1998) presents that what is valued by society is maximum species diversity, so preservation efforts should be fixated on the threatened species that are genetically most distant from other species. He depicts that optimal conservation of biodiversity (Lindenmayer et al., 2006) is impossible without a sense of the magnitude of the appropriate species "distinctiveness", extinction probabilities, and the costs of improving species endurance. Van der Heide et al. (2002) have also argued that Weitzman’s proposal may guide to objectionable policies, because it abandons ecological relationships, focusing totally on genetic distances.

2.2.1.3. Ecosystem Diversity

Ecosystem Diversity is the diversity at an upper level of organization, the ecosystem (richness in the various processes to which the genes ultimately contribute). Ecosystem diversity denotes to the diversity of a place at the level of ecosystems.

Ecosystem diversity insinuates to diversity at the community level, i.e., at supra-species level. A long-standing theoretical paradigm has envisaged that species diversity is imperative because it boosts the productivity and stability of ecosystems. The latest studies, however, admit that no pattern or finite relationship is necessary for the existence of species diversity and the stability of ecosystems (Johnson et al, 1997).

A protracted stability perception comes in two alternates (Nunes et al., 2003). One states to the properties of the ecosystem, which is close to some stable equilibrium. This notion, investigated by Pimm (1984), is bothered with the time it takes for a distressed system to return to some preliminary state, i.e. the resilience of an ecosystem is assessed by its speed of return to equilibrium. The second alternate is about the magnitude of disturbance that can be attracted before an ecosystem is relocated from one state to another. This notion, investigated by Holling (1973, 1986, 1987 and 1992), is disturbed with the ability of an ecosystem to uphold its self-organization without undergoing the devastating and probably irreversible change comprised in crossing the threshold between stability domains.

Reid and Miller (1989) and Pearce (1996) advice six main rules of ecosystem dynamics which connect environmental changes, biodiversity and ecosystem processes.

1. The combination of species is made up communities and ecosystem changes incessantly;

2. Species diversity amplifies as environmental heterogeneity or the patchiness of a habitat do, but augmenting patchiness does not unavoidably ensue in increased species richness.

3. Habitat patchiness impacts to not only the composition of species in an ecosystem, but also the interfaces among species.

4. Intermittent disturbances are significant while creating the patchy environments that foster high species richness. They assist to maintain an array of habitat patches in diverse successional states.

5. Both size and isolation of habitat patches can inspire on not only species richness, but also the extent of the transition zones between habitats. These transitional zones, or “ecotones”, encourage species, which would not appear in continuous habitats. In temperate zones, ecotones represent many species richer than continuous habitats, although the contrary may be true in tropical forests.

6. Specific species have a disproportionate impact on the characteristics of an ecosystem. These involve keystone species, whose loss would transmit or weaken the ecological processes or principally modify the species composition of the community.

2.2.1.4. Functional Diversity

Functional Diversity is the diversity of ecosystem functions. It is the result of the interfaces of the structure and processes of the ecosystem. Ecosystem structure signifies to the perceptible items, namely plants, animals, soil, air and water of which an ecosystem is comprised. Ecosystem processes brings up the dynamics of transformation of matter or energy between living and abiotic systems. Ecosystem functions are the outcome of interfaces of the structure and its processes.

The value of ecosystem structure is normally more easily assessed than that of ecosystem functioning. Estimating ecosystem functions are tremendously complicated. Ecosystem structure is partially recognized as well. The conservation of ecosystem preprocesses and their subsequent functioning is imperative aim to conserve and to preserve an ecosystem structure.

The discussion has displayed on how biodiversity is a very complex and all-embracing notion, which can be interpreted and analyzed at a number of levels and scales. The next section presents some approaches for measuring these concepts.

2.2.2. Role and Measurement of Biodiversity in Environmental Processes

The scrutiny of biodiversity is delved in the sphere of both natural and social sciences and its modeling infers a review of knowledge on the rapports of biodiversity, the dynamics of ecosystems and the level of human economic activities. One cause that biodiversity modeling has been so tricky, is associated with the convoluted and partially the unnoticeable nature of the biodiversity-ecosystem relationships included, namely biotic-abiotic interactions, food webs, nutrient flows, and species interrelations. Irrespectively, the complex nature of the biodiversity-ecosystem relationships is a central characteristic, which is the recognition where the alterability of the biological resources persuades the functioning and the structure of ecosystems (EASAC, 2005). In the literature, three main approaches to modeling are researched by OECD (2001a), namely:

1. Cogitation of Holling (1987 and 1992) is made use of the “4-box model”, specifically exploitation, conservation, release and reorganization.
2. The biotic richness approach is contemplated in ecological indicators of biodiversity.
3. The ecosystem health approach is observed in ecological indicators of biodiversity.

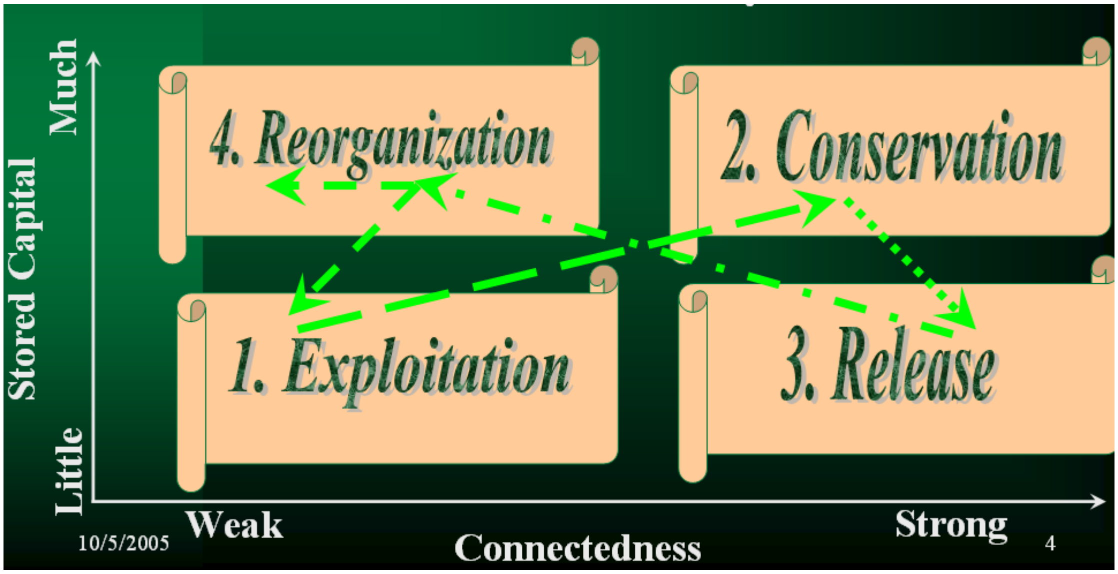
2.2.2.1. The “4-Box Model”

Holling (1987 and 1992) recommended a model to define and clarify the dynamics of a terrestrial ecosystem in terms of a structure that is distinguished by the consecutive interfaces between the four principal functions or phases - the “4-box model”, which is shown in *Figure 2.1*. The functions are:

(1) Exploitation;
(2) Conservation;
(3) Release;
(4) Reorganization.

Within this model, ecosystems evolve from the exploitation phase during which systems apprehend simply manageable resources, to the conservation phase during which systems construct and stow gradually convoluted structure, and then develop to the release phase during which systems release some of the mature structures. The released structure is afterward obtainable for reorganization and perception in the exploitation phase. The exploitation function indicates to the ecosystem processes that are in charge of “colonizing disturbed sites”. The conservation function infers to the ecosystem processes that are responsible for “resource accumulation that builds and stores energy and material”. The release or destruction function stands for an unexpected variation in the ecosystem rooted in outward disturbance, releasing energy and material that have been accrued during the conservation phase. Samples of the release phase are fire, storms, and pests (Costanza et al., 1995). As a final point, the reorganization function directs to the ecosystem processes that are in control to mobilize released energy and materials and are freeing them up to the next exploitative phase.

Figure 2.1: A Sequential Interfaces Between Four Basic Functions or Phases - the "4-Box Model"



Source: Holling (1987 and 1992)

Founded in a categorization of the ecosystem functions originally made by Odum (1971), de Groot (1994) defines the affiliation between biodiversity and ecosystem. In universal terms, de Groot typifies the ecosystem structure in terms of four categories of biodiversity functions:

(1) Life support functions;
(2) Carrier functions;
(3) Production functions;
(4) Information functions.

Biodiversity is pondered to boast a life support function, i.e., a regulation of important ecological processes. The life support functions implies on the group of the biodiversity service flows that impact on the maintenance of a healthy environment, by making available clean air, water and soil, flood control and absorption of carbon storage and waste. The majority of the life support functions are regularly fuzzy (e.g., provision of carbon storage), and consequently not straightforwardly established and recognized (Nasiri and Huang, 2007; Kangas et al., 2007). The carrier functions point to the provision of space for human activities, namely habitation, agriculture and recreational activities. The production functions indicate to the provision of environmental resources, fluctuating from the industrial raw materials to the water and energy resources. The information functions reveal the maintenance of mental health, stipulating chances for reflection, spiritual enhancement and aesthetic involvement.

In recent times, Norberg (1999) recommended a substitute approach to categorize ecosystem functions and services of Nature. The author has selected this approach from the idea of Antonovics (1990), who applied his tactic to the genetic diversity. Norberg picked groups of ecosystem services to which mutual ecological concepts request as:

(1) Are the goods and the services interior to the ecosystem or is a part of other systems?
(2) Are the goods and the services of abiotic or biotic source?
(3) At which level of the ecological ladder are goods and services preserved?

Remembering the aforesaid selected criteria, ecosystem functions and services of Natures are ranked into three categories:

(1) Preservation of the populations;
(2) Guidelines of material and energy flows;
(3) Grouping of biological units through the choosy processes.

These categories stand for three chief fields in ecology that have deep-rooted theoretical foundations. Levin (1998) and Levin et al. (1997) illustrate three categories as:

(1) The research of the population or community ecology;
(2) The research of the ecosystem;
(3) The organization of biological entities.

The first category matches to the group of ecosystem services that are "…related to the specific species or a group of alike species" (Norberg, 1999). Samples of those services evolve precious foods and goods by ways of fish, timber, pharmaceuticals chemicals and flowers. The second category contains of processes that control the exogenous chemical or physical cycles, i.e. the processes that direct material and energy flows in ecosystems. The biota plays an important role in the most global cycles of chemical compounds, specifically, water, CO_2 and nitrogen. At last, the third category of ecosystem services is connected to the organization of biotic entities. Organization is virtually contemporaneous at all gradations:

(1) Organization of genes through natural choice;
(2) Spatial distribution of a population through the spreading ;
(3) Comparative elimination or the growth of food webs and ecosystems through invasion and elimination processes.

2.2.2.2. Ecological Indicators of Biodiversity: the Biotic Richness Approach

A better picture of biodiversity can be attained when the examination is performed in exactly what is measured in order to assess the biological diversity. Yet, the range of interpretations and the significance of different hierarchical levels of biodiversity are highlighted by scholars of various disciplines, and by policy makers. Reid et al. (1992) have noted that even in nowadays there is no well-defined agreement on how biodiversity should be assessed. Certainly, arguments on the measurement of biodiversity have become a considerable part of the ecological literature since the 1950s. This lack of agreement has also significant inferences on the economics of biodiversity conservation. At its most principal level, any estimation of cost-effectiveness used to lead investments in conservation must carry an index or set of biodiversity change indices. Pereira and Cooper (2006) stated to the global monitoring of biodiversity change. Later on, some aspects of biodiversity appraisals are reviewed, pointing to the same components of biodiversity (*Figure 2.2*) as referred levels of biodiversity in *Table2.1*:

Figure 2.2: Components of Biodiversity

- **Genetic Diversity:**
  - *Allelic Frequencies*
  - *Phenotypic Traits*
  - *DNA sequences*
- **Species Diversity:**
  - *α-diversity*
  - *β-diversity*
  - *γ-diversity*
- **Ecosystem Diversity:**
  - *Large-scale ecological systems, i.e. eco-regions or eco-zones*

Source: Nunes et al. (2001) and OECD (2001a)

1. Measurement of Genetic Diversity

   The estimation, conception and measurement of variations within and among populations are, in general, indistinguishable despite of whether a “population” is supposed to be a local group of creatures, geographical race, subspecies, species or higher taxonomic cluster. Genetic alterations can be computed in terms of:

   (1) Allelic Frequencies;
   (2) Phenotypic Traits;
   (3) DNA sequences.

(1) Allelic Frequencies

The identical gene can survive in numerous variations and these variations are named alleles. Measures of allelic diversity crave acquaintance of the allelic structure at individual loci. This information is normally attained using protein electrophoresis, which studies the migration of enzymes under the pressure of electric field. Allelic diversity may be estimated at the individual or population level. Generally, the more alleles, the greater reasonable their frequencies, and the more polymorphism loci, the greater the genetic diversity. The mean expected heterozygosity (the probability that two alleles chosen randomly will be various) is generally accepted as an overall measure. A lot of alternative indices and coefficients can be requested as the quantifications to appraise the genetic distance. The discovery of an allelic variation by electrophoresis has the gain that it can be correctly measured to impart comparative quantities of the genetic variation. Nonetheless, the shortcomings are that it may not be a member of the differences in the genome as a whole and a thought of the functional or selective significance of particular alleles.

(2) Phenetic Traits

Phenetic traits are supposed as phenetic diversity with the measurements of individuals' phenotypes, while individuals share the identical characteristics. This tactic keeps away a study of the underlying allelic composition. It is typically taking care of the measurement of the variance of a precise trait, and usually evolves promptly quantifiable morphological and physiological characteristics. Phenetic traits can be without difficulty appraised, and their ecological or practical utility is either clear or can be promptly assumed. Nevertheless, their genetic grounds are frequently hard to measure. Standardized comparisons are complicated as well when populations or taxa are assessed for qualitatively various traits.

(3) DNA Sequence

A part of DNA is arranged applying the polymerize chain reaction (PCR) method. This method signifies the requirement of only a very small amount of material, probably one cell, to get the DNA sequence data. Only a drop of blood or even just one hair is enough as an example for the derivation of the DNA sequence data. Intimately related species may have in common even 95 percent or more of their nuclear DNA sequences, indicating to the great resemblance in a whole genetic information.

2. Measurement of Species Diversity

The ideal way is to present the species diversity measurement, which contains a full catalog of the distribution and abundance of all species in the particular field. Though, this measurement is frequently impossible unless the particular field is a tiny region. So, in practice, the measurement of species diversity usually relies on the samples. As Whittaker (1960 and 1972) suggested the core measures of species diversity, which are:

(1) α species diversity;
(2) β species diversity;
(3) γ species diversity.

(1) *α-diversity* indicates to the number of species, which are present in a particular region. Therefore, it assessed the species richness of a particular sample plot. Its usage of species diversity measurement infers to the preference of a region with a high number of species to one with a marginally smaller number of species (Huston, 1994).

(2) Principally, *β -diversity* appraises the output of species between local regions, such as the rate of alteration in species structure among certain sites or habitat units. Per se, it is incoherent to the number of species, appearing for an index and explaining as a species output rate. *β-diversity* is predominantly utilized to assess average alterations in species as a feedback of the site or habitat heterogeneity.

(3) The last measure of species richness is *γ-diversity*. It is commonly employed to appraise the total diversity within a large area. Its conception has forward inferences of biodiversity at the landscape level (Waldhardt, 2003). The available lists of national species usually handled as the lower bounds on gamma diversity. As a sample, Colombia and Kenya are the residences for over 1,000 species of birds, while the UK and the forests of eastern North America are residences for approximately 200 species. A coral reef of northern Australia is assumed as a residence of 500 species, while the rocky shoreline of Japan is considered as a residence for just 100 species of birds(UNEP, 1995).

Species richness measurement is valuable, but a biased diversity estimation can be depicted (Sousa et al., 2005). First, researchers encounter to enormous uncertainties about the full lists of species. Consequently, species richness can be only assessed for some species, which were examined. Actually, approximate estimation of the full lists of species is available only in a very few places in the world. Second, the size of the field is often random. Species diversity is related with the habitat scale in a compound way. Therefore, the comparison of the species diversity of the regions, which vary greatly in size, should be performed with caution. Additionally, species diversity is an output of compound genealogical relationships that are discarded here. Substitute species diversity estimates insert species richness with estimates of the degree of the genealogical variation. This kind of diversity assesses covers the weighting of closely related species, higher-taxon richness, spanning tree length and taxonomic dispersion. Until now, real complications, regarding the application of such measures, compel dependency on the simplest indicators of species richness.

3. Measurement of Ecosystem Diversity

The measurement of ecosystem diversity at the organizational level includes a multi-complicated relationship, both at the intra- and supra-species level that play a vital role in outlining the total species distribution. For this purpose, a number of factors are counseled to assess more blurred and less markedly defined ecosystem diversity. In reality, numerous opposed units of ecosystem diversity are included, fluctuating from the patterns of habitats to the age arrangements of populations, together with the patterns of communities on the landscape and patch dynamics. It is unclear where to delineate the border outlining the biodiversity units at these levels. When a wetland, as a sample, is disturbed, the impacts of the disturbance should be surveyed at the largest landscape level. The ecological value of an ecosystem can differ from the aggregate value of the similar system's compounds.

In a different way, the system is more than only the collection of its singular parts; it owns a key value. Moreover, Cutter and Renwick (2005) reviewed that the conservation of biodiversity at the ecosystem level does not only highlight the preservation of species, but also lead to the protection of the ecosystem services and functions. Hence, the complete range of biodiversity values relies on the processes that maintain the functioning of large-scale ecological systems. Bearing in mind those defined borders, diverse measurement approaches are applied, where biogeographical provinces depend on the distribution of species and ecoregions or ecozones depend on physical attributes(UNEP, 1995).

Examples for Operationalization of the Biotic-Richness Approach

Ecologists are repeatedly given a task to donate with their skills and assists of policy makers to outline conservation priorities. A substantial role of the ecologist’s aid is somehow linked to Usher’s ecological view to environmental protection (Usher, 1989). As pointed by the Usher's conservation estimation, decisions are typified by three stages.

1. The attributes are specified and are used to imitate the conservation interest of the species or the site.
2. The criteria are created for the expression of the attributes in a form that permits appraisals.
3. The values are joined to the special levels of criteria.

The Red Data Book is one imperative tool for estimating species variety (e.g. ICN, 1993). Consistent with their introduction, Red Data Books were created to detect threats or reasons of decay of diverse species around the world (Fitter and Fitter 1987, IUCN 1993, Mace and Stuart 1994). In brief, Red Data Book is an appraisal technique illustrated by the assortment of a species list (the attribute) to evaluate the species richness (the criterion). Red Data Books rank species in one of eight distinct sets, depicted as the structure of species categories in *Figure 2.3*:

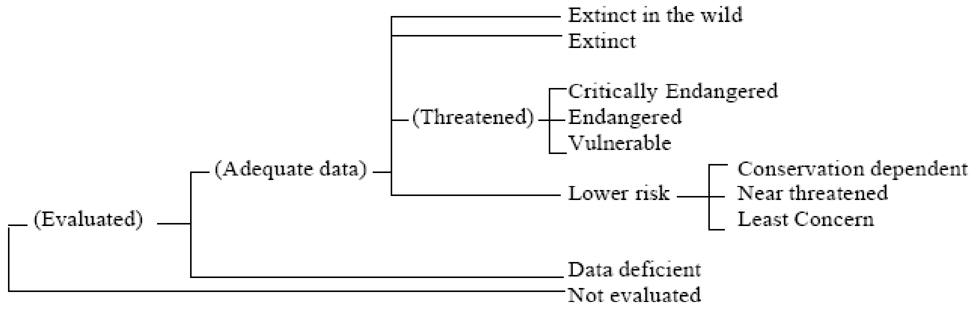
- Extinct;
- Extinct in the wild;
- Critically endangered;
- Endangered;
- Vulnerable;
- Lower risk;
- Data deficient;
- Not evaluated.

The aim is to endow a simply and broadly known technique to instruct species in categories as stated to their threat of extinction under the present conditions such as:

(1) To give information on which to ground conservation programs;
(2) To help the drafting of laws;
(3) To carry information understandable to a non-specialist.

For this purpose, Red Data Books are often utilized by many governmental and non-governmental organizations for the policy leadings and the foundings of conservation priorities (Runes et al., 2000).

Figure 2.3: Structure of Species Categories



Source: http://www.iucn.org/themes/ssc/redlists/categor.htm

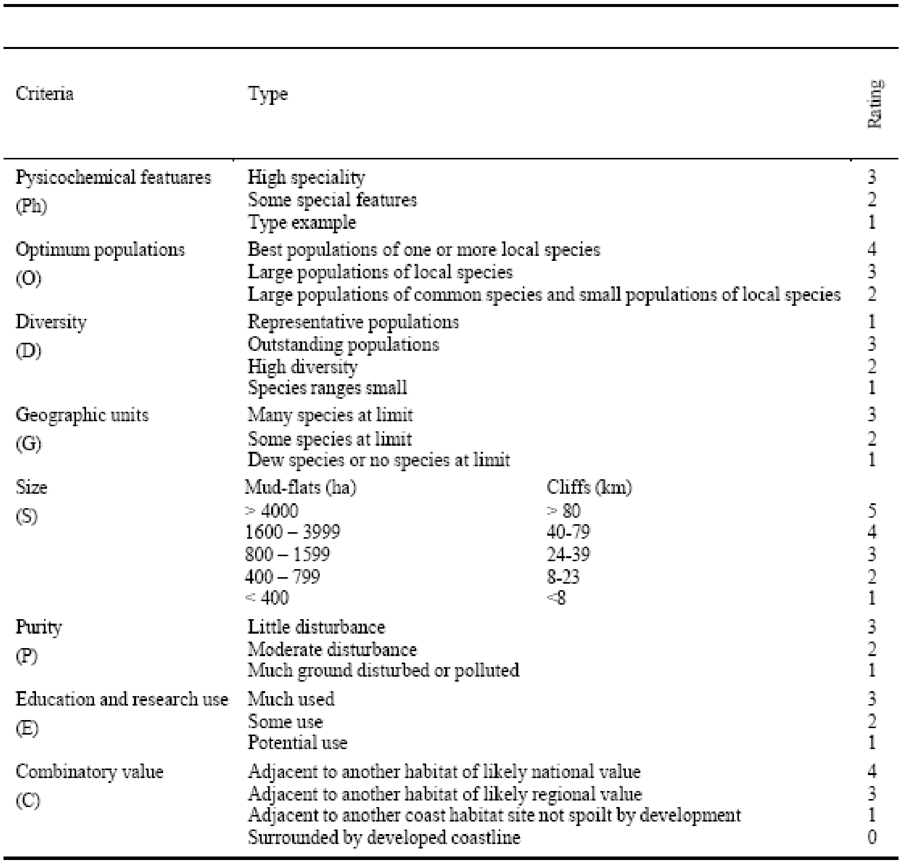
A number of problems are present, nevertheless, executing category evaluation is quite hard to process. While, the categorization of a species is based on an objective appraisal, the real definitions of these categories depend on a subjective view. Practically, the extremely many available criteria (e.g. α, β and γ criterion) used for estimation somehow by now imitate the complexities that are present in conceptualizing its value. In addition, the species category of threat is not unavoidably enough to verify the precedence for conservation accomplishments. So, if Red Data Books were selected as the ecological technique performed in the OECD countries for the setting up of the biodiversity priorities, it would be a jeopardy that numerous sites would not have much of a value (and therefore hard to protect). Seeing as this evaluation method purely presents an evaluation of the likelihood of species disappearance. At last, specified the scientific knowledge of population and ecosystems, it is probable to progress alternative indicators, involving the application of various other criteria apprehending the conservation action.

Randwell (1969) proposed an early example of a multi-criteria rating. The technique was used to assess coastal habitats and gather the application of eight aforementioned criteria into a single score, which is shown by the *Comparative Biological Value Index (CBVI) in Equation 2.1*. Each of these criteria are ranked with the scale as described for the rating of the criteria used by Randwell for evaluating coastal habitats in *Table 2.2*, and with the final score is attained by summing up the scores for all the nine criteria:

Equation 2.1: Comparative Biological Value Index (CBVI)

$$\mathbf{CBVI = Ph + O + D + G + S + P + E + C}$$

Table 2.2: Rating of the Criteria Used by Randwell for Evaluating Coastal Habitats



Criteria	Type		Rating
Pysicochemical featuares	High speciality		3
(Ph)	Some special features		2
	Type example		1
Optimum populations	Best populations of one or more local species		4
(O)	Large populations of local species		3
	Large populations of common species and small populations of local species		2
Diversity	Representative populations		1
(D)	Outstanding populations		3
	High diversity		2
	Species ranges small		1
Geographic units	Many species at limit		3
(G)	Some species at limit		2
	Dew species or no species at limit		1
Size	Mud-flats (ha)	Cliffs (km)	
(S)	> 4000	> 80	5
	1600 – 3999	40-79	4
	800 – 1599	24-39	3
	400 – 799	8-23	2
	< 400	<8	1
Purity	Little disturbance		3
(P)	Moderate disturbance		2
	Much ground disturbed or polluted		1
Education and research use	Much used		3
(E)	Some use		2
	Potential use		1
Combinatory value	Adjacent to another habitat of likely national value		4
(C)	Adjacent to another habitat of likely regional value		3
	Adjacent to another coast habitat site not spoilt by development		1
	Surrounded by developed coastline		0

Source: Randwell (1969)

The maximum possible value is 28 and the minimum value is 7. The higher CBVI value is, the greater prerequisite is to protect the spots. From the times of Randwell, the application of indices establishes a widespread practice in ecological valuation and management. In addition, Spellerberg (1992) enlarged the review of CBVI assessment of the landscape and urban habitats. Still, this appraisal approach depends on input criteria, which may not be advantageous to the decision-making policies, which should be unlocked, non-controlling, apparent, comprehensible, participatory and should guide to a constructive role distribution, such as stated initially (Soderbaum, 2005; Siebenhqner and Suplie, 2005). The existing hindrance is bewildered while estimating and characterizing the ecological values for the control of the decision-making policy.

Ecological assessment found in computer modeling shows three expressive advantages.

(1) It has inspired greater severity in data evaluation, since it allows the introduction of subjective elements within an obvious and reiterated structure.

(2) It tolerates a direct contrast of various conservation policies, sovereignly from the quantity of the included criteria and own attributes. For instance, it allows the contrast of the pursuing approaches:

- A conservation strategy containing a criterion with ten attributes which could get a maximum score of 50.
- Another preservation policy comprising a criterion with two attributes that could only score a maximum of 10.

(3) Lastly, it certifies an evaluation even when some of the attribute data are absent, which usually happens in practice.

2.2.2.3. Ecological Indicators of Biodiversity: the Ecosystem Health Approach

Ecological valuation techniques are not only intended at estimating diversity and scarcity of species, but also the compound interactions between the biotic and abiotic environments, consistent with the hypothesis that the variability of abiotic conditions is uniformly vital as variability of species. For example, abiotic diversity is envisaged to be united to the occurrence of endemic species and therefore to biotic diversity and scarcity in a natural way (Bertollo, 1998). Thus, from an ecosystem view, the identification of biodiversity value is essentially shared with the ecosystem execution and reliability. Besides, the terminology “value” points to how well an ecosystem is operating when contrasted to its individual capacity and how imperative this is for the operation of extra ecosystems and, eventually, for the operating of the global ecosystem (Sijtsma et al., 1998).

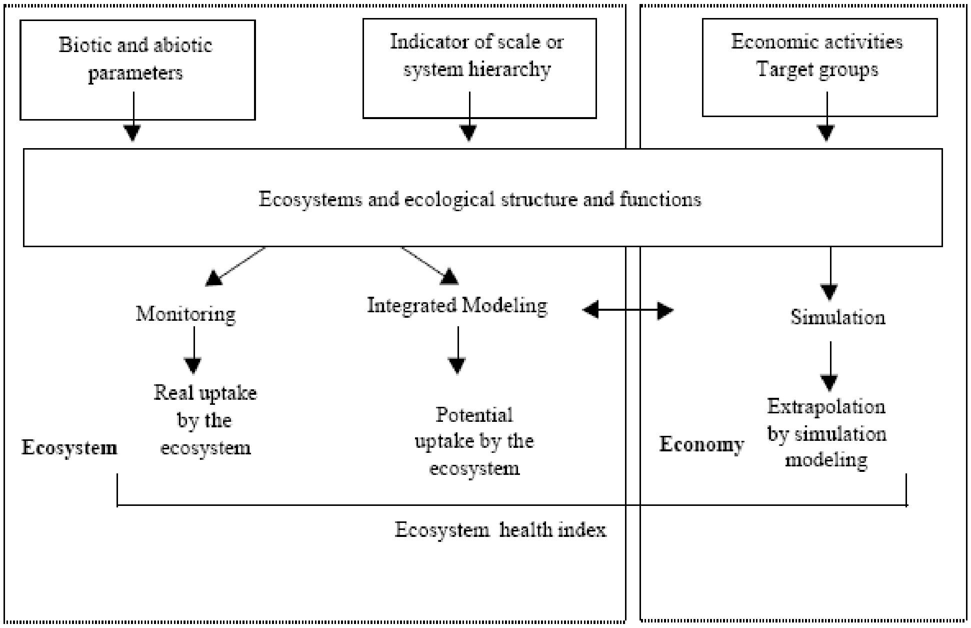
The following contemptations will be obscured here via:

1. Ecosystem health;
2. Examples of ecosystem health indicators;
3. Ulanowicz’s ascendency index;
4. The ecosystem classification method;
5. Nature measurement method;
6. Ecological effect measurement method;
7. Ecological capital index.

(1) Ecosystem health is a complete indicator of the ecosystem operating (or ecosystem reliability), considering both ecological and human processes. An ecological system is expected to be healthy, if it is constant and sustainable, i.e. if it is active and upholds its establishment and vitality over time and is robust to irritation. In brief then, the definition of the ecosystem health can be as a measure of the complete execution of a complicated system that is expanded from the behaviour of its parts (Costanza, 1992). Beforehand the health of an ecosystem can be estimated, it is important to carry on the

identification of biotic and abiotic parameters or indicators, aim human economic activities and the scale or hierarchy of analysis by the definition of the health indices in *Figure 2.4*.

Figure 2.4: The Definition of the Health Indices



Source: Nunes et al. (2001) and OECD (2001a)

When choosing the parameters and indicators, which are related to the research. The majority of the biotic and abiotic parameters or indicators, namely soil, flora, and fauna indices, have appeared from the ecological literature (Odum, 1971). In addition, the quantification of the certain biotic and abiotic indicators requires to be a viable undertaking to come up with reasonable and justifiable figures. Furthermore, it is vital to establish the scale or hierarchy of analysis. The selection of the scale relates to the imperative decisions over the limited and chronological viewpoint of analysis (Norton and Ulanowicz, 1992). It is shared that borders are illustrated with correspondence to the ecosystem’s land characteristics or its geography (e.g. wetlands ecosystem). In conclusion, the measurement of ecosystem health obligates to recognize the human actions that effect on the ecological hierarchy and processes. The emphasizing concept is that human economic activity or aim groups, which induce their environment. Consequently, the information on the influence of economic activity of the ecological hierarchy and processes, overall, and on the economic indicators, in particular, requires to be contemplated when evaluating the ecosystem health.

It is unobstructed that both ecological and human dimensions are dynamic; they vary in diverse ways in accordance with multiple frames of time. As a result, biotic, abiotic, and economic indicators must be satisfactorily dynamic to change correspondingly. For instance, even if the spatial and temporal boundaries of analysis are clearly defined, there could persist vital questions according to the hierarchy of the ecosystem. Hence, there would be the necessity to indicate borders on a tiny scale. Each feature is exemplified by its individual set of indicators and is evaluated by itself. Consistent with Costanza et al. (1992), this set of indicators can vary considerably from portion to portion, i.e., from ecosystem to ecosystem.

After making a decision upon the biotic and abiotic indicators, scale or ranking of analysis and the aim economic groups, the scientist are able to proceed with the measurement of the complete ecosystem execution, such as ecosystem health. One conceivable approach is to employ directly the available data endowed by observing activities. This data will endow information with regard to the original uptake by the ecosystem and this way consent to measure the total ecosystem health. Instead, one can join the relevant ideas and progress an analytical framework. The blend of the existing data and such a model formulation will permit for an extra step in the estimation of ecosystem health. At this level, the scientist is not only employing the existing data to infer ecosystem health, but also explore the dynamics of incorporated modelling in the way to assess the potential uptake by the ecosystem. Irrevocably, the scientist has the capability to simulate diverse conservation scenarios by handling the examined characteristics, or controlling variables, such as, input of a new set of concentration quotients. In every conservation scenario, the scientist has the capability to calculate the related ecosystem health index and therefore give crucial information as to categorize the extra management policy scenarios.

(2) Examples of ecosystem health indicators

The composition of ecosystem health indexes permits policy makers to envisage ecosystem response as a consequence of numerous exact management options and natural variations. Practically, this formulation proceeds to the following way for a total system health index (HI) as shown in *Equation 2.2*:

Equation 2.2: Health Index (HI)

$$HI = V \times O \times R$$

Where

- V elects system "Vigour" and corresponds to a basic measure of the ecological system activity, metabolism, or primary productivity;

- O elects system “Organisation” and corresponds to a 0-1 index of the comparative degree of the ecological system’s organisation, involving its diversity and connectivity;

- R elects system “Resilience” and corresponds to a 0-1 index of the comparative degree of the ecological system’s resilience

These three indices, i.e. vigour, organization and resilience are represented in *Table 2.3*.

Table 2.3: Indices of Vigour, Organization and Resilience

	Related Concept	**Related Measure**	**Field of origin**	**Measure-ment solution**
Vigour	Function	GPP, NPP, GEP	Ecology	Monitoring
	Productivity	GNP	Economics	
	Throughput	Metabolism	Ecology	
Organization	Structure	Diversity Index	Ecology	Network Analysis
	Biodiversity	Mutual information predictability	Ecology	
Resilience		Scope for growth	Ecology	Simulation modeling

Source: Costanza (1992)

In conclusion, the total ecological system health is provided by its activity weight through indices for the comparative system’s organisation and resilience. To operate the vigour, organisation and resilience compounds of the health index will expect the application of various measurement solutions to the data, including the employment of expertise from both economics and ecology.

(3) Ulanowicz’s ascendency index is one vital instance of ecosystem-health index, which permits for an integrated, quantitative and hierarchical measurement of ecosystem health (Ulanowicz, 1992). In easy terms, the ascendency index redirects any degradation of the system. On the other hand, such an indicator wants data on all transports occurring in the considered ecosystem. The compilation of such a data is habitually a hardworking and costly task. This is a reason that entirely quantified networks of ecosystems even now remain scarce (Costanza 1992). Additionally, it is imperative to recall the difference between a scientific-orientated methodology and a policy-orientated approach. Practically, several valuation techniques can be easily obtained to unite a set of

ecosystem integrity indicators into one communal denominator that has a socio-politically application and therefore a sense for the policy makers.

(4) The ecosystem classification method is a General Method for the Description and Evaluation of Ecosystems, which is recognized by the Dutch acronym AMOEBE (Algemene Methode voor OEcosysteembeschrijving en Beooordeling), is developed by Brink and Hosper (1989). This technique was initially employed to estimate the quality of aquatic ecosystems by contrasting the existence of the chosen species with their existence in a benchmark situation of 1930. The chosen species, which Brink and Hosper referred as "target variables", were opted on the basis of:

(i) Their representativeness (i.e. is a healthy aquatic ecosystem represented for them?);

(ii) Their flexibility (i.e. can human interventions influence on them?);

(iii) Their measurability and data availability (i.e. is the measurement simple and is any data-basis available for them?).

Since the AMOEBE does not imply whether one ecosystem is more valuable than another, the valuation technique is not often opted with the aim of policy formula guidance.

(5) Nature's measurement method is developed by the Dutch Centre for Agriculture and Environment in Utrecht in 1995 to estimate the natural values of agricultural areas. The natural values are quantified in terms of species abundance and its variation from its initial diversity potential. Species are elected that are existing on agricultural plots, straightforward to identify and that depicts natural quality (Buys, 1995). An identical formulation was developed by the Foundation for Spatial Economics of the University of Groningen to estimate the costs and benefits of the National Ecological Network (Sijtsma and Strijker, 1995). The costs were valued in monetary terms and the benefits mainly in ecological terms. The National Ecological Network employed the recognition of "nature target types" (i.e. pre-outlined the types of nature namely the European CORINE network) that are supposed to give the habitat mosaic for "target species". This is the reason why digital thematic maps are created as geographic information system land cover habitat types. Target species are categorized and picked on the basis of national and international scarcity. Zurlini et al. (2000) has currently used this valuation technique to draw the map of Italian nature.

(6) Ecological effect measurement method is developed by the Centre for Environmental Studies in Leiden in 1996 to value the consequences of housing development projects on nature and landscape. This technique is

initially illustrated by the characterization of the reference situation and human intervention measures, surveyed by the determination of the consequences for nature and, lastly, progressing to the combination of sequences (Cuperus and Canters, 1995). The general ecosystem biotic and abiotic features were employed for valuation, involving spatial diversity, abiotic functioning, fauna and flora communities in addition to their correspondences to the surroundings. Because this valuation technique is considered as both biotic and abiotic diversity which is estimated by means of the variance from a reference situation, it can simply be relocated to the policy arena and employed to determine the compensation measures in the case of damage to available natural areas.

(7) Ecological capital index is developed by the Dutch Environmental Planning Bureau in Bilthoven to estimate the state of both natural and cultural ecosystems relative to human activities. This index is computed by multiplying the ecosystem's quantity by its quality. In this case, the abiotic environment is considered as a conditional variable for the biodiversity reference situation (Nunes et al., 2000). The international appliance of the ecological capital index esteems the recommendations for a key biodiversity indicators as suggested by the Convention on Biological Diversity (UNEP, 1997) and therefore is consistent with the international classification (IUCN, 1991) of ecosystems on the root of the human influence degree.

In conclusion, ecosystem health indices permit the scientist to estimate the total ecosystem performance. Numerous examples have been identified in this subsection of the current chapter. These indices play an important role in the policy leadings since ecosystem response is envisaged by the afore-indicated ecosystem health indices which response is a result of alternative management scenarios and making probable scenario's hierarchies to be compared.

2.2.3. Biodiversity and Forest, in the Mediterranean Region

2.2.3.1. The Role of Forestry

Forest output has been insulating the involvement of national incomes. Between 1950 and 1957 years, the gross national product of industrial and underdeveloped countries has increased by just about 30% while the output of the world's forests by not more than 15% (Glesinger, 2007). Eventually, as recorded by UNASYLVA (1974/75), forest policies require to be formulated judiciously, as an intrinsic part of national development plans. Land should be earmarked to forestry consistence with the forestry capability to contribute to the improvement of living standards. Foresters are not under fear as whether such criteria are applied, their outcome will be as the second best. Quite the opposite, forests, forestry and forest industries are inherently well suited to the solution of numerous problems of underdevelopment and to the enhancement of numerous discomforts of industry (King, 2007). The role of forests is paying unique attention in the development of biodiversity and sustainable forest in regard with 1992. The forestry segment, which is feasibly more than any other sector, is well situated to contribute the worldwide leadership in the sustainable development practice. Sustainable development of Mediterranean forestland is indicated in the IAMF Bulletin (2005) and its multiple economic and environmental values include indefinitely upholding not only the productive and renewal capacities, but also the species and ecological diversity of forest ecosystems without obnoxious loss (Maini, 2007).

2.2.3.2. Biodiversity and Forest

Biological diversity (biodiversity) indicates to the richness, variation or numerous diverse species of living organisms. Almost 1.4 million diverse organisms, ranking from mammals to bacteria and viruses, have been recited (Wilson, 1988; Van Kooten, 1994). While worries on biodiversity extinction (usually species exhaustion), ordinarily, the emphasize on forests and biodiversity in tropical, temperate and Mediterranean climates, is imperative as well. In reality, more below-the-ground diversity may exist in temperate forests because soils in temperate zones incline to be rich in nutrients.

Operational clarifications of biodiversity essentially cogitate wildlife species; subsequently decisions are possible to hold on biodiversity if all organisms have an obligation to be classified. A few numbers of authors would wrangle with the concept, which is the significance of microorganisms heartily cannot be eliminated but from a practical stance, biodiversity highlights of wildlife or animal species (macro-fauna) that are based on the top of the food chain. In certain cases, only keystone species are viable to be concentrated, since they are important to the entire ecosystem.

Biological diversity is the sum of all life forms on Earth. It is the composed variability and variety of living organisms, i.e. all species of microorganisms, animals and plants, and the ecosystems. Our lives are contingent with biodiversity in uncountable ways. For instance, biodiversity is elemental to agriculture (Borner et al., 2007; Engstrom et al., 2007). The development of medicines, clean water, flood control and numerous resource-based industries, namely fisheries and ecotourism, is essentially a subject to biodiversity.

Forests are centers of biodiversity and vital to the livelihoods of billions of people - namely in the developing countries - as sources of food, fuel, building materials and timber. Moreover, forests play a key role in carbon storage and in the water cycle.

World’s forests are known to be crucial habitats expressed by their contained biological diversity and served ecological functions. Counting species as an exemplification of biodiversity, the number of illustrated organisms in total is close to 1.75 million, and the approximate estimation is that they may be only 13% of the true total, which is almost 13.6 million real species (Hawksworth and Kalin-Arroyo, 1995; Stork, 1999). What proportion of this unclear total resides is unknown in the worldwide forests. Whatever the exact number of forests in general, and Mediterranean forests in particular, which are major locations for biodiversity. The values of forests thus embody the values of the contained biodiversity since the huge majority of the bio-resources in question could not occupy forest habitats, which idea seems unlikely.

Forests control local and global climate, upgrade weather events, utilize the hydrological cycle, conserve watersheds with their vegetation, water flows and soils, and contribute a huge store of genetic information much of which has yet to be uncovered. Scientists argue on the linkages between biodiversity and ecological services. Those boffins whose beliefs are in a strong link quarrel that any forest ecosystem cannot cope with the stresses and shocks if its diversity has been condensed. In unison, others bicker that the majorities of species are “redundant” in the sense that their elimination would not weaken ecosystem functioning. On balance, unvarying systems are more vulnerable, where diversity matters for the ecosystem performance (Mooney et al., 1995; CBD, 2001a).

The necessity to understand the values, that are residents in the forests, arises from the assessed rates of forest loss in biodiversity. Species-land relationships, which envisage the number of species lost in relation to the land lost, evoke that loss rates are close to the thousands per year. The species-area relationship as well entails that recent rates of conversion of “natural” areas will not ensue in extreme quick rates of species loss contrasted to the loss rates that will result when hitherto further land conversion occurs. Alternatively, loss rates build up rapidly as the questioned area is condensed as: “fewer extinctions appear now, many more will appear later” (Pimm and Raven, 2000). The current situation is exacerbated by the concentration of much diversity into “hot spots” where land conversion rates have a tendency to be the highest. Even if all remaining hot spot land was immediately protected, it has been suggested that 18% of their species will disappear. If just currently protected hot spot areas remain in a decade’s time, 40% of hotspot species will disappear (Pimm and Raven, 2000). An African Unity organization has created the “model Law”, where recognizes the significance of indigenous knowledge and highlights unique guidelines for its protection (Zerbe, 2005). Recently, a huge number of “protective” forests fall into the “Aesthetic Forests” category, where several are further protected on the “Nature 2000” European protection regime grounds (Christopoulou et al., 2007).

In the spirit of the increasing environmental awareness in the last decades, we witness recently a growing interest in biological diversity, both locally and worldwide. Biological diversity wants our attention for two reasons.

(1) Biodiversity imparts a wide range of benefits to humankind and human activities.

(2) Numerous human activities have sourced with unprecedented rates of biological diversity loss, which threaten the ecosystems' stability and continuity with ecological systems' provision of goods and services to humankind.

Subsequently, nowadays much attention has been instructed towards the analysis and valuation of the biodiversity loss. The biodiversity valuation can be approached from an ecological, economic, or combined standpoint. This insertion bestows an overview of economic and ecological indicators of biodiversity, identifies the essential valuation approaches, debates key conceptualizations, and reviews the corresponding applications.

2.2.3.3. Mediterranean Region

Several descriptions about Mediterranean Region are illustrated:

- Mediterranean Lands occur between about 31° and 40° north and south of the equator on the western sides of continents: The Mediterranean Basin, California, Chile, South Africa and South East Australia (Capparos, 2003);
- The Surface Area of the Mediterranean Region can be estimated as 2.300.000km^2;
- The Mediterranean Region has the most complicated geology in the world and an extremely fragmented pattern;
- The metamorphism, volcanism, and deposition in shallow seas have produced a complex lithology of crystalline rocks, lave and limestone;
- The Mediterranean Climate is usually characterized by summer drought and cool – moist winters;
- Annual rainfall ranges between 100 and 3000 mm and average annual temperature between 5 and 18°C;
- The Mediterranean florist richness shows a number of approximately 25.000 species and more than half are endemic.

2.2.3.4. Representative Characteristics of the Mediterranean Region

Scarascia-Mugnozza et al. (2000) exemplifies the representative characteristics of the Mediterranean region which are exhibited:

- *Geographical and topographic variability* (jagged coastline and mountain with high elevation);

- *Climatic Seasonality with*

  - Dry and hot summer;
  - Moisture and cool autumns and winters;
  - Occasional violent precipitation episodes;
  - Large yearly variability of the total rainfall as well as frequent strong and dry winds;

- *High diversity of plant and animal species*

  - Rich variability natural vegetation types and land use forms;
  - Many endemic species;

- *A long history of manipulation* of trees, forest and landscapes.

2.2.3.5. Mediterranean Forest - Benefits to Society

Mediterranean forests (*Figure 2.5*) are one of the world's most core centers of plant diversity, with an assessed 25,000 species of which approximately half are endemic. They also contribute a wide range of essential benefits and services to society that go far beyond the traditional forest products. According to Albanis et al. (2000), Greece's geographic position is such that it can host plenty of flora elements from three different photo-geographic regions. Species from the Mediterranean, Mid Europe and Asia appear in Greece's forest vegetation and compose the rich flora in number and the origin of species. The general conclusions about the health condition of the Greek forests are as follows (IMFE&FPT, 1997):

- It seems that the condition of the Greek forests is determined mainly by abiotic (drought) and biotic (insects, fungi, grazing) factors and not by air pollution.
- Broadleaved species are in worse condition than the coniferous species.
- A deciduous broadleaved species with the "severe damage" (defoliation >60%) need more time to recover than the coniferous species.

Figure 2.5: The Mediterranean Forest

The forests of the Mediterranean regions are essential to maintaining water and soil resources. The forests protect watersheds and regulate the local climate by increasing the air humidity and thereby reducing the intensity of drought. In this way, they are barriers against desertification. The actions for desertification in Greece, i.e. Athens, are conferred in SMAP (2005), Hellenic Ministry for the Environment (2002). The forests also serve as natural barriers to storms and floods and have the considerable water retention capacity that reduces runoff and landslides during periods of heavy rain. Forests have always played and still play an important role in the daily life of the Mediterranean peoples. People have been harvesting forest animal and plant products on a large scale in the region for thousands of years, developing numerous uses and management systems and acquiring sophisticated knowledge of their environment. In the past, forests and trees attributed to longstanding cultural values that have defined the Mediterranean landscapes. Many endangered ecosystems and rare, endemic species in the Mediterranean still coexist in close relationship with humans.

Although Mediterranean forests provide low direct economic returns on wood products in comparison to the Northern European forests, they play a crucial role in maintaining key components for securing human welfare and life in the region (Albanis et al., 2000). For instance, forests of the Northern Mediterranean region support tourism in a major way by providing recreation opportunities and scenic value. Given the significant differences in economic and social development across the region, the role of forests in society varies greatly between on one hand the Northern Mediterranean and the Eastern and Southern parts of the Mediterranean on the other hand. Furthermore, according to a MCPFE Implementation Report – Part 1 (2002), forestry in Greece has no major financial importance, but rather a protective one, since the main stakeholders do not give high priority to the sustainable management. Association International Mediterranean Forests (2007; 2006) attempted to design quality policies for Mediterranean forest management in protected areas. According to Trommetter (2005), the management of biodiversity is constrained by the implementation of national (local) incentive policies.

- The proportion of the forest relative to the total land area, quite different among sub-regions;
- Variation from 20-30% in the Northern Med to 1-8% and 5-10% in Southern and Eastern Med;
- In Greece and Albania, forest cover 50% although only ⅓ of the forest utilized for wood and timber production;
- The average forest land per citizen in Greece is 0.00667 Ha (Christopoulou et al., 2007).

Table 2.4: Area of Forests in Greece According to the Tree Species

TYPES	%
ABIES	8,34
PINUS(HALEPENSIS, BRUTIA)	8,72
PINUS NIGRA	4,33
PINUS SYLVESTRIS	0,32
PINUS LEUCODERMIS	0,13
PINUS PINEA	0,005
ABEIS, PINUS NIGRA	0,07
PICEA	0,04
FAGUS	5,17
CASTANEA	0,51
QUERCUS	22,8
PLATANUS	1,33
BETULA PENDOULA	0,02
NON-INDYSTRIAL FOREST	48,215

2.2.3.6. Threats to Mediterranean Forests

Several years ago, the exploitation of the natural landscape was long, unhurried and somehow sustainable. In the past decades, the balance between nature and humanity has been veered. Nowadays, the forests are fragile and under threat. Intensive agricultural practices (Sekhar, 2007) and climate change threaten many of the rare species that characterize the Mediterranean regions. Other major causes of forest damage in the Mediterranean include fires (Chuvieco and Congalton, 1988; Natural Hazards Project, 2001), clearance and degradation mainly due to ill-conceived land use policies and development pressure. Moreover, grazing is still considered by many to be a threat to the regeneration of European Mediterranean forests, yet it is also a factor that maintains biodiversity richness and diversity.

2.2.4. Biodiversity Loss and Forest Degradation

Biodiversity is under threat everywhere (Rouget et al., 2003). The most publicized biodiversity loss is the destruction of natural ecosystems and loss of species, which is primarily caused by various human activities such as not only industrializations and urbanizations, but also the over-exploitation of living resources and industrial pollution. As species disappear, today’s and probably tomorrow’s foods, medicines and industrial products can be lost. As genetic diversity erodes, the capacity to maintain and enhance agricultural, forest and livestock decreases. Additionally, Nsiah-Gyabaah (1995) discusses that the degradation of ecosystems guides to the loss of the valuable services which are provided by natural and semi-natural systems. Yet agricultural species and varieties are also disappearing. Since the beginning of the twentieth century, about three quarters of the genetic diversity of agricultural crops have been lost and people’s knowledge about the properties of plants and animals are being lost with them. The greatest factor leading to this loss has been the spread of high-input industrial agriculture.

The highest estimation of the world’s remaining forested land is about 3.6 billion hectares compared to an originally forested land of more than 6.0 billion hectares. Due to current uncertainties about planetary species richness, no one can say exactly how many species deforestation claims. However, recent estimations, by IUCN and The World Conservation Monitoring Center, suggest that since tropical forests are home to 50 - 90 percent of the world’s species, annual forest loss in the tropics may lead 13 percent of the world’s species to extinction by the year 2015 (IUCN, 1999).
Dealing with the destruction and degradation of the forest, particularly Mediterranean forest, an interesting approach to the causes of Mediterranean forest degradation is suggested in *Figure 2.6*. It has been retrieved that causes are divided into two major parts:

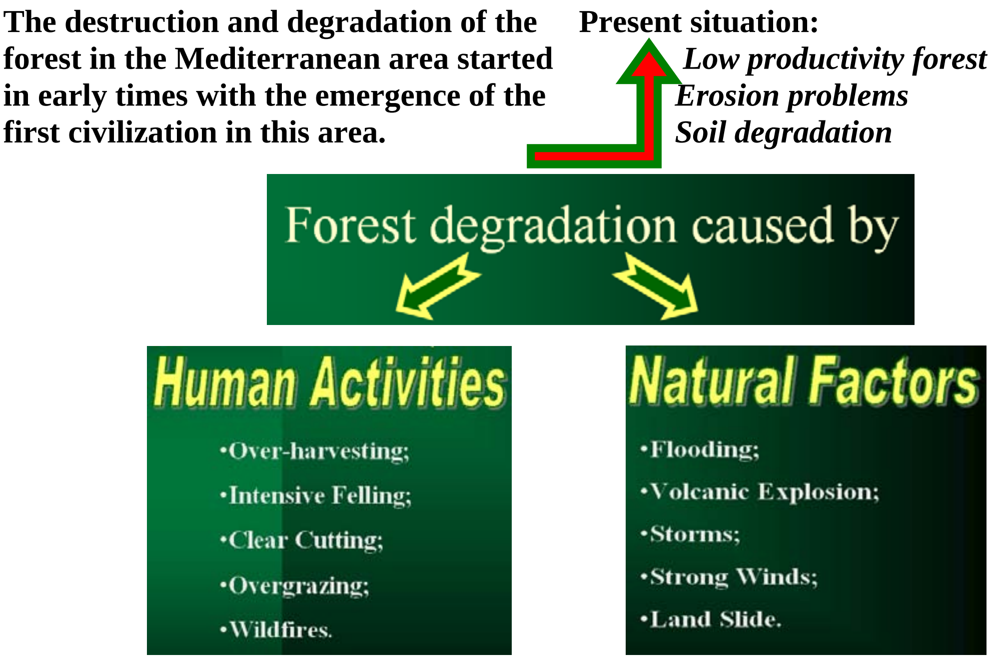
(1) Human Activities:

- Over-harvesting;
- Intensive Felling;
- Clear Cutting;
- Overgrazing;
- Wildfires.

(2) Natural Factors:

- Flooding;
- Volcanic Explosion;
- Storms;
- Strong Winds;
- Land Slides.

Figure 2.6: Causes of Mediterranean Forest Degradation



The destruction and degradation of the forest in the Mediterranean area started in early times with the emergence of the first civilization in this area.

Present situation:

Low productivity forest
Erosion problems
Soil degradation

Forest degradation caused by

Human Activities

- **Over-harvesting;**
- **Intensive Felling;**
- **Clear Cutting;**
- **Overgrazing;**
- **Wildfires.**

Natural Factors

- **Flooding;**
- **Volcanic Explosion;**
- **Storms;**
- **Strong Winds;**
- **Land Slide.**

“Forests lie at the nexus of local livelihoods, biodiversity maintenance and reducing land degradation, for example due to erosion (Diodato and Ceccarelli, 2004; Boisvert and Vivien, 2005). They also regulate floods of water and it is essential that wider functions of forests are recognized by managers of the Mediterranean region,” said Jamie Skinner, Director of the IUCN Center for Mediterranean Cooperation.

The massive exploitation and degradation of forest during the last decades have played a vital role in diminishing biological diversity.

Causes of Biodiversity Loss

Further on, the causes of biodiversity loss for the Mediterranean Forest are suggested as follows:

- *Natural disasters* have been discussed above as Natural Factors.
- *The growth of human population* is another factor that leads to the overuse of natural resources. The demand for goods and services becomes higher with the increase in population. Therefore, the control of the environment and its biodiversity stands as a problem.
- *A market failure* is one of the factors that contribute to the biodiversity problem or impact. Non-market presence in the control of the environmental products, miss-management and overuse are there to suffice. It is thus reasonable to initiate the policy that could promote Privatization Systems.
- *Intervention failures*
  If the Government fails to guide green economy, in a way by establishing rules and regulations on the usage of natural resources, then the mismanagement of natural resources is in evidence to lead towards environmental damage. The intervention of the Government therefore will direct to a sustainable use of capital wealth, which will involve the ecosystem and biodiversity preservation.
- *The shortage of sustainable economic development*
  The wrong-management and incorrect supervision of the ecosystem in economic activities trigger excessive use of the natural environment. The sustainable economic development is necessary for a proper evaluation of environmental goods. This will assist to maintain biodiversity while economic activities are taking place.
- *Poverty as an impact to biodiversity*
  Poverty, which affects to the biodiversity loss, is one among the important elements (Roe and Elliot, 2004). Unavailability of sources of income could cause the inhabitants to overuse and consume whatever is provided by the nature without giving any consideration to biodiversity in it.

Estimations of precise rates of loss of biological diversity are hampered by the absence of any baseline measurement. However, from the evidence of island habitats it seems that the expansion of the human niche by various forms of conversion is geometrically related to extinctions. Further, based on the recent evidence from the observation of the potential "indicator", species such as amphibians and birds provide some indication of accelerated loss in excess of historical or background rates (Pechmann et al, 1991; Myers, 1993). The estimations of the current rates of species extinction are shown *Table 2.5*. These estimations are based on extrapolations of human land use trends related to species area curves which are the basis of island biogeography. Over the next century, the projected loss of species might be expected to be as high as 20 to 50 percent of the world's total, which represents a rate between 1000 to 10000 times of the historical rates of extinction (Wilson, 1988). The rate of loss is outstripping the natural regenerative capacity of evolution to throw up new or evolved species. The extinction "outputs" far exceed the specification "inputs" (Ehrlich and Ehrlich, 1992). The potential effects of accelerated extinction and depletion of the genetic base may be discerned over varying time horizons. On the long term, the processes of natural selection and evolution may be dependent on a diminished resource base, simply because fewer species are being born. The implications of species depletion for the integrity of many vital ecosystems are far from clear. The possible existence of depletion thresholds, associated system collapse, and huge discontinuities of related social cost functions, is potentially the worst outcome in any reasonable human time horizon. Such scenarios are indicative on the links between ecosystem integrity and economic well-being. More immediately, the impoverishment of biological resources in many countries might also be regarded as an antecedent to a decline in community or cultural diversity, indices of which are provided in diet, medicine, language and social structure.

Table 2.5: Estimations of the Current Rates of Species Extinction

Estimate of loss of species (%)	*Basis*	*Source*
33–50 by the year 2000	Forest area loss	Lovejoy (1980)
50 by the year 2000	Forest area loss	Ehrlich (1981)
25–30 in the 21st century	Forest area loss	Myers (1989)
33 in the 21st century	Forest area loss	Simberloff (1986)

Source: Pearce and Moran (1994)

At least four questions emerge from the scientific uncertainty surrounding species loss:

1. What is the number of species from which to measure current rates of loss and the detection of this rate, allowing for background evolutionary turn-over?

2. How much are the principals and predictions of island biogeography and by how much are current extinction estimates (probably) understated?

3. Given the likely time horizons at issue, the concerns can be the perversion of the evolutionary processes as opposed to the immediacy of system thresholds and flips?

4. What is the potential for using indicator species or a more sophisticated index to guide conservation efforts. Is there any scientific consensus on appropriate species or ecosystems to be used?

The need to pursue cost-effective investment interventions in biodiversity conservation has added considerable urgency of these issues. Reliance on pivotal keystone or umbrella species (Noss et al., 1992) is appealing but crude. Similarly, focusing on wider taxonomic groups or ecosystem functions provides few indications of the likelihood of successful interventions given wider socio-economic pressures on wilderness ecosystems and protected areas. Criteria such as species sensitivity to habitat disruption or poor reproductive capacity can be combined with other socioeconomic data, such as population density, deforestation or figures on conservation investment, expenditure to provide some indication of where species are threatened. However, assuming some consensus definition of threat raises the issue of whether funding is most effectively directed to those areas most under threat, or away from them entirely in favor of areas with a higher likelihood of success. This in turn implies some objective assessment of a “successful” intervention. Given that no species can be saved indefinitely, the objective decision criterion becomes the extra cost of an increment to the probability of endurance (Montgomery et al., 1994).

Understandably, the development of investment criteria designed to maximize diversity per dollar and incorporating a composite threat indicator, is likely to take time. Inevitable data restrictions are certain to further complication which is already a contentious exercise.

At some point a consensus measurement of biodiversity is required to guide the investment of scarce funds. The resulting index may seem arbitrary and will inevitably contravene with disparate sections of scientific opinion but will be necessary to provide a general direction for biodiversity investment. Moreover, using this index, any cost-effective system of area triage will necessarily require some consideration of complementary of resulting fauna designations. In other words, the selection of successive areas for protection ideally needs to be based on the incremental complement to diversity afforded by the last fauna until the complement is reduced to zero (Faith, 1994). This is clearly a massive undertaking, requiring precise taxonomic inventories and as much socio-economic information as dictated by the guiding index. At the same time such a process could show how an excessive concentration on certain biota can yield diminishing returns. The process of building on rapid appraisal rules of thumb such as hot spot or mega-diverse areas has already begun. Emerging prescriptions are considerably less discriminating than the precise genealogical indices and do not as yet attempt any fauna complementary ranking. Tevertheless, these prescriptions attempt to combine the basic species richness indicators with the socio-economic parameters most immediate to biodiversity loss.

2.3. ECONOMIC FOUNDATIONS FOR BIODIVERSITY ANALYSIS AND VALUATION

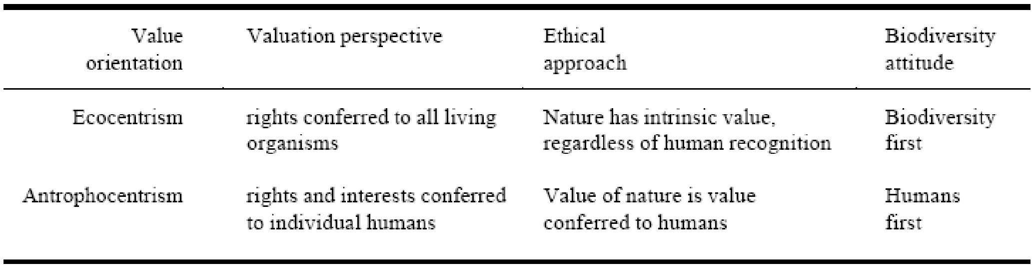
2.3.1. Why Economists Pursue Economic Valuation

The economic valuation of natural resources, in general, and biodiversity, in particular, is among the most pressing and challenging issues confronting today’s environmental economists. In the opinion of Nunes et al. (2000), economists value biodiversity because such a valuation technique allows a direct comparison of economic values with alternative options and facilitates. For example, cost-benefit analysis represents a crucial tool for the policy formulation. In addition, the monetary valuation of biodiversity allows economists to perform environmental accounting to assess natural resource damage and to carry out proper pricing. Moreover, the valuation technique is shown to be essential in the research on individual consumer behavior and investigates what the individual consumer thinks of certain biodiversity management objectives or identifies individual consumer’s motivations with respect to biodiversity conservation. Many people, however, are not willing to place monetary values of biodiversity. Arguments against it are rooted in the human preference orientation that “guides” consumer behavior with respect to biodiversity (Ehrenfeld, 1988; Lockwood, 1999). At the risk of oversimplification, two broad ranges of value orientations with their environmental attitudes are distinguished (see *Table 2.6*).

(1) According to the *“anthropocentric”* orientation, the value of biodiversity is an outcome of its role in human welfare, as humans conceive it “… whether they are selfish, altruistic, loyal, spiteful or masochistic …” (Becker, 1993).
(2) A second valuation perspective is rooted in a “*biocentric*” or “*ecocentric*” value orientation, which claims that nature has an intrinsic value and therefore deserves protection.

In reality, however, value orientations are overlapping and several versions of “*anthropocentrism*” and “*ecocentrism*” can exist within one individual. Altruism and stewardship are examples of such “*mixed*” attitudes (Norton, 1982; Van der Veer and Pearce, 1986). Stewardship is a form of altruism that is fully divorced from any explicit notion of consumption. It corresponds to a sense of responsibility – usually in a Christian perspective – for the conservation and maintenance of the resource. Q-altruism is rooted in the firm belief that living organisms are incapable of protecting themselves against human actions. Therefore, the conservation of living organisms merits human sympathy or compassion.

Table 2.6: Value orientations and environmental attitudes



Value orientation	Valuation perspective	Ethical approach	Biodiversity attitude
Ecocentrism	rights conferred to all living organisms	Nature has intrinsic value, regardless of human recognition	Biodiversity first
Antrophocentrism	rights and interests conferred to individual humans	Value of nature is value conferred to humans	Humans first

Adapted from Lockwood (1999)

2.3.2. The Link Between Economy and Environment

Consumption is a common concept in economy and gives rise to derived concepts such as consumer debt. Generally, the consumption is defined in part by opposition to production, but the precise definition can vary because various schools of economists define production quite differently. According to mainstream economists, only the final purchase of goods and services by individuals constitutes consumption, while other types of expenditure — in particular, fixed investment and government spending — are placed in separate categories. Other economists define consumption more broadly, as the aggregation of all economic activity which does not entail the design, production and marketing of goods and services.

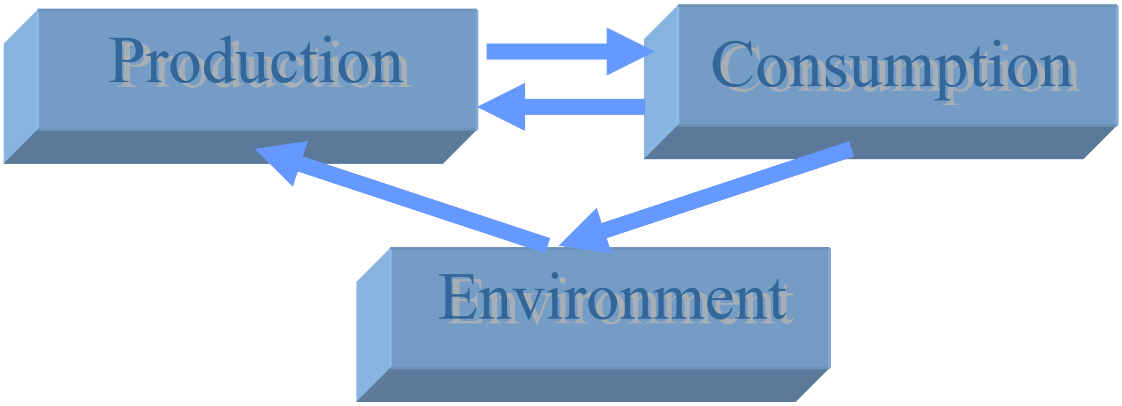
Production is converting raw materials to finished products. It involves a number of factors to be able to produce the goods and services that cater to our needs. Production means the development and creation of goods and services using resources to stimulate exchange. It is the physical output of a manufacturing or service company. Production involves three processes such as:

- Raw materials;
- Work in process;
- Finished goods.

Production is the combined from resources and equipment, which are needed to come up with the goods.

The link between Economy and Environment is based on the concepts of Environment, Production and Consumption as depicted in *Figure 2.7*. The consumption of the product can be retrieved either from the production of the product or from the environment. The production goods are taken from the Environment. In addition, production should satisfy human wants, i.e. consumption.

Figure 2.7: The Link Between Economy and Environment



2.3.3. Why Value Biodiversity?

Biodiversity is considered to form the very basis of life on earth (Roosen et al., 2003). Representatives of 190 countries at the 2002 Johannesburg World Summit on Sustainable Development committed themselves to "… achieving by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level…". By adopting the Convention on Biological Diversity's 2010 target, governments are explicitly recognizing the value of biodiversity (Balmford et al., 2005; EEA, 2006a; Strand et al., 2007). The preamble of the Convention on biological diversity states that the contracting parties are "conscious of the intrinsic value of biological diversity" and "conscious also of biodiversity, setting goals for its conservation, and holding themselves accountable (the importance of biological diversity for evolution and for maintaining life (Harker et al., 1995) sustaining systems of the biosphere." Secretariat General De Media Ambiebte (2000) affirms that "the conservation of biological diversity is a common concern of humankind" and that the secretariat is "aware that conservation and sustainable use of biological diversity is of critical importance for meeting the food, health and other needs of the growing world population." The Conference of the Parties (COP) Decision IV/10 acknowledges that "economic valuation of biodiversity and biological resources is an important tool for well-targeted and calibrated economic incentive measures."

Markets not, or at least not completely, capture the value of biodiversity. It is an implicit value that constantly tends to be underestimated because of the absence of well-defined property rights. Despite continuous progress in the evaluation of non-market goods, the empirical literature fails to evaluate the entire range of biodiversity benefits (Nunes and van den Bergh, 2001). Four factors have been identified as responsible for the high biodiversity values of Greece, one of the richest in Europe and the Mediterranean (Spyropoulou, 2002):

a. The biogeographic position of the country at the crossroad of three continents;

b. The high topographic diversity;

c. The complex geological and ecological history;

d. The relatively mild human interface.

One way biodiversity value may be understood is as an asset for future generations. Consistent with this is a view of biodiversity as insurance in the face of uncertainty. Because the value of biodiversity is not completely captured in markets, its conservation is often at a loss in comparison to land-use developments for market goods and access. Internalizing the economic value of natural resources beyond the private value of direct use is hence important to fully assess the trade-offs involved in land-use allocations. As some papers have recently outlined (e.g. Costanza et al., 1998), the natural capital is the very foundation of economics. In this perspective, valuing biodiversity is important because it makes markets and economics commensurate with the actual functioning of the world. Furthermore, Soderqvist et al. (2004) notes that estimated economic values are dependent on a number of circumstances:

1. The method selected for valuation influences the estimates;

2. The institutional context matters;

3. Nature’s heterogeneity might make value estimates unique for a specific setting;

4. The economic context is of importance.

In the opinion of the OECD (2001a), three principal reasons for tackling with economic valuation of biodiversity and biological resources. These reasons are:

(i) To promote cost-benefit analysis (CBA);

(ii) To integrate the systems of national accounts;

(iii) To institute appropriate pricing to the biological resources.

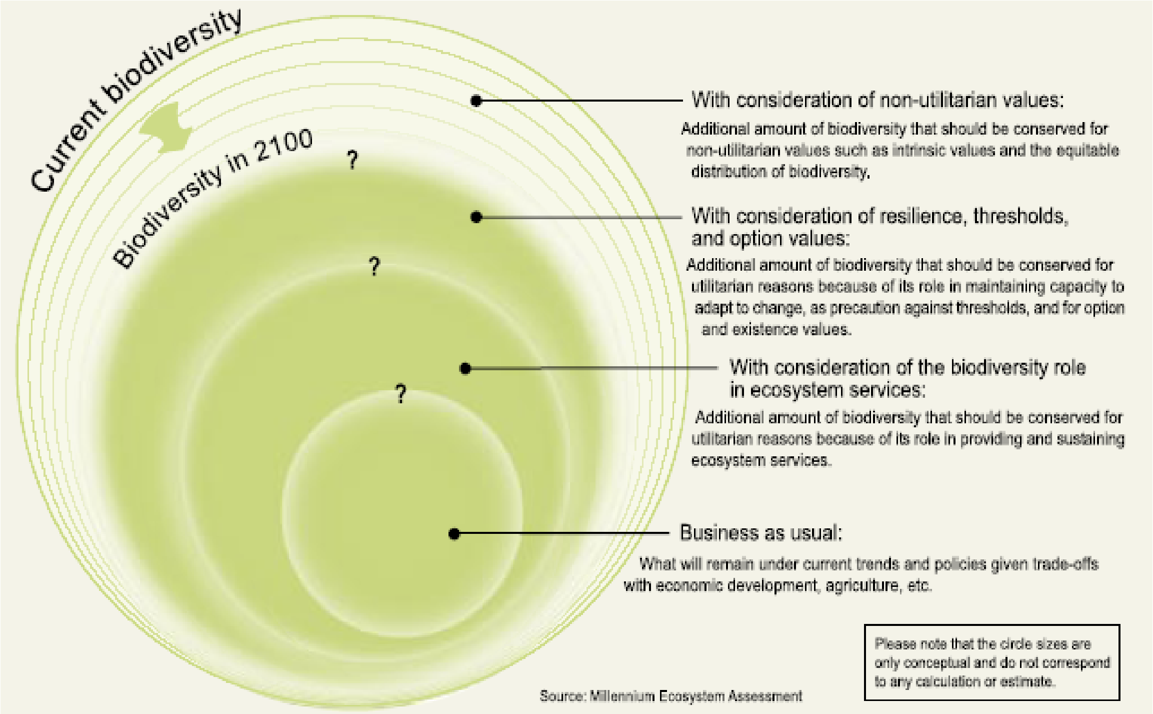
Afterwards, Christie et al. (2004) notices the significance of determining the economic value of biodiversity and certifies a broad range of applications for such values, covering:

- Instituting the value of biodiversity,
- Governing harms for loss of biodiversity,

- Re-examining the national economic values,
- Placing charges, taxes and fines,
- Land use decisions, e.g. to prosecute a contingency for sustainable agriculture / forestry or to preserve an area,
- Restricting biological invasions,
- Controlling or prohibiting trade in an endangered species,
- Estimating the biodiversity impacts of non-biodiversity investments, e.g. road building,
- Prioritizing biodiversity conservation within a constrained biodiversity fund.

Millennium Ecosystem Assessment (2005) outlines the levels of biodiversity, which will remain a century from now under different value frameworks. The outer circle of “How much Biodiversity will Remain a Century from Now under Different Value Frameworks?” represents the present level of global biodiversity shown in *Figure 2.8*. Each inner circle represents the level of biodiversity under different value frameworks. The white area represents non-utilitarian values like ensuring equitable access to biodiversity and intrinsic values. Question marks indicate uncertainties (Silleos and Gitas et al., 2005) where the boundaries are present.

Figure 2.8: How much Biodiversity will Remain a Century from Now under Different Value Frameworks?



Source: Millennium Ecosystem Assessment (2005)

2.3.4. The Value of Biodiversity

The debate over how much and what kinds of biodiversity should be protected are rife with uncertainty (Van Overwalle, 2005). Scientists do not know how much biological diversity exists on the planet, nor exactly how biological diversity supports the ecological services on which humankind depends. Attempts to highlight the importance of biodiversity point to myriad outputs whose production depend on:

- Hydrological services;
- Climate regulation;
- Soil management;
- Pollination services:
- Desalinization;
- Biosphere resilience;
- Tourism;
- Pharmaceutical and industrial chemical research;
- Consumptive outputs such as timber, fuel-wood, meat, medicines, fruits, nuts, ornamental plants, domestic pets and a variety of other non-timber ecosystem products.

Theoretical and empirical work has identified links between changes in biodiversity and the way ecosystems function (Lore au et al., 2002). Economists (Alexander, 2000; Simpson, 2000) and biologist (Wilson, 1984) have also noted that biodiversity can be valued for no consumptive uses such as spiritual or artistic inspiration. Finally, arguments can be made for protecting biodiversity based solely on our current ignorance. There may be substantial value in retaining the option to discover more about the biodiversity importance and hidden role in human lives by irreversibly extinguishing it beforehand.

Given all of these potential values, one might then ask, “How much is biodiversity worth?” This question is not only controversial (Alcamo et al., 2003), but largely unanswered at this point in time. Economists have made modest and incomplete attempts to value ecosystems and related ecosystem services in developing nations (e.g., Kramer and Mercer, 1997; Pattanayak and Kramer, 2001). To our knowledge, no attempt to estimate the value of a specific endangered species has been completed in a developing nation, although a few studies have been completed in the U.S. Even if they had been completed, however, the way in which these values should be aggregated and then incorporated into policy decisions is an open question. The exercise of putting a dollar value on a globally valued ecosystem (e.g., tropical rain forest) or species (e.g., owls) puts extreme theoretical and empirical demands on already controversial valuation methods (Carson, 1998).

Given the discussion above about the important benefits of biodiversity protection, Newton and Kapos (2002) may wonder:

- If biodiversity is so valuable?
- Why do the declines still appear in biodiversity indicators?”

Wells (1997) is curious:

- If the tourism associated with the visitation of ecosystems and wildlife, is so important in a lot of developing nations?

UNDP (2003) solicits:

- Why doesn't the tourism industry invest in maintaining one of its most important inputs?
- Why do water users not invest in protecting the biodiversity that contributes to their maintaining their water supply?

Part of the answer lies in the same attribute of biodiversity that makes it so valuable: it is a global resource from which all humans on the planet derive appraisals.

Biodiversity protection is a classic public good: once it is provided, no one can be excluded from the benefits and one person's enjoyment of these benefits does not reduce the benefits available to other people. However, when people destroy biodiversity through their consumptive use of species and habitat, the benefits from that destruction are private. Thus people receive tangible private rewards for destroying biodiversity, but people who protect biodiversity have few incentives to offer this protection because they cannot exclude non payer from benefiting from that protection.

Thus, markets alone will always stay under the supply of biodiversity. Governments and other actors must apply programs and policies to supply the socially optimal grade of biodiversity. However, the coordination of the total number of individuals and governments, who benefit from biodiversity, is difficult and growing the likelihood of free-riding behavior. Additionally, the beneficiaries of biodiversity protection are often rambling, while the beneficiaries of unorthodox applications of biodiversity that indicates to its disappearance are often focused in small groups that win large private gains from snuffing biodiversity. The location of substantial amounts of biodiversity in low-income nations with weak institutions, high discount rates, and pressing social and economic needs only serves to hurt the loss of biodiversity.

Further complicating matters, many of the benefits associated with biodiversity protection, such as contributions to global ecosystem functions, the potential for pharmaceutical discoveries and the survival of charismatic species, grow to people who are far removed from the sources of biodiversity in developing nations. Without institutions that can transfer some of the global value of protecting biodiversity to local and regional decision makers who bear much of the cost of protecting biodiversity, little progress is likely to be made in stopping the decline in biodiversity in developing nations in the foreseeable future.

2.3.5. Alternative Perspectives on Biodiversity Value

Given the four levels of diversity (*Table 2.1*), it should be evident that there is no single notion of biodiversity. This section presents additional considerations, which suggest that the biodiversity value can be interpreted in various ways:

(i) Instrumental vs. Intrinsic Values

Many people do not feel comfortable with placing an instrumental value on biodiversity. The common argument is that biodiversity has a value on its own—also known as "*intrinsic value*". A more extreme version of this perspective even claims that the "*instrumental*" valuation of biodiversity, often translated into monetary terms, is a nonsense exercise (Ehrenfeld, 1988). Many others, however, accept placing a monetary value on biodiversity, arguing that this merely makes explicit the fact that biodiversity is used for "*instrumental*" purposes, in terms of production and consumption opportunities (Fromm, 2000). Two additional related motivations are that making public or private decisions which affect biodiversity implicitly means attaching a value to it, and that monetary valuation can be considered as a democratic approach to decide about public issues, including biodiversity ones.

(ii) Monetary vs. Biological Indicators

"*Monetary*" valuation of biodiversity is anchored in an economic perspective, based on biological indicators of the impacts of biodiversity on human welfare (Randall, 1988). Economic valuation of biodiversity leads to "*monetary*" indicators, regarded as a common unit for comparison and ranking of alternative biodiversity management policies. On the contrary, "*biological*" assessments of biodiversity value give rise to non-monetary, i.e. "biological" indicators. These include, for example, species and ecosystems richness indices (Whittaker, 1960 and 1972), which have served as important valuation tools in the definition of "Red Data Books" and "Sites of Special Interest". It is not guaranteed, however, that "*monetary*" and "*biological*" indicators point to the same direction. They should be best regarded as complementary methods for appraisal of biodiversity shifts. Adding, economic indicators should, where possible indirectly, be based on accurate "*biological*" indicators.

(iii) Direct vs. Indirect Values

The notion of the "*direct*" value of biodiversity is sometimes used to refer to human uses of biological diversity in terms of production and consumption. The notion of "*indirect*" value of biodiversity has been associated with a minimum level of ecosystem infrastructure, without which there would not be the goods and services provided by it (Farnworth et al., 1981). Barbier (1994) recently described the "*indirect value*" of biodiversity as "… support and protection provided to economic activity by regulatory environmental services…”. In the literature, one can find other terms such as “*contributory value*”, “*primary value*”, and “*infrastructure value*” of biodiversity, which all seems to point to the same notion (Costanza et al., 1998). Some of these authors subscribe to the opinion that monetarization of biodiversity benefits is possible, but that it will always guide to an under-estimation of the “real” value, since “*primary value*” of biodiversity cannot be translated into monetary terms. As Gowdy (1997) has recently said, “… although values of environmental services may be used to justify biodiversity protection measures, it must be stressed that the value constitutes a small portion of the total biodiversity value…”.

(iv) *Biodiversity vs. Biological Resources*

Whereas “*biological diversity*” refers to the variety of life, at various levels, “*biological resources*” refer to the manifestation of that variety. According to Pearce (1999), “… much of the literature on the economic valuation of “*biodiversity*” is actually about the value of “*biological resources*” and it is linked only tenuously to the value of diversity…”. The precise distinction is not always clear and the two categories seem to be somewhat overlapping. Therefore, care is calling for evaluating studies that claim to present economic values of “*biodiversity*”.

(v) *The Value of Levels vs. Changes of Biodiversity*

Economists stress that the “*valuation*” should focus on “*changes*” rather than levels of biodiversity. Non-economists have frequently tried to *value biodiversity levels*, for instance, the recent example of value assessment of ecosystem services and natural capital for the entire biosphere level (Costanza et al., 1998). However, economic-theoretical support for such a valuation approach is weak. The reasons are that willingness to pay (WTP) or willingness to accept (WTA), are based on compensation or equivalence variations of a “*change*”, and that “*change*” should be relatively small in comparison with income levels.

(vi) *Local vs. Global Diversity*

The design of a valuation context involves important decisions about the spatial frame of analysis. Whereas biodiversity loss is usually discussed in a “*global*” or “*worldwide*” context, valuation biodiversity studies frequently address policy changes or scenarios defined at “*local*”, “*regional*” or “*national*” levels. Although this seems contradicting, it can be argued that biodiversity and its loss are relevant at multiple spatial levels, from local to global (Hammond et al., 1995a).

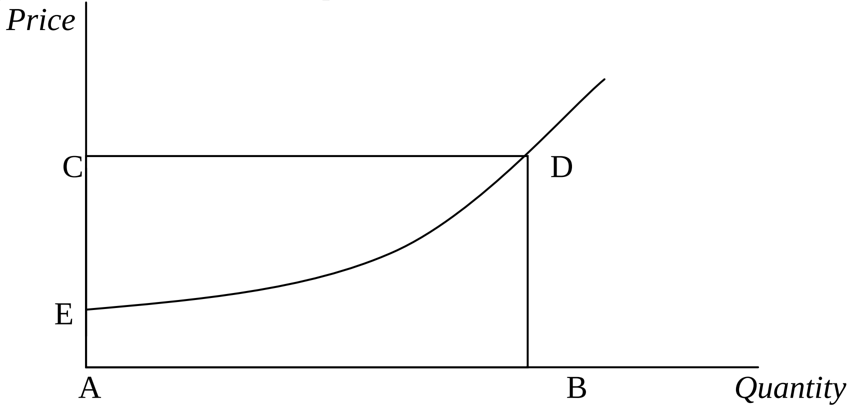
2.3.6. Valuation Concept

A prime distinction in the evaluation of the environmental elements is allocated between intrinsic and instrumental values. By defining the intrinsic value, ecological functions and services are pointed, which are measured through its contribution to the maintenance of the health and integrity of an ecosystem or species, regardless of human behavior. On the other hand, the instrumental value reflects the willingness of the human preferences towards the preservation or the loss of ecological functions and services

A similar approach is found between the classification of anthropocentric and ecocentric classification instead of the instrumental and intrinsic ones. According to the anthropocentric perspective, the values exclusively respond to the utility derived by the ecological functions and services to human beings while the ecocentric approach focuses on the contribution of the ecological functions and services to the ecosystem resilience. Many critical comments on this classification argue that a valuation approach could be validated only through the measurement of human preferences and not any other methodological approach. Since humans are the only ones to rationally appraise the contribution of the ecological functions and services towards the ecological resilience and further on the social welfare, an ecocentric perspective for human prosperity would be rather pointless.

On this ground, the prevailing economic theory attempts to infer values from the contribution of each ecological function and service to human welfare. Its contributions towards human welfare can be initially assessed through the productivity theory. In particular, each ecological functions and services are assessed as a coefficient in the productivity process or a direct market good. If it is assumed that the derived market good or the co-efficient of such ecological functions and services are traded by producers in the market, then the supplier is expected to have a benefit, known as the "*producer's surplus*" condition, as shown in *Figure 2.9.*

Figure 2.9: Producer's Surplus



Xenarious (2009)

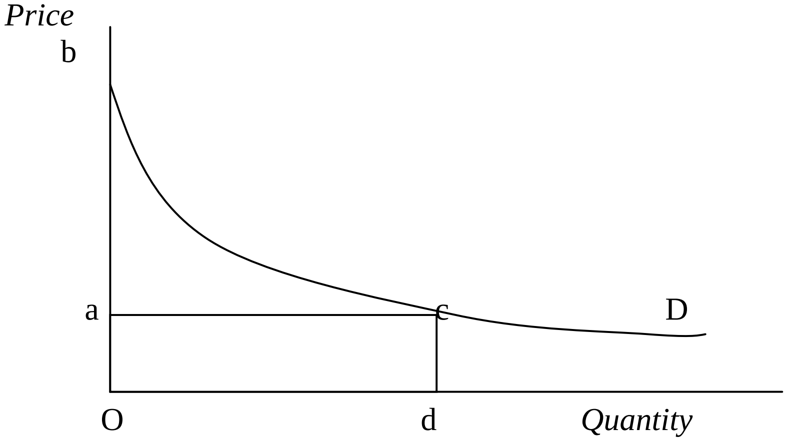
The "*producer surplus*" condition actually notes that each producer will benefit an amount equal to the CABD rectangle minus the area of EABD if trading the commodity in a competitive market. Point D depicts the optimal pricing from the producer's and consumer's perspectives by concurrently designating the optimal use of the trading commodity. However, the vast majority of the ecological functions and services are difficult to account in the productivity process because of the following particular characteristics:

- They are non-divisible so that is unlikely to be measured through integral units (e.g. river flowing).
- Non-exclusive, so that many people could concurrently make use of an environmental asset (e.g. fishing in a river).
- Often non visible and tangible as single items (e.g. contribution of a wetland towards micro-climatic stabilization).
- Above all, there are non-easily identifiable property rights (e.g. property rights of a river- ecosystem).

For that reason, it is mainly the citizens or according to the prevailing economic theory, the consumers that are to assess the economic value of the ecological functions and services. However, the individuals will be possibly unaware of many of the ecological functions and services occurring in an ecosystem and more interested in secondary or complement functions that promote their personal welfare. The aesthetic beauty for instance, of a river-ecosystem or the accomplishment of outdoor activities in a natural park, is provisions that do not straightly reflect the ecological functions and services but some additional or supplement characteristics that nonetheless affect human welfare. For that reason, the adoption of the "environmental functions and services" team could broadly represent the putative ecological functions by also incorporating derivative functions and services for human welfare.

The economic valuation as assessed by citizens and their preferences, was initially assessed according to the prime "consumer's surplus" theory. As principally stated, consumer's surplus represented as the difference between the actual amount of money spent for the acquisition of a commodity and the willingness of the consumer to pay for this commodity. The pricing mechanism should adjust the consumer's demand with the producer's supply in the optimal point for both sides. The shaping demand curve known as the "*Marshallian curve*", had been principally designed under the assumptions that the preferential aspect of individuals remains stable and inelastic in relation to the consumption goods. In other words, the individuals' preferences were taken as granted in relation to the consumption process.

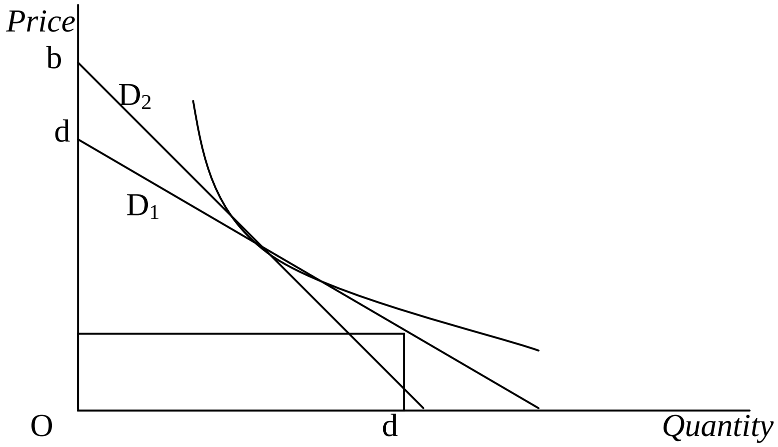
Figure 2.10: Marshallian Consumer's Surplus



Xenarious (2009)

However, the inability to predict the potential alterations in consumers' behavior and consequently in the demand curve, could not amplify the scientific background of the "*Marshallian curve*" as shown in Figure 2.10. The "*Hicksian curve*" came to significantly improve the scientific drawbacks of the Marshallian one, by permitting the fluctuation of demand curve on one hand and simultaneously holding the utility levels at a steady rate.

Figure 2.10: Hicksian Demand Curve



Xenarious (2009)

The intersection point between the "Hicksian demand curve", which is shown in *Figure 2.11*, and the supply one, accentuates the consumer's surplus and the optimal levels of social welfare that could emerge from the application of the market forces. In this context, each individual will have to state her/his willingness to pay (henceforth WTP) for the preservation of an ecological function or her/his willingness to accept (henceforth WTA) the damage of an ecological function in case compensation at least equal for the damage will be provided. For instance, a person would be WTP a certain amount of money for the avoiding the development of a Wastewater Treatment Plant next to his/her neighborhood equal to the benefit that he/she would preserve before the development. This means that although he/she will lower his income because of the money spent, however, his/her utility levels will remain unchanged. On the other hand, it could be assumed that a person is WTA a certain amount of money for the development of the Wastewater Treatment Plant as a direct compensation for all the potential impacts occurring in the developing and the operational phase. However, although his/her income will increase, the utility levels will remain unaltered due to the welfare loss occurred because of the development of the project. In any case, the utility levels of each individual should remain unaltered by preserving its economic welfare.

However, it is strongly doubted that the summation of the individuals' preferences should be the sole indicator for the economic valuation of ecological functions. Numerous arguments, such as the unawareness about major life support systems, the unequal economic conditions within the society and the inability to represent ecological functions and services in monetary units, weaken the theoretical background of this approach. It is therefore suggested that the environmental functions and services should be appraised through a multidimensional prism by promoting a heterogeneous concept through an ecological-economic interface. Significant school of economic thought, like the ecological economics, environmental economics, institutional economics, evolutionary economics and few others have already elaborated highly sophisticated evaluation methods for the assessment of environmental functions and services.

In the present analysis, an integrated evaluation framework is structured through the incorporation of all the prevailing evaluation assessments as designated by both the prevailing economic theory as well as from ecological-economic approaches. In this context, the development of the Total Economic Valuation (TEV) framework should be elaborated as an essential guideline for the assessment of all the existent valuation categories and sub-categories in regard to the relevant literature review (Croitoru, 2003).

2.3.7. The Nature of Economic Value

Forests are multi-functional: they provide an often-complex array of goods and services. It is important to understand that describing, and where possible quantifying, these functions does not always entail that the functions can co-exist under particular management regimes. Forests managed for ecotourism may not be usable for timber extraction; forests conserved for the supply of genetic information from the canopy can similarly not be converted to other uses and so on.

Economic valuations of forest goods and services are based on the notion of willingness to pay which, in turn, is based on the measurement of individuals' preferences, the basis for "welfare economics". Willingness to pay is determined by motivations which may vary from pure self-interest to altruism, concern for future generations, environmental stewardship and a concern for other sentient beings.

Survey techniques in environmental economics reveal that motivations vary significantly between individuals, but that self-interest is only one of many motives for environmental valuations. Willingness to pay has a direct counterpart in markets where it is formally equivalent (when expressed in "marginal" terms) to the demand curve familiar in basic economics textbooks. Market prices thus reflect willingness to pay for the last unit purchased. Total willingness to pay will exceed the price paid because some consumers will be willing to pay more than the market price, thus gaining "something for nothing", which is known as the consumers' surplus. As long as the forest good or service is being valued in marginal terms – i.e. what is being valued is a small change in the level of provision – then willingness to pay as revealed by market price is a sound indicator of economic value. If the interest is in discrete changes – e.g. a 10 or 20% change in provision – then the price will understate true willingness to pay by the amount of consumer surplus. While there has been a lot of interest in valuing the totality of ecosystem services (e.g. Costanza et al, 1998), such exercises have no economic meaning. The removal of all forests, for example, would involve the loss of a major life support system. Economic values have no meaning in this context because the question as to what is the "value of everything" has no meaning (Pearce, 1998). The appropriate context for economic valuation is therefore the value of a small or a discrete change in the provision of goods and services through, say, the loss or the gain of a given increment or decrement in forest cover.

Many forest goods and services do not have markets and it is accordingly necessary to resort to non-market valuation techniques. In all cases these techniques seek to elicit individuals' willingness to pay for a change in the level of provision of a forest good or a set of such goods. Approaches to "valuing the forest" may therefore comprise attempts to value individual goods and services with subsequent aggregation of the values, or the approach may involve valuing a change in the level of the provision of the forest generally. The former approach, the bottom up approach, risks a "part-whole" bias whereby the sum of the individual components is greater than or less than the value of the total set of goods and services. The latter approach, the top down approach, may similarly have errors if individuals are not aware of the full range of services provided by the forest. Both approaches have been used in the forest values literature. Valuing the "whole" forest does not breach the requirement that what is valued is an increment or decrement, since "whole forest" studies tend to relate to specific forests which can then be seen as a small change with respect to the totality of forests in a region or, indeed, in the world as a whole.

Non-market valuation techniques are twofold. The first involves looking for markets where the forest service affects that market, even though the service is not bought and sold directly. An example would be the value of property located near to woodland or forest. Studies show that other things equal, property prices are higher in such locations than in locations without proximity to forests. The differential in the house price is a first approximation of the economic value of the forest. This is an example of a revealed preference procedure, in this case the "hedonistic property price” approach (Snyder et al., 2007). Other revealed preference procedures relevant to forests include:

(1) The travel cost method, whereby willingness to pay is inferred from expenditures on travel to and from the forest for recreational purposes.

(2) The discrete choice method whereby values are inferred by looking at the choices people make between two alternatives.

An example would be certificated timber: if individuals are willing to pay more for certified timber than for identical non-sustainable timber, the increment reflects individuals’ valuation of the environmental benefits from sustainable timber regimes.

The alternative approach to reveal preference is stated preference (Batman et al., 2002). This is essentially a questionnaire-based approach in which individuals are asked attitudinal questions about the forest good and is then asked their willingness to pay to conserve the good or improve its quality etc. The approach is essentially a variant of market research and has the same attractions and difficulties. The main problem is hypothetical bias, i.e. determining the extent to which individuals reply truthfully about their willingness to pay. Stated preference procedures have become very sophisticated and early studies are now generally not regarded as being reliable. Questionnaires that ask “what is your maximum willingness to pay” or “are you willing to pay $X” are known as contingent valuation procedures. Questionnaires that present respondents with “bundles” of attributes and ask them to choose between these bundles, or to rank or rate them, are known as choice modeling procedures. In choice modeling, respondents are not asked their willingness to pay, but one of the attributes of the choice sets they are confronted with is a price, so that willingness to pay can be inferred. Contingent valuation has been used extensively in the forest context, choice-modeling tended to be more recent.

The types of economic value to be found in forests are use values and non-use values. Use values refer to willingness to pay to make use of forest goods and services. Such uses may be direct, e.g. extractive uses, or indirect, e.g. watershed protection or carbon storage. Use values may also contain option values, willingness to pay to conserve the option of future use even though no use is made of the forest now. Such options may be retained for one’s own use or for another generation (sometimes called a 'bequest' value). Non-use values relate to willingness to pay which is independent of any use made of the forest now or any use in the future. Non-use values reveal the multi-faceted nature of the motivations for conservation, e.g. being driven by concerns about future generations, the “rights” of other sentient beings etc. The sum of use and non-use values is the total economic value. It is this value that is lost if a forest area is converted to other uses or seriously degraded. Total economic value can then be estimated by summing individual use and non-use values, or by seeking some all-encompassing willingness to pay for “the forest” generally.

2.3.8. Economic Valuation

Valuation can simply be defined *"as an attempt to put monetary values on environmental goods and services or natural resources"*. It is a key exercise in economic analysis and its results provide important information about values of environmental goods and services. This information can be used to influence decisions about the wise use and conservation of forests and other ecosystems. The basic aim of valuation is to determine people's preferences: how much they are willing to pay for (give up other benefits) and how much worse off they would consider themselves to be as a result of changes in the availability of given goods and services from an ecosystem such as a forest. Proper valuation of all the goods and services provided by the forest or nature area can help understand the extent to which those who profit from the forest also bear the cost of managing it (Lette and de Boo, 2002; Van der Lubbe, 2001). The environmental goods and services consist of direct consumable goods and services, indirect ecological services and other non-use benefits such as cultural and religious values. The term "forest" is used to describe any tree-dominated landscapes be it woodlands, tropical forests and even plantations. Thus for purposes of this paper, the term forest is therefore not used in the strict biological sense.

Forest valuation provides a means of quantifying the benefits that people receive from forests, the costs associated with their loss, and the relative profitability of land and other resources uses which are compatible with forest conservation vis-à-vis those economic activities that contribute to their degradation. Valuation also helps to predict and understand the economic motives, decisions and activities that impact on forest integrity and the status. The fact that not all forest goods and services are bought or sold in markets (e.g. climate regulation, catchment's value and other ecological services) makes them particularly difficult to put monetary value on. The economic benefits generated by forests and the economic costs associated with forest degradation or loss, are frequently overlooked by government and private industry, as well as by the land and resource users such as local communities. Valuation has an important role to play in environmental planning and management activities such as the Crossborders Project because it helps to answer many questions including the following about any given forest ecosystem (De Vries et al., 2003):

- How much is the forest worthier and to whom?
- How do the degradation and loss of forest ecosystems lead to costs to different segments of society?
- How can forest conservation be efficiently and equitably financed?
- How can people be motivated to take into account forest benefits and costs of its loss in the course of their economic activities?
- How can policy, planning and decision making with regard to forest ecosystems be better influenced?

If a valuation exercise can provide acceptable answers to the above questions, then it goes a long way to becoming a useful tool into the assessment and planning for biodiversity conservation. Steps Involved in the Economic Assessment and Planning of Biodiversity are shown in *Table 2.7,* where a series of important steps that any assessment and planning for biodiversity conservation go through helps to locate the role of valuation (especially steps 1 and 2).

Table 2.7: Steps Involved in the Economic Assessment and Planning of Biodiversity (Including Forest Conservation)

Step 1	Identify environmental economic benefits and costs of a forest ecosystem
Step 2	Put a value on the environmental economic benefits and costs
Step 3	Analyze the profitability of economic activities in terms of their environmental effects
Step 4	Highlight the economic causes of environmental degradation and the need for economic measures to reverse them
Step 5	Set of place incentives for environmental conservation
Step 6	Put in place financing mechanisms for environmental conservation
Step 7	Ensure that economic measures for conservation are sustainable
Step 8	Ensuring economic measures for conservation are appropriate and sustainable.

Source: Emerton (1996)

Traditionally, economists and decision-makers in general tend to appreciate and measure the value of forests in terms of the raw materials and physical products that they generate for human production and consumption, especially focusing on financial or commercial economic activities such as fisheries, agriculture, urban and industrial water supplies. However, these direct uses represent only a small proportion of the total value of forests, which generate economic benefits far in excess of just physical products. When attempting to put monetary values to forest goods and services it is necessary to take account of the full range of economic benefits associated with forests, as defined by the concept of "total economic value" (TEV), (Amjath Babu and Suryaprakash, 2004; Pagiola et al., 2004; Shechambo et al., 2001; OECD, 2001a; Torras, 2000). The concept of "total economic value" (TEV) is the sum of the following four main elements of value (U.S. Environmental Protection Agency, 2002).

2.3.9. Identifying the Service Flows and Other Values Provided by an Environmental Resource

There are numerous types of goods and services provided by ecological resources that have economic value to some or all individuals in society. This section discusses the various types of goods and services and offers their taxonomy, which may be useful in developing a comprehensive list of specific economic benefit endpoints (U.S. Environmental Protection Agency, 2002).

Figure 2.12: The Service Flows and Other Values Provided by an Environmental Resource

U.S. Environmental Protection Agency (2002)

Some of the goods and services provided by ecological resources are obvious because they are directly used or enjoyed by society, such as the fish provided by a fishery, the timber/lumber provided by a forest, or the swimming and boating opportunities provided by a coastal area. These types of goods and services are defined as direct, market uses, when the good or service is bought and sold through open markets, and direct, non-market uses, when the good or service is not bought and sold through a market.

The direct, market uses of an ecological resource are typically the most obvious and most easily valued goods provided by an ecological resource because the price and quantity information for each good and service are generally available. The direct, non-market uses of an ecological resource may be readily apparent, such as recreational opportunities, although more difficult to value.

Valuation of changes to direct, non-market uses is more difficult because the goods or services are not sold through markets, making it more difficult to obtain information on the "price" of the service and the number of people enjoying the service (i.e., how many people benefit from the resource through a specific use).

Ecological resources will also provide some services and ecological processes that indirectly benefit society. For example, a coastal wetland provides services as a wildlife habitat and fish nursery, as a means for flood control, and as a filtering system for run-off waters. These types of services, which are not bought and sold through markets, are referred to as indirect, non-market uses. Individuals may value these services even though they are not directly using the resource. Sometimes these types of services can be connected to other activities that humans value and, therefore, are valued through that relationship.

Economists also recognize several different categories of non-use values. As the term implies, non-use values represent the value that an individual places on the ecological resource that does not depend on the individual's current use of the resource. Existence value, for example, refers to the value people place on knowing that a particular resource exists, even if they have no expectation of using the resource. Other examples of non-use values include bequest value, which refers to the value people place on a maintaining a resource for future generations, and altruism, or the value people place on maintaining resources that are important to their family and friends.

The benefits of an action that improves a specific ecological resource can be estimated by estimating people's willingness-to-pay (WTP) for improvements to the various types of goods and services provided by the resource. For example, in estimating the benefits of an action to improve the quality of a wetland area, one might consider that the wetland area serves as a primary breeding area for several species of birds. Therefore, one might estimate the change in the value of bird watching and recreational fowl hunting to the individuals using the area. To capture the total value or benefits of a change to a specific ecological resource, one also needs to consider the value of its role in supporting the ecosystem and the indirect benefits it provides to mankind. That is, one needs to also identify and evaluate the indirect, non-market uses and non-use values associated with an ecological resource.

The economic benefit analysis should identify as many different goods and services (and values) affected by the policy or action. For example, if a policy is expected to improve the ecological resources that support various bird populations, the economic benefit analysis might consider potential impacts on the following goods and services society derives from birds:

- Food source (direct, market use);
- Hunting, bird watching, and contributing to the aesthetic environment for hikers, campers, anglers, and other re-creationists (direct, non-market use);
- Component of an ecosystem that supports or provides other goods and services and contributes to maintaining biodiversity (indirect, non-market use);
- As an endangered species or to maintain the bird species for future generations (non-use value).

The following four Sections elaborate on the types of goods and services that might be provided by an ecological resource and identify the economic techniques that might be appropriate for estimating the economic value of changes to these goods and services.

2.3.9.1. Direct, Market Uses

Direct, market uses refer to those goods and services provided by an ecological resource that are directly used by society and are bought and sold through the market system (Mohd-Shahwahid and McNally, 2001). Direct, market uses primarily refer to those goods produced by an ecological resource that are consumed by humans or serve as inputs in the production of other goods, such as food products, water, fuel sources, and building materials. Prices and quantities produced for these goods and services are directly observable. For example, one benefit of a policy to improve air quality might be measured through the value (i.e., change in welfare) of the increased productivity of commercial crops and timber production. Similarly, the benefit of an action to improve water quality might be measured through the value of the increased production of a commercial fishery (i.e., more fish caught and sold). It is important to remember, however, that the change in value of the direct, market uses (e.g., timber, crops, or fish) provided by an ecological resource (e.g., air, water) may represent only a portion of the total benefits of the change experienced by the ecological resource.

Examples of Direct, Market Uses Provided by Ecological Resources:

- Food Source
    - Fish (specific species) -- commercial fishery
    - Crops (specific type: corn, beans, apples, etc.) -- commercial and home production
    - Animal (fowl, deer, etc.) -- commercial consumption

- Building Materials
    - Timber (specific species)
    - Stone

- Fuel
    - Timber (specific species)
    - Coal
    - Oil

- Drinking Water Supply
    - Ground water reservoir
    - Surface water reservoir

- Medicine

- Chemicals/Minerals

2.3.9.2. Direct Non-Market Uses

Direct, non-market uses of an ecological resource include those goods and services that are directly observed and used by humans, but are not sold or traded through an open, competitive market. Direct, non-market uses include both consumptive uses (e.g., recreational fishing and hunting) as well as non-consumptive uses (e.g., bird watching or boating). Direct, non-market uses are generally considered quasi-public/quasi-private goods because access or use of the resource can be controlled but is often not strictly regulated and the benefit or value to one individual does not affect the benefit or value to others up to a point (i.e., congestion reduces the benefit/value to all users).

Examples of Direct, Non-Market Uses Provided by Ecological Resources

- Fishing
  - ❖ Recreational Fishing (specific species, area)
  - ❖ Subsistence Fishing (specific species, area)
- Beach Use (sunbathing, swimming, walking)
- Recreational Hunting (specific species) - for sport and/or personal consumption
- Bird Watching (general, specific species)
- Tourism
- Boating
- Hiking / Camping
- Animal Viewing, Photography, Feeding (general, specific species)
- Sightseeing
- Aesthetic Value

2.3.9.3. Indirect, Non-Market Uses

Indirect, non-market uses of an ecological resource include those goods and services that provide an observable benefit to mankind but are not directly consumed or used by individuals. Indirect, non-market uses include many ecological processes that indirectly benefit mankind by supporting other ecological resources, maintaining viable ecosystems, and protecting the local environment. Indirect, non-market goods and services are usually public in nature because the access or use of the ecological resource cannot generally be excluded and any number of individuals can benefit from the use of the ecological resource through these services without reducing the benefits accruing to anyone else. These goods and services are not sold or traded through an open, competitive market, although a community may pay for replacement or substitute goods (often through taxes) that provide the same public services as provided by the ecological resource.

Examples of Indirect, Non-Market Uses Provided by Ecological Resources

- Ground Water Recharge;
- Wave Buffering;
- Habitat Value;
- Storm Water Treatment;
- Pollution Mitigation;
- Nutrient Cycling;
- Flood Control;
- Climate Control;
- Soil Generation;
- Biodiversity

2.3.9.4. Non-Market, Non-Use Values

Non-market, non-use values of an ecological resource are the values that individuals hold for the resource unrelated to their current use of the goods and services provided by the resource. Individuals may value the existence of the ecological resource or the availability of the goods and services provided by the ecological resource although they do not directly consume or use the resource themselves. Non-market, non-use values may stem from the desire to ensure the availability of the resource for future generations, benevolence toward relatives and friends, sympathy for people and animals adversely affected by environmental degradation, or a sense of environmental responsibility. Additionally, the specific non-use values associated with a particular ecological resource may not be mutually exclusive: when asked directly, people are unlikely to be able to separately identify the non-use values they hold or distinguish between the value they place on direct or indirect uses and their non-use value(s).

Examples of Non-Market Non-Use Values Provided by Ecological Resources

- Scarcity Value;
- Existence Value;
- Bequest Value;
- Option Value (although some consider this a use value);
- Cultural/Historical Value;
- Altruistic Value;
- Intrinsic Value;
- Philanthropic Value

2.4. SUMMARIES AND PROPOSALS

2.4.1. Summaries

An important step in the analysis and valuation of Biodiversity is the definition of the term “biodiversity”. As Turner et al. (1999) exemplified that biodiversity encompassed four levels, shown in Table *2.1*, as:

- Gene
- Species
- Ecosystem
- Function

Richerzhagen and Holm-Mueller (2005) represented another simpler and clearer, but more challenging definition, which shows the totality of genes, species and ecosystems of an area.

Biodiversity is a complex and an abstract concept. It can be associated with a wide range of benefits to human society, most of them still not understood. In general terms, the value of biodiversity can be assessed in terms of its impact on the provision of inputs to production processes, in terms of its direct impact on human welfare, and in terms of its impact of the regulation of the nature-ecosystem-ecological functions relationships. Usually, market valuation mechanisms that price the value of biodiversity are not enough. Therefore, valuation of biodiversity requires the use of special valuation tools. This chapter has reviewed some economic valuation studies of biodiversity. Monetary valuation of changes in biodiversity involves monetary choices with respect to:

(a) The level of life diversity;
(b) The biodiversity value category;
(c) The most appropriate valuation method;
(d) The overall perspective on the value of biodiversity.

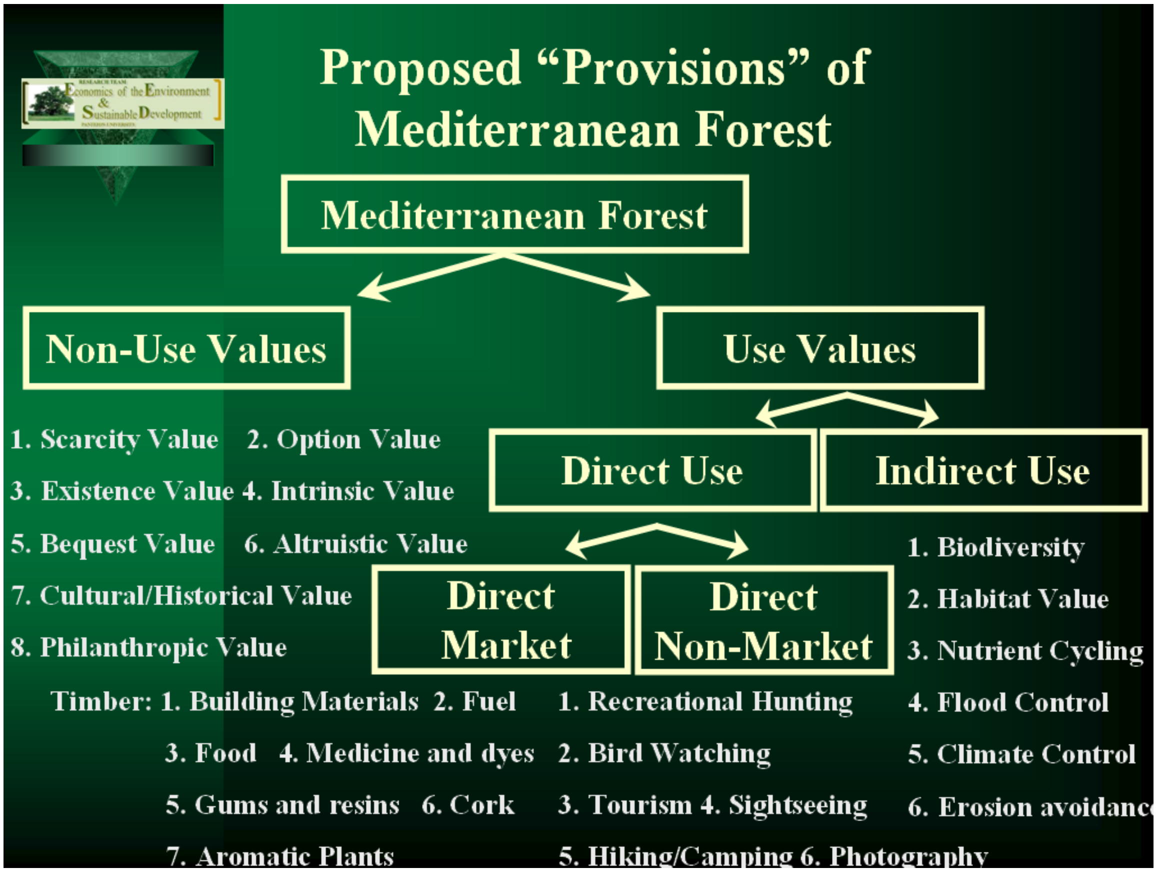
The main conclusion is that the monetary valuation of changes of biodiversity can make sense. This requires, that a clear life diversity level is chosen, that a concrete biodiversity change scenario is formulated, that a multidisciplinary approach seeking the identification of direct and indirect effects of the biodiversity change on human welfare is used, and, very importantly, that the change is well defined and not too large. So far, relatively few valuation studies have met all these requirements. As a matter of fact, from the review of the economic valuation studies it is clear that the assessment of biodiversity values does not lead to an unequivocal, unambiguous monetary indicator. Nevertheless, the prudent interpretation of the monetary valuation results can shed some light on the value of biodiversity, leading to lower bounds.

Despite Economic Valuation of Biodiversity, the concept of biodiversity is visible through the landscape metrics, which is located in **Chapter 3 – Landscape Metrics based on Remote Sensing Data**.

2.4.2. Proposed "Provisions" of Mediterranean Forest

As described in Sub-Section 2.3.9 – Identifying the Service Flows and Other Values Provided by an Environmental Resource of the current chapter, the "*provisions*" of valuations are proposed, while emphasizing the Mediterranean Forest.

Figure 2.13: Proposed "Provisions" of Mediterranean Forest



Proposed "Provisions" of Mediterranean Forest

Mediterranean Forest

Non-Use Values

1. Scarcity Value 2. Option Value
3. Existence Value 4. Intrinsic Value
5. Bequest Value 6. Altruistic Value
7. Cultural/Historical Value
8. Philanthropic Value

Use Values

Direct Use

Direct Market

Timber: 1. Building Materials 2. Fuel
3. Food 4. Medicine and dyes
5. Gums and resins 6. Cork
7. Aromatic Plants

Direct Non-Market

1. Recreational Hunting
2. Bird Watching
3. Tourism 4. Sightseeing
5. Hiking/Camping 6. Photography

Indirect Use

1. Biodiversity
2. Habitat Value
3. Nutrient Cycling
4. Flood Control
5. Climate Control
6. Erosion avoidanc

All of these categories of benefits have a value because they contribute to economic activity and enhance human welfare. To enjoy any of the values, some resources should be given up in terms of opportunity costs. Valuation attempts, as far as possible, to measure the monetary value of all the four components of the total economic value forest ecosystems. Thus the concept of total economic value (TEV) is a key to valuate, while it captures all possible values of resources. The idea behind TEV is to go beyond the traditional practice of valuation, which normally captures only direct uses, therefore, leaving out (and consequently undervaluing) other benefits and costs. TEV includes option values and existence values in consideration to the future values of the environmental resources. The following formula is applied to define *Total Economic Value (TEV)* as is shown in E*quation 2.3*:

Equation 2.3: Total Economic Value (TEV)

TEV = Use Value (UV) + Non Use value (NUV)

Where:

- UV = Direct Use Value (DUV) +
  \+ Indirect Use Value (IUV)

- DUV= Direct Market Use Value (DMUV) +
  \+ Direct Market Non Use Value (DMNUV)

➡ **TEV= DMUV + DMNUV + IUV + NUV**

CHAPTER 3

LANDSCAPE METRICS BASED ON REMOTE SENSING DATA

The current chapter articulates about Landscape Metrics based on Remote Sensing Data to profound estimation of environmental indicators pondered as inputs of EN dimension towards sustainability. The proceeding chapter encompasses of six (6) initial categories:

(1) Area / Density / Edge;
(2) Shape;
(3) Isolation Proximity;
(4) Connectivity;
(5) Contagion Interspersion;
(6) Diversity.

In the current chapter, a vast exploration of the literature has been contained with:

a The assortment of all the landscape metrics based on remote sensing data,
b The literature ranking involving indices by beforehand indicated categories'
c Their inferences through their performance.

Moreover, the occurrence of used papers is divided into five groups. The frequency of used papers equals to the number of used papers per subcategory over the number of used papers per main category. It has been found that min=1/17=0.059 and max=12/15=0.8. The range from min to max has been divided into five equal pieces accordingly representing five groups, i.e. from Group A till Group E. To have a better idea of each group appearance per subcategory and main categories according to the frequency of used papers per each index, the first three before-mentioned groups has the following order:

(a) Group A:

- Euclidean Nearest Neighborhood (Isolation Proximity category);
- Shannon Diversity Index (Diversity category;
- Shape Index (Shape category);
- Patch Density (Area / Density / Edge category).

(b) Group B:

- Patch Cohesion Index (Connectivity category);
- Connectance Index (Connectivity category);
- Contagion Index (Contagion Interspersion category);
- Proximity Index Distribution (Isolation Proximity category);
- Number of Patches (Area / Density / Edge category);
- Interspersion Juxtaposition Index (Contagion Interspersion category).

(c) Group C:

- Largest Patch Index (Area / Density / Edge category);
- Edge Density (Area / Density / Edge category);
- Class Area (Area / Density / Edge category);
- Patch Richness (Diversity category).

An explanation of the aforementioned results is shown at the end of the present chapter, where only the four (4) proposed indices of group A and two (2) suggested indices from the group B are considered, viewed and explained.

3.1. INTRODUCTION

Indicators are investigative and interpretive tools of ecological dynamics (Venturelli and Galli, 2006). In this sense, landscape ecology is very useful to define indicators even though it is not the only scientific field where they can be used successfully. Landscape ecology often uses not only “structural” indicators (Miller et al., 1997; Rocky Mountain Institute, 2001; Urban Institute, 2001; Urban Quality Communication, 2001; National Association of Environmental Professionals, 2001; Opdam et al., 2002; Bastian and Steinhardt, 2002) which are connected with the various components of the areas being studied and with how they have become organized (e.g. the size of the patches, which reveals a series of features linked to it), but also “functional” (Berry, 2001; Bastin et al., 2002; Tarzia, 2003) indicators.

Identifying ecological indicators is an important element in illustrating an ecological system, instituting latent metrics of change, and constructing an effective environmental monitoring system (Jensen, 2000; Olsen et al., 2007). The suite of indicators signify the range of ecological conditions in the ecological system, serve as signals of environmental change, and is simple enough to permit cost-effective monitoring and modelling (Hunsaker and Carpenter, 1990; Kelly and Harwell, 1990; Noss, 1990; Cairns et al., 1993; Dale and Beyeler, 2001). Landscape pattern, environmental change, and fragmentation are central points of landscape ecology as have an important role in driving ecological processes (Forman and Godron, 1986; Turner et al., 1989; Hargis et al., 1998; Bailey et al., 2007). Societal values, in relation to the example indicators and candidate landscape ecology metrics are illustrated by an attractive *Table 3.1*, where the concept is taken from Jensen (2000).

Table 3.1: Societal Values, Example Indicators and Candidate Landscape Ecology Metrics

Societal Value	*Indicator*	*Candidate Metrics*
Biodiversity	Wildlife habitat suitability	Patch statistics (number, total area, average size, largest size, distance between, the ratio of perimeter to area, shape, fractal dimension, square pixel model, etc.), fragmentation, contagion, zone fragmentation index, patch per-unit-area index, dominance, adjacency of land-cover types, Shannon diversity, biophysical attribute patterns.
	Stream biological condition	Diversity, square pixel model, dominance, fragmentation, zone fragmentation index, patch per-unit-area index, adjacency of land-cover types, slope, elevation, diffusion rates, percolation threshold, erosion index, texture, biophysical attribute patterns, geochemical attributes.
	Forest plant species richness	Diversity, dominance, fragmentation, zone fragmentation index, patches per-unit-area index, slope, erosion index, texture, patch statistics, square pixel model, biophysical attribute patterns.
	Landscape sustainability	Patch statistics, contagion, zone fragmentation index, patch per-unit-area index, fragmentation, texture, dominance, fractal dimension, square pixel model, biophysical attribute patterns.
Watershed integrity	Water quality	Patch statistics, erosion index, hydrologic modification, adjacency of land-cover types, dominance, contagion, zone fragmentation index, patch per unit area index, fractal dimension, square pixel model, elevation, slope, biophysical attribute patterns, and geochemical attributes.
	Vulnerability to flooding	Patch statistics, adjacency of land-cover types, erosion index, dominance, contagion, zone fragmentation index, patch per-unit-area index, fractal dimension, square pixel model, hydrologic modification, elevation, slope, texture, biophysical attribute patterns.

Societal Value	*Indicator*	Candidate Metrics
Landscape resilience	Landscape sustainability	Patch statistics, dominance, contagion, zone fragmentation index, patch per-unit-area index, fragmentation, fractal dimension, square pixel model, biophysical attribute patterns.

Source: Jensen (2000)

Landscape metrics that comprise quantifiable measures of landscape indicators have been expanded to detain important aspects of landscape pattern in a few numbers (O’Neill et al., 1988; Hulshoff, 1995; Riitters et al., 1995; Turner et al., 2001; Ortega et al., 2004). These numbers can often be correlated with land-use change and ecological processes (Symeonakis et al., 2005). By using such metrics to observe and measure landscape patterns through time, researchers may determine the long-term impacts of previous land use (e.g., Burgi, 1999; Griffith et al., 2003). Landscape metrics can capture changes in pattern, be executed along a variety of spatial scales, and be useful indicators of land-cover changes due to prior land use and management. Remote sensing data significantly contributed to the estimation of the landscape metrics.

In the literature, a large number of landscape metrics have been encountered which were used to monitor environmental quality at regional scales (e.g. O’Neill et al., 1997); to measure and monitor landscape change (e.g. Zaizhi, 2000; Lausch and Herzog, 2002; Hersperger and Burgi, 2009); to examine habitat fragmentation (e.g. Hargis et al., 1998; Riitters et al., 2000); to quantify ecological processes (e.g. Fahrig and Jonsen, 1998; Mazerolle and Villard, 1999; Tischendorf, 2001; Bender et al., 2003); to study the effects of society on landscape (e.g. Luck and Wu, 2002; Saura and Carballal, 2004) and to aid in landscape design (Gustafson and Parker, 1994). Moreover, recent studies have demonstrated that land use and landscape changes have significantly affected biodiversity (Gachet et al., 2007; Otte et al., 2007; Cousins and Eriksson, 2002).

In this paper, an extensive investigation of the literature has been performed in order to:

a) Collect all the landscape metrics based on remote sensing data, that are found in the literature;

b) Classify them;

c) Evaluate them through their use.

Their classification resulted in six (6) general groups:

- Area / Density / Edge, which is classified into 10 subcategories and uses 22 papers;
- Shape, which is classified into 13 subcategories and uses 17 papers;
- Isolation Proximity, which is classified into 2 subcategories and uses 15 papers;
- Connectivity, which is classified into 2 subcategories and uses 5 papers;
- Contagion Interspersion, which is classified into 8 subcategories and uses 12 papers;
- Diversity, which is classified into 9 subcategories and uses 20 papers.

In *Section 3.2* – *Landscape Metrics*, each group is further classified to subcategories with a brief description, some definition and/or some metrics' relations to sustainable development. Each subcategory represents an index of Class or/and Landscape Metrics. A table with chosen authors, correspondingly utilized remote sensing data and programs is given to each index. Generally, 32 papers were used as references for each index while constructing the tables. In addition, all types of remote sensing data, i.e., very high, high, medium resolution, aero-photographs and even simulated data, are considered accordingly per author's work. Categorization of metrics and indices initially established by the Fragstat program and then adopted by other remote sensing programs.

3.2. LANDSCAPE METRICS

McGarigal and Marks (1995) have developed a program called Fragstat, where the authors represented as seven (7) categories. Some research is done in the current chapter and six (6) general groups out of seven (7) are suggested:

- Area / Density / Edge;
- Shape;
- Isolation Proximity;
- Connectivity;
- Contagion Interspersion;
- Diversity.

The aforementioned six (6) core groups are acknowledged in the subsequent allotments.

3.2.1. Area / Density / Edge

The first category of the six (6) above acknowledged ones is the Area / Density / Edge, which accommodates the consecutive ten (10) indices:

(1) Class Area (CA);
(2) Percentage of Land (PLAND);
(3) Number of Patches (NP);
(4) Patch Density (PD);
(5) Largest Patch Index (LPI);
(6) Landscape Shape Index (LSI) and Normalized Landscape Shape Index (NLSI);
(7) Total Edge (TE);
(8) Edge Density (ED);
(9) Patch Area Distribution (AREA_X);
(10) Radius of Gyration (GYRATE_X).

The beforehand ten (10) indices of the first core group, i.e. Area / Density / Edge, are alleged in the below asserted allotments.

3.2.1.1. Class Area (CA) – Class Metrics; Total Area – Landscape Metrics

Class Area (CA) is a measure of landscape composition; especially, how much of the landscape is comprised of a particular patch type. Class area is a sum of areas of all patches belonging to a given class, in map units (Sivrikaya et al., 2007). Total landscape area (TA) often does not have a great deal of interpretive value for evaluating the landscape structure, but it is important because it defines the extent of the landscape (McGarigal and Marks, 1995). The used authors, data and programs per Class Area (CA) are represented in the *Table 3.2*.

Table 3.2: Used Authors, Data and Programs per Class Area (CA)

Authors	*Data*	*Program*
Bock et al. (2005)	Landsat 7 ETM+ and 5 TM; VHR RS images; HRSC; soil map; IKONOS	Tool extension (V-LATE) calculated within ArcGIS 8.x (Lang and Tiede, 2003)
Dramstad et al. (2006)	Aerial Photographs	ArcView TM (ESRI)
Dramstad et al. (2001)	Simulated data	3Q programme
Kim and Pauleit (2007)	Topographic maps; Aerial photographs	GIS

Authors	*Data*	*Program*
Kupfer (2006)	Landsat TM; AVHRR; MODIS; TIGER DLG	GIS
Lee & Thompson (2005)	Aerial photographs	GIS; Fragstat
Sivrikaya et al. (2007)	IKONOS images	ArcGIS 9.0; Fragstat
Zhang and Wang (2006)	Landsat TM	ArcView 3.2; Fragstat (McGarigal and Marks, 1995)

3.2.1.2. Percentage of Land (PLAND) – Class Metrics

Percentage of Land is a measure that computes the percentage of landscape (%LAND) occupied by each patch type (McGarigal and Marks, 1995). Percentage of land is the proportion of each land use in the study area, which represents the landscape composition (Miyamoto and Sano, 2008). Percentage of land is the percentage of area occupied by certain land cover class (Schindler et al., 2008). Percentage of landscape quantifies the proportional abundance of each patch type in the landscape (Ribeiro and Lovett, 2009). If one class dominates completely the landscape then it will provide little support for multi-habitat species (Botequilha Leitao and Ahern, 2002). At its lowest limit, there is only one land-use type and landscape lacks diversity. The arrangement of coarse/fine-grained areas within the landscape is doubtless a key factor to achieve a sustainable environment (Forman, 1995). The used authors, data and programs per Percentage of Land (PLAND) are represented in the *Table 3.3*.

Table 3.3: Used Authors, Data and Programs per Percentage of Land (PLAND)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Kupfer (2006)	Landsat TM; AVHRR; MODIS; TIGER DLG	GIS
Miyamoto & Sano(2008)	Aerial photographs	GIS; Fragstat version 3.1
Ribeiro & Lovett (2009)	Data are derived from land-use map sheets	ArcGIS; Fragstat version 3.3 (McGarigal et al., 2002)

Authors	*Data*	*Program*
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Sivrikaya et al. (2007)	IKONOS images	ArcGIS 9.0; Fragstat
Weiers et al. (2004)	CORINE, Landsat MSS & TM, IRS-IC data, aerial photo; land & soil maps	ERDAS Imagine; Fragstat

3.2.1.3. Number of Patches (NP) – Class Metrics, Landscape Metrics

Number of patches (NP) of a particular habitat type may affect a variety of ecological processes, depending on the landscape context; for example, the number of patches may determine the number of subpopulations in a spatially dispersed population, or meta-population, for species exclusively associated with that habitat type. The number of subpopulations could influence the dynamics and persistence of the meta-population (Gilpin and Hanskiv, 1991). Number of Patches equals the number of patches of the corresponding patch type (Ribeiro and Lovett, 2009). If mean patch size is small and the number of patches is high it can indicate a fragmented landscape (Botequilha Leitao and Ahern, 2002). The used authors, data and programs per Number of Patches (PLAND) are represented in the *Table 3.4*.

Table 3.4: Used Authors, Data and Programs per Number of Patches (NP)

Authors	*Data*	*Program*
Bock et al. (2005)	Landsat 7 ETM+ and 5 TM; VHR RS images; HRSC; soil map; IKONOS	Tool extension (V-LATE) calculated within ArcGIS 8.x
Dramstad et al. (2006)	Aerial Photographs	ArcView TM (ESRI)
Dramstad et al. (2001)	Simulated data	3Q programme
Kim and Pauleit (2007)	Topographic maps; Aerial photographs	GIS
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine; ArcView; Fragstat; ATtILA (Ebert et al., 2001)

Authors	*Data*	*Program*
Quine & Watts (2009)	Raster data layers	ARCGIS; Fragstat
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Sivrikaya et al. (2007)	IKONOS images	Arc GIS 9.0; Fragstat
Venturelli & Galli (2006)	Regional Technical Map	GIS
Wenguang et al. (2008)	Landsat MSS; TM and ETM+	ERDAS Imagine 8.7; ARCGIS 9.0 (ESRI); Fragstat

3.2.1.4. Patch Density (PD) – Class metrics, Landscape Metrics

Patch density is the number of patches per 100 ha (Miyamoto and Sano, 2008). Patch density is the number of patches per unit area (Uuemaa et al., 2005). Patch Density equals the number of patches of the corresponding patch type divided by total (Ribeiro and Lovett, 2009). Patch Density is the number of patches per area (Schindler et al., 2008). The used authors, data and programs per Patch Density (PD) are represented in the *Table 3.5*.

Table 3.5: Used Authors, Data and Programs per Patch Density (PD)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Lee & Thompson (2005)	Aerial photographs	GIS; Fragstat
Miyamoto & Sano (2008)	Aerial photographs	GIS; Fragstat version 3.1
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3

Authors	*Data*	*Program*
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Sivrikaya et al. (2007)	IKONOS images	ArcGIS 9.0; Fragstat
Uuemaa et al. (2008)	Soil data are derived from the Estonian Soil Map (1:10,000)	Idrisi Kilimanjaro (Eastman, 2003); Fragstat version 3.3
Uuemaa et al. (2005)	Land use data is derived from a Map	Idrisi Kilimanjaro; Fragstat
Venturelli & Galli (2006)	Regional Technical Map	GIS
Weiers et al. (2004)	CORINE, Landsat MSS & TM, IRS-IC data, aerial photo; land & soil maps	ERDAS Imagine; Fragstat
Zhang & Wang (2006)	Landsat TM	ArcView 3.2; Fragstat

3.2.1.5. Largest Patch Index (LPI) – Class Metrics; Landscape Metrics

The largest patch index (LPI) is computed at the class and landscape levels that quantify the percentage of total landscape area comprised by the largest patch (McGarigal and Marks, 1995). Indicators for change in landscape structure caused by urbanization provided information about specific aspects of landscape structure and thus were helpful to "guide" the process of urbanization towards sustainability (DiBari, 2007; Ji et al., 2006). Largest Patch Index is the percentage of total area occupied by the largest patch (Schindler et al., 2008). The used authors, data and programs per the Largest Patch Index (LPI) are represented in the *Table 3.6*.

Table 3.6: Used Authors, Data and Programs per the Largest Patch Index (LPI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat

Authors	*Data*	*Program*
Lee & Thompson (2005)	Aerial photographs	GIS; Fragstat
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine TM; ArcView TM; Fragstat; ATtILA
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Sivrikaya et al. (2007)	IKONOS images	ArcGIS 9.0; Fragstat
Wenguang et al. (2008)	Landsat MSS; TM and ETM+	ERDAS; ARCGIS; Fragstat

3.2.1.6. Landscape Shape Index (LSI) and Normalized Landscape Index (NLSI) – Class Metrics, Landscape Metrics

The Landscape Shape Index measures the perimeter-to-area ratio for the landscape as a whole. This index is identical to the habitat diversity index proposed by Patton (1975). Landscape Shape Index is the ratio of the total edge to the minimum total edge. Normalized Landscape Shape Index is the ratio of the total edge to the minimum total edge per class, rescaled according the proportion of the classes (Schindler et al., 2008). The used authors, data and programs per the Landscape Shape Index (LSI) are represented in the *Table 3.7*.

Table 3.7: Used Authors, Data and Programs per the Landscape Shape Index (LSI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Pelorosso et al. (2009)	Cartographic data; Landsat 5 TM & 7 ETM; Digital vegetation photographs	GIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Zhang & Wang (2006)	Landsat TM	ArcView 3.2; Fragstat

3.2.1.7. Total Edge (TE) – Class Metrics, Landscape Metrics

Total edge (TE) is an absolute measure of the total edge length of a particular patch type (class level) or of all patch types (landscape level). In applications involving comparisons of landscapes of different sizes, this index may not be useful (McGarigal and Marks, 1995). The used authors, data and programs per Total Edge (TE) are represented in the *Table 3.8*.

Table 3.8: Used Authors, Data and Programs per Total Edge (TE)

Authors	*Data*	*Program*
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine TM; ArcView TM; Fragstat; ATtILA
Quine & Watts (2009)	Raster data layers	ARCGIS; Fragstat

3.2.1.8. Edge Density (ED) – Class Metrics, Landscape Metrics

Edge density is the total length of patch edge per ha (Miyamoto and Sano, 2008). Edge density is total length of edge per unit area (Schindler et al., 2008). Edge density is the total length of all edge segments per ha for the landscape of consideration (Uuemaa et al., 2005). The used authors, data and programs per Edge Density (ED) are represented in the *Table 3.9*.

Table 3.9: Used Authors, Data and Programs per Edge Density (ED)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Miyamoto & Sano(2008)	Aerial photographs	GIS; Fragstat version 3.1
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Uuemaa et al. (2008)	Soil data are derived from the Soil Map	Idrisi Kilimanjaro; Fragstat

Authors	*Data*	*Program*
Uuemaa et al. (2005)	Land use data is derived from a Map	Idrisi Kilimanjaro; Fragstat
Venturelli & Galli (2006)	Regional Technical Map	GIS
Zhang and Wang (2006)	Landsat TM	ArcView 3.2; Fragstat

3.2.1.9. Patch Area Distribution (AREA_X) – Class Metrics, Landscape Metrics

Mean (AREA_MN): Patch Area is the area of a patch (Miyamoto and Sano, 2008). Patch area is size of the patches (Schindler et al., 2008). Patch mean equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type (McGarigal and Marks, 1995).
Weighted Mean (AREA_AM) – Class Metrics; Landscape Metrics: Patch area-weighted mean equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric value multiplied by the proportional abundance of the patch (McGarigal and Marks, 1995).

Coefficient of Variation (AREA_CV) – Class Metrics, Landscape Metrics: Patch area coefficient of variation equals the standard deviation divided by the mean, multiplied by 100 to convert to a percentage, for the corresponding patch metric (McGarigal and Marks, 1995).

The used authors, data and programs per Patch Area Distribution (AREA_X) are represented in the *Table 3.10*.

Table 3.10: Used Authors, Data and Programs per Patch Area Distribution (AREA_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Miyamoto & Sano(2008)	Aerial photographs	GIS; Fragstat version 3.1

Authors	*Data*	*Program*
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine TM; ArcView TM; Fragstat; ATtILA
Quine and Watts (2009)	Raster data layers	ARCGIS; Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Uuemaa et al. (2008)	Soil data are derived from the Soil Map	Idrisi Kilimanjaro; Fragstat

3.2.1.10. Radius of Gyration (GYRATE_X) – Class Metrics, Landscape Metrics

Mean (GYRATE_MN); Weighted Mean (GYRATE_AM); Coefficient of Variation (GYRATE_CV): GYRATE equals the mean distance (m) between each cell in the patch and the patch centroid (Schindler et al., 2008). Radius of gyration is a measure of patch extent; thus it is affected by both patch sizes and patch compaction (McGarigal and Marks, 1995). The used authors, data and programs per Radius of Gyration (GYRATE_X) are represented in the *Table 3.11*.

Table 3.11: Used Authors, Data and Programs per Radius of Gyration (GYRATE_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.2. Shape and Core Area

The second category of the six (6) before acceded ones is the Shape and Core Area, which acquiesced the next thirteen (13) indices:

(1) Perimeter Area Fractal Dimension (PARFAC);
(2) Perimeter Area Ratio Distribution (PARA_X);
(3) Shape Index Distribution (SHAPE_X);
(4) Fractal Dimension Index Distribution (FRAC_X) ;
(5) Related Circumscribing Circle Distribution (CIRCLE_X);

(6) Contiguity Index Distribution (CONTIG_X);
(7) Total Core Area (TCA);
(8) Number of Disjunct Core Areas (NDCA);
(9) Disjunct Core Area Density (DCAD);
(10) Core Area Distribution (CORE_X);
(11) Disjunct Core Area (DCORE_X);
(12) Core Area Index (CAI_X);
(13) Core Area Percent of Land (PLAND).

The afore-adduced thirteen (13) indices of the second key group, i.e. Shape and Core Area, are alleged in the below professed shares.

3.2.2.1. Perimeter Area Fractal Dimension (PARFAC) – Class Metrics, Landscape Metrics

The perimeter area Fractal dimension patch is shape complexity measure, which approaches 1 for shapes with simple perimeters and 2 for complex shapes. The used authors, data and programs per Perimeter Area Fractal Dimension (PARFAC) are represented in the *Table 3.12*.

Table 3.12: Used Authors, Data and Programs per Perimeter Area Fractal Dimension (PARFAC)

Authors	*Data*	*Program*
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.2.2. Perimeter Area Ratio Distribution (PARA_X) – Class Metrics, Landscape Metrics

Mean (PARA_MN); Weighted Mean (PARA_AM); Coefficient of Variation (PARA_CV):

Perimeter Area Ratio is patch shape complexity measure that measures perimeter per area (Schindler et al., 2008). “Heterogeneity appears useful to planning a sustainable environment, but more important is the actual arrangement of patches and corridors”. “Geometry patterns are indicators of human disturbance (roads, urban areas)” (Forman, 1995). The used authors, data and programs per Perimeter Area Ratio Distribution (PARA_X) are represented in the *Table 3.13*.

Table 3.13: Used Authors, Data and Programs per Perimeter Area Ratio Distribution (PARA_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine TM; ArcView TM; Fragstat; ATtILA
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.2.3. Shape Index Distribution (SHAPE_X) – Class Metrics, Landscape Metrics

A shape index (SI) is equal to 1 when all patches are circular, which increases with complexity of patch shapes and is independent from patch size (Schindler et al., 2008). Shape complexity of patches of the focal class, where shape is defined by perimeter–area relationships (Cushman et al., 2008). SI_i is the patch shape index for patch i, P_i the perimeter of the patch, a_i the area of the patch i. It assumes that the patch shape index = 1 when the patch is circular, and increases without limit as patch shape becomes more irregular (Kim and Pauleit, 2007).

<u>*Mean (SHAPE_MN):*</u> Mean patch shape complexity, equals 1 when all patches are square and increases without limit as patch shape becomes more irregular. It is the simplest and most straightforward measure of overall shape (Miyamoto and Sano, 2008).

A patch-level shape index averaged over all patches in the landscape (*Equation 3.1*):

Equation 3.1: Patch Shape Index

$$SHAPE\_MN = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(\frac{P_{ij}}{\sqrt[2]{\pi a_{ij}}}}{N}$$

Where P_{ij} is the perimeter and a_{ij} is the area of patch ij, and N is the total number of patches in the landscape (unit less) (Uuemaa et al., 2005).

<u>*Weighted Mean (SHAPE_AM); Coefficient of Variation (SHAPE_CV)*</u>

The used authors, data and programs per Shape Index Distribution (SHAPE_X) are represented in the *Table 3.14*.

Table 3.14: Used Authors, Data and Programs per Shape Index Distribution (SHAPE_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Gasper and Menz (1999)	Images of the COFUNE land cover	Created program of ENVIIDL
Kim and Pauleit (2007)	Topographic maps; Aerial photographs	GIS
Lee & Thompson (2005)	Aerial photographs	GIS; Fragstat
Miyamoto & Sano (2008)	Aerial photographs	GIS; Fragstat version 3.1
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Sivrikaya et al. (2007)	IKONOS images	ArcGIS 9.0; Fragstat
Uuemaa et al. (2008)	Soil data are derived from the Soil Map	Idrisi Kilimanjaro; Fragstat
Uuemaa et al. (2005)	Land use data is derived from a Map	Idrisi Kilimanjaro; Fragstat
Weiers et al. (2004)	CORINE, Landsat MSS & TM, IRS-IC data, aerial photo; land & soil maps	ERDAS Imagine; Fragstat

3.2.2.4. Fractal Dimension Index Distribution (FRAC_X) – Class Metrics, Landscape Metrics

Fractal dimension is patch shape complexity measure that approaches 1 for simple shapes and 2 for complex shapes (Schindler et al., 2008). Indicators for change in landscape structure caused by urbanization provided information about specific aspects of landscape structure and thus were helpful to “guide” process of urbanization towards sustainability (DiBari, 2007; Ji et al., 2006).

Mean (FRAC_MN); Weighted Mean (FRAC_AM); Coefficient of Variation (FRAC_CV)

The used authors, data and programs per Fractal Dimension Index Distribution (FRAC_X) are represented in the *Table 3.15*.

Table3.15: Used Authors, Data and Programs per Fractal Dimension Index Distribution (FRAC_X)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Li and Wu (2004)	RS and map data	GIS
Pelorosso et al. (2009)	Cartographic data; Landsat 5 TM & 7 ETM; Digital vegetation photographs	GIS; Fragstat version 3.3
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.2.5. Related Circumscribing Circle Distribution (CIRCLE_X) – Class Metrics, Landscape Metrics

Related circumscribing circle is patch elongation measure; equals 1 minus patch area divided by the area of the smallest circumscribing circle (Schindler et al., 2008).

Mean (CIRCLE_MN); Weighted Mean (CIRCLE_AM); Coefficient of Variation (CIRCLE_CV)

The used authors, data and programs per Related Circumscribing Circle Distribution (CIRCLE_X) are represented in the *Table 3.16*.

Table 3.16: Used Authors, Data and Programs per Related Circumscribing Circle Distribution (CIRCLE_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.2.6. Contiguity Index Distribution (CONTIG_X) – Class Metrics, Landscape Metrics

Contiguity index equals 0 for a one-pixel patch and approaches 1 as patch contiguity, or connectedness increases (Schindler et al., 2008).

Mean (CIRCLE_MN); Weighted Mean (CIRCLE_AM); Coefficient of Variation (CIRCLE_CV)

The used authors, data and programs per Contiguity Index Distribution (CONTIG_X) are represented in the *Table 3.17*.

Table3.17: Used Authors, Data and Programs per Contiguity Index Distribution (CONTIG_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.2.7. Total Core Area (TCA) – Class Metrics, Landscape Metrics

TCA equals the sum of the core areas of each patch (m^2) of the corresponding patch type, divided by 10,000 (to convert to hectares) (McGarigal and Marks, 1995). The used authors, data and programs per Total Core Area (TCA) are represented in the *Table 3.18*.

Table 3.18: Used Authors, Data and Programs per Total Core Area (TCA)

Authors	*Data*	*Program*
Bock et al. (2005)	Landsat 7 ETM+ and 5 TM; VHR RS images; HRSC; soil map; IKONOS	Tool extension (V-LATE) calculated within ArcGIS 8.x
Kupfer (2006)	Landsat TM; AVHRR; MODIS; TIGER DLG	GIS

3.2.2.8. Number of Disjunct Core Areas (NDCA) – Class Metrics, Landscape Metrics

Number of disjunct core areas equals the sum of the number of disjunct core areas contained within each patch of the corresponding patch type; that is, the number of disjunct core areas contained within the landscape (McGarigal and Marks, 1995).

The used authors, data and programs per Number of Disjunct Core Areas (NDCA) are represented in the *Table 3.19*.

Table 3.19: Used Authors, Data and Programs per Number of Disjunct Core Areas (NDCA)

Authors	*Data*	*Program*
Bock et al. (2005)	Landsat 7 ETM+ and 5 TM; VHR RS images; HRSC; soil map; IKONOS	Tool extension (V-LATE) calculated within ArcGIS 8.x

3.2.2.9. Disjunct Core Area Density (DCAD) – Class Metrics, Landscape Metrics

DCAD equals the sum of the number of disjunct core areas contained within each patch of the corresponding patch type, divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares) (McGarigal and Marks, 1995). The used authors, data and programs per Disjunct Core Area Density (DCAD) are represented in the *Table 3.20*.

Table 3.20: Used Authors, Data and Programs per Disjunct Core Area Density (DCAD)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2

3.2.2.10. Core Area Distribution (CORE_X) – Class Metrics, Landscape Metrics

The core area is defined as the area within a patch beyond some specified edge distance or buffer width. Core area metrics reflect both landscape composition and landscape configuration (McGarigal and Marks, 1995).

Mean (CORE_MN); Weighted Mean (CORE_AM); Coefficient of Variation (CORE_CV)

The used authors, data and programs per Core Area Distribution (CORE_X) are represented in the *Table 3.21*.

Table 3.21: Used Authors, Data and Programs per Core Area Distribution (CORE_X)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2

3.2.2.11. Disjunct Core Area (DCORE_X) – Class Metrics, Landscape Metrics

Mean (DCORE_MN); Weighted Mean (DCORE_AM); Coefficient of Variation (DCORE_CV)

The used authors, data and programs per Disjunct Core Area (DCORE_X) are represented in the *Table 3.22*.

Table 3.22: Used Authors, Data and Programs per Disjunct Core Area (DCORE_X)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2

3.2.2.12. Core Area Index (CAI_X) – Class Metrics, Landscape Metrics

Core Area Index (CAI) equals to the patch core area (m^2) divided by total patch area (m^2), multiplied by 100 (to convert to a percentage); in other words, CAI equals the percentage of a patch that is a core area (McGarigal and Marks, 1995).

Mean (CAI_MN); Weighted Mean (CAI_AM); Coefficient of Variation (CAI_CV)

The used authors, data and programs per Core Area Index (CAI_X) are represented in the *Table 3.23*.

Table 3.23: Used Authors, Data and Programs per the Core Area Index (CAI_X)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2

3.2.2.13. Core Area Percent of Land (PLAND) – Class Metrics, Landscape Metrics

PLAND equals to the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, PLAND equals the percentage the landscape comprised of the corresponding patch type (McGarigal and Marks, 1995). The used authors, data and programs per Core Area Percent of Land (PLAND) are represented in the *Table 3.24*.

Table 3.24: Used Authors, Data and Programs per Core Area Percent of Land (PLAND)

Authors	*Data*	*Program*
Bock et al. (2005)	Landsat 7 ETM+ and 5 TM; VHR RS images; HRSC; soil map; IKONOS	Tool extension (V-LATE) calculated within ArcGIS 8.x

3.2.3. Isolation Proximity

The third category of the six (6) before asserted ones is the Isolation Proximity, which is shown in the next two (2) indices:

(1) Proximity Index Distribution (PROX_X)
(2) Euclidean Nearest Neighborhood Distance (ENN_X)

The afore-fostered two (2) indices of the second key group, i.e. Isolation Proximity, are alleged in the below cited segments.

3.2.3.1. Proximity Index Distribution (PROX_X) – Class Metrics, Landscape Metrics

This index defines the spatial context of landscape patches in relation to their neighbors (Gustafson and Parker, 1994). The proximity index combines spatial information on patch size and spacing, and will clearly distinguish a site with small patches distantly spaced from a site with large patches closely spaced. If these are perennial vegetation patches, intuitively, the latter site will more efficiently retain resources than the former. A site with larger and more closely packed vegetation patches will provide more obstructions to trap windblown litter and soil particles, and any such particles are flowing in run-off (Tongway and Ludwig, 1997). Thus, the proximity index may provide a useful indicator for the potential of a landscape to capture resources (Bastin et al., 2002). Proximity Index considers size and proximity of all patches with the same land cover type inside a specified search radius (Schindler et al., 2008). Proximity is the degree of isolation of patches from nearby patches of the same class (Cushman et al., 2008). Proximity index equals the sum of patch area (m^2) divided by the nearest edge-to-edge distance squared (m^2) between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance (m) of the focal patch (Kim and Pauleit, 2007).

Mean (PROX_MN); Weighted Mean (PROX_AM); Coefficient of Variation (PROX_CV)

The used authors, data and programs per Proximity Index Distribution (PROX_X) are represented in the *Table 3.25*.

Table 3.25: Used Authors, Data and Programs per Proximity Index Distribution (PROX_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Bastin et al., (2002)	Near-ground digital photography, aerial videography and high-resolution satellite imagery	Statistical Calculations

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Kim and Pauleit (2007)	Topographic maps; Aerial photographs	GIS
Kupfer (2006)	Landsat TM; AVHRR; MODIS; TIGER DLG	GIS
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Wenguang et al. (2008)	Landsat MSS; TM and ETM+	ERDAS Imagine 8.7; ARCGIS 9.0 (ESRI); Fragstat

3.2.3.2. Euclidean Nearest Neighborhood Distance (ENN_X) – Class Metrics, Landscape Metrics

Euclidean nearest neighborhood distance is the average distance between patches of the same class, representing patch isolation (Miyamoto and Sano, 2008). Euclidean nearest neighborhood distance is minimum edge-to-edge distance to the nearest neighboring patch of the same type (Schindler et al., 2008). Euclidean nearest neighborhood distance is proximity of patches of the focal class, based on the average or area–weighted average distance between nearest neighbors (Cushman et al., 2008). Nearest neighborhood distance equals the nearest-neighbor distance from a patch to another of the same type, based on shortest edge-to-edge distance (Kim and Pauleit, 2007). A patch level the distance (m) to the nearest neighboring patch of the same type, based on shortest edge-to-edge distance is averaged over all patches in the landscape given by the *Equation 3.2*:

*Equation 3.2: Euclidean Nearest Neighborhood Distanc*e

$$ENN\_MN = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} h_{ij}}{N}$$

where h_{ij} distance from patch ij to nearest neighboring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center, and N is the total number of patches in the landscape (unit: m) (Uuemaa et al., 2005). “Greenways offer a promising planning strategy to address the challenge of making landscape planning sustainable” (Ahern, 1995). The spread of disturbances such as diseases and fire is greater when MNND is low and when PROXIM values are high

(Botequilha Leitao and Ahern, 2002). Consensus is emerging: some form of ecological infrastructure is necessary to achieve a sustainable landscape condition (Rescia et al., 2006).

Mean (ENN_MN); Weighted Mean (ENN_AM); Coefficient of Variation (ENN_CV)
The used authors, data and programs per Euclidean Nearest Neighborhood Distance (ENN_X) are represented in the *Table 3.26*.

Table 3.26: Used Authors, Data and Programs per Euclidean Nearest Neighborhood Distance (ENN_X)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Bar and Loffler (2007)	Aerial Photos	ArcView extension "patch 2.0"
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Kim and Pauleit (2007)	Topographic maps; Aerial photographs	GIS
Kupfer (2006)	Landsat TM; AVHRR; MODIS; TIGER DLG	GIS
Lee & Thompson (2005)	Aerial photographs	GIS; Fragstat
Miyamoto & Sano(2008)	Aerial photographs	GIS; Fragstat version 3.1
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine TM; ArcView TM; Fragstat; ATtILA
Quine and Watts (2009)	Raster data layers	ARCGIS; Fragstat
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Uuemaa et al. (2005)	Land use data is derived from a Map	Idrisi Kilimanjaro; Fragstat

3.2.4. Connectivity

The fourth category of the six (6) before mentioned ones is the Connectivity, which consist of two (2) indices:

(1) Patch Cohesion Index (COHESION);
(2) Connectance Index (CONNECT).

The before highlighted two (2) indices of the fourth key group, i.e. Connectivity, arises in the below recognized fragments.

3.2.4.1. Patch Cohesion Index (COHESION) – Class Metrics, Landscape Metrics

Patch cohesion index is measure of the physical connectedness of the focal land cover class (Schindler et al., 2008). COHESION equals 1 minus the sum of patch perimeter (in terms of the number of cell surfaces) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage (McGarigal and Marks, 1995). The used authors, data and programs per Patch Cohesion Index (COHESION) are represented in the *Table 3.27*.

Table 3.27: Used Authors, Data and Programs per the Patch Cohesion Index (COHESION)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.4.2. Connectance Index (CONNECT) – Class Metrics, Landscape Metrics

Connectance index is the percentage of patches which are joined, i.e. inside a specified threshold distance (Schindler et al., 2008). CONNECT equals the number of functional joining between all patches of the corresponding patch type (sum of c_{ijk} where $c_{ijk} = 0$ if patch j and k are not within the specified distance of each other and $c_{ijk} = 1$ if patch j and k are within the specified distance), divided by the total number of possible joining between all patches of the corresponding patch type, multiplied by 100 to convert to a percentage (McGarigal and Marks, 1995). The used authors, data and programs per Connectance Index (CONNECT) are represented in the *Table 3.28*.

Table 3.28: Used Authors, Data and Programs per the Connectance Index (CONNECT)

Authors	*Data*	*Program*
Dramstad et al. (2001)	Simulated data	3Q programme
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Zhang and Wang (2006)	Landsat TM	ArcView 3.2; Fragstat

3.2.5. Contagion Interspersion

The fifth category of the six (6) before highlighted ones is the Contagion Interspersion, which is investigated in the following eight (8) indices:

(1) Clumpiness (CLUMPY);
(2) Proportion of Like Adjacencies (PLADJ);
(3) Aggregation Index (AI);
(4) Interspersion Juxtaposition Index (IJI);
(5) Landscape Division (DIVISION);
(6) Splitting Index (SPLIT);
(7) Effective Mesh Size (MESH);
(8) Contagion Index (CONTAG).

The afore-adduced eight (8) indices of the fifth key group, i.e. Contagion Interspersion, are stated in the below professed shares.

3.2.5.1. Clumpiness (CLUMPY) – Class Metrics

CLUMPY equals the proportional deviation of the proportion of like adjacencies involving the corresponding class from that expected under a spatially random distribution. If the proportion of like adjacencies (G_i) is less than the proportion of the landscape comprised of the focal class (P_i) and $P_i < 0.5$, then CLUMPY equals G_i minus P_i, divided by P_i; else, CLUMPY equals G_i minus P_i, divided by 1 minus P_i. Note: it can be shown that G_i equals 1 when the patch type is maximally clumped, but this requires adjustment for the perimeter of the class. If a_i is the area of class i (in terms of number of cells) and n is the side of a largest integer square smaller than a_i, and $m = a_i - n^2$, then the minimum perimeter of class i (i.e., when it is maximally clumped), min-$e_{i,}$ will take one of the three forms (Milne, 1991): min-e_i = 4n, when m = 0, or min-e_i = 4n + 2, when $n^2 < a_i \leq n(1+n)$, or min-e_i = 4n + 4, when $a_i >$

n(1+n). The used authors, data and programs per Clumpiness (CLUMPY) are represented in the *Table 3.29*.

Table 3.29: Used Authors, Data and Programs per Clumpiness (CLUMPY)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Olsen et al. (2007)	Landsat ETM and MSS images	Imagine TM; ArcView TM; Fragstat; ATtILA

3.2.5.2. Proportion of Like Adjacencies (PLADJ) – Class Metrics, Landscape Metrics

Percentage of like adjacencies is percentage of neighboring pixel, being the same land cover class, based on double-count method (Schindler et al., 2008). An exciting paper of Hersperger and Burgi (2009) demonstrates patch adjacency by referring to the landscape element and its immediate adjoining elements. The used authors, data and programs per Proportion of Like Adjacencies (PLADJ) are represented in the *Table 3.30*.

Table 3.30: Used Authors, Data and Programs per Proportion of Like Adjacencies (PLADJ)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Uuemaa et al. (2008)	Soil data are derived from the Soil Map	Idrisi Kilimanjaro; Fragstat

3.2.5.3. Aggregation Index (AI) – Class Metrics, Landscape Metrics

Aggregation index is the percentage of neighboring pixel, being the same land cover class, based on single-count method (Schindler et al., 2008). The used authors, data and programs per Aggregation Index (AI) are represented in the *Table 3.31*.

Table 3.31: Used Authors, Data and Programs per the Aggregation Index (AI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.5.4. Interspersion Juxtaposition Index (IJI) – Class Metrics, Landscape Metrics

Interspersion juxtaposition index is the measure of evenness of patch adjacencies, equals 100 for even and approaches 0 for uneven adjacencies (Schindler et al., 2008). Interspersion juxtaposition index is degree of intermixing of patch types (Cushman et al., 2008). Indicators for change in landscape structure caused by urbanization provided information about specific aspects of landscape structure and thus were helpful to "guide" process of urbanization towards sustainability (DiBari, 2007; Ji et al., 2006). The used authors, data and programs per Interspersion Juxtaposition Index (IJI) are represented in the *Table 3.32*.

Table 3.32: Used Authors, Data and Programs per the Interspersion Juxtaposition Index (IJI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Venturelli & Galli (2006)	Regional Technical Map	GIS

3.2.5.5. Landscape Division (DIVISION) – Class Metrics, Landscape Metrics

Landscape division equals the probability that 2 randomly chosen pixels in the landscape are not situated in the same patch (Schindler et al., 2008). The used authors, data and programs per Landscape Division (DIVISION) are represented in the *Table 3.33*.

Table 3.33: Used Authors, Data and Programs per Landscape Division (DIVISION)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.5.6. Splitting Index (SPLIT) – Class Metrics, Landscape Metrics

Splitting index equals the number of patches of a landscape divided into equal sizes keeping landscape division constant (Schindler et al., 2008). The used authors, data and programs per Splitting Index (SPLIT) are represented in the *Table 3.34*.

Table 3.34: Used Authors, Data and Programs per the Splitting Index (SPLIT)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.5.7. Effective Mesh Size (MESH) – Class Metrics, Landscape Metrics

MESH equals the sum of patch area squared, summed across all patches of the corresponding patch type, divided by the total landscape area (m^2), divided by 10,000 (to convert to hectares) (McGarigal and Marks, 1995). The used authors, data and programs per Effective Mesh Size (MESH) are represented in the *Table 3.35*.

Table 3.35: Used Authors, Data and Programs per Effective Mesh Size (MESH)

Authors	*Data*	*Program*
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Tasser et al. (2008)	Digital land-use & street, Vegetation, Municipality borders, Geological maps	Arc View

3.2.5.8. Contagion Index (CONTAG) – Landscape Metrics

Contagion index equals 0 for a one-pixel patch and approaches 1 as patch contiguity, or connectedness increases (Schindler et al., 2008). Contagion index indicates the aggregation of patches (Equation 3.3) (below).

Equation 3.3: Contagion Index

$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]\left[\ln (P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)} \right](100)$$

where P_i is the proportion of the landscape occupied by patch type i; g_{ik} is the number of adjacencies between pixels of patch types (classes) i and k based on the double-count method; and m is the number of patch types (classes) in the landscape (Uuemaa et al., 2005). The Contagion-Index specifies the degree of aggregation of the existing patches in the image. A patch is the smallest unit in the classified image and consists of pixels of the same class. The index therefore is used as a measure of dissection and fragmentation of the landscape. The changed values of the index point to the splitting of great homogeneous areas into little isolated areas as well as to the loss of corridors between habitats (Gasper and Menz, 1999). The used authors, data and programs per Contagion Index (CONTAG) are represented in the *Table 3.36*.

Table 3.36: Used Authors, Data and Programs per the Contagion Index (CONTAG)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Gasper and Menz (1999)	Images of COFUNE landcover	Created program of ENVIIDL
Li and Wu (2004)	RS and map data	GIS
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Uuemaa et al. (2008)	Soil data are derived from the Soil Map	Idrisi Kilimanjaro; Fragstat
Uuemaa et al. (2005)	Land use data is derived from a Map	Idrisi Kilimanjaro; Fragstat

3.2.6. Diversity

The last category of the six (6) before spoken ones is the Diversity, which consist of the further nine (9) indices:

(1) Patch Richness (PR);
(2) Patch Richness Diversity (PRD);
(3) Relative Patch Richness (RPR);
(4) Shannon Diversity Index (SHDI);
(5) Simpson Diversity Index (SIDI);
(6) Modified Simpson Diversity Index (MSIDI);
(7) Shannon Evenness Index (SHEI);
(8) Simpson Evenness Index (SIEI)
(9) Modified Simpson Evenness Index (MSIEI).

The afore-adduced indices (9) indices of the last key group, i.e. Diversity, are discussed in the below professed states.

3.2.6.1. Patch Richness (PR) – Landscape Metrics

While ecosystems are evolving, the number of integrated species is regularly increasing steadily and also the abiotic features are becoming more and more complex. This development is accompanied by a rising degree of information, heterogeneity and complexity (Muller, 2005). “The heterogeneity provided by patches and corridors in an area plays a key role in sustainability” (Forman, 1995). PR equals the number of different patch types present within the landscape boundary (McGarigal and Marks, 1995). The used authors, data and programs per Patch Richness (PR) are represented in the *Table 3.37*.

Table 3.37: Used Authors, Data and Programs per Patch Richness (PR)

Authors	*Data*	*Program*
Aubert et al. (2003)	Species data	ADE software (Thioulouse et al., 1997); Canonical correspondence analysis (CCA) (Ter Braak, 1987; Ter Braak and Prentice, 1988)
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat

Authors	*Data*	*Program*
Duro et al. (2007)	IKONOS; Quickbird; CASI-2; SPOT; AVHRR; Landsat TM	Fragstats; Tassel Cap Transformation (TCT) (Healy et al., 2005)
Ribeiro & Lovett (2009)	Data are derived from the land - use map	ArcGIS; Fragstat version 3.3
Ricketts and Imhoff (2003)	AVHRR	Gap Analysis Program (Scott et al. 1993)
Tasser et al. (2008)	Digital land-use & street, Vegetation, Municipality borders, Geological maps	Arc View
Venturelli & Galli (2006)	Regional Technical Map	GIS

3.2.6.2. Patch Richness Diversity (PRD) – Landscape Metrics

Patch richness diversity equals the number of patch types (i.e. Land cover categories) per 100 ha (Schindler et al., 2008). The number of patch types per unit area (unit: patches per 100 ha) (Uuemaa et al., 2005). The used authors, data and programs per Patch Richness Diversity (PRD) are represented in the *Table 3.38*.

Table 3.38: Used Authors, Data and Programs per Patch Richness Diversity (PRD)

Authors	*Data*	*Program*
Bailey at al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Duro et al. (2007)	IKONOS; Quickbird; CASI-2; SPOT; AVHRR; Landsat TM	Fragstats; TCT
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

Authors	*Data*	*Program*
Tasser et al. (2008)	Digital land-use & street, Vegetation, Municipality borders, Geological maps	Arc View
Uuemaa et al. (2005)	Land use data is derived from a Map	Idrisi Kilimanjaro; Fragstat

3.2.6.3. Relative Patch Richness (RPR) – Landscape Metrics

Relative patch richness is the percentage of present patch types out of all categories (Schindler et al., 2008). RPR equals the number of different patch types present within the landscape boundary divided by the maximum potential number of patch types specified by the user, based on the particular patch type classification scheme, multiplied by 100 (to convert to percent) (McGarigal and Marks, 1995). The used authors, data and programs per Relative Patch Richness (RPR) are represented in the *Table 3.39*.

Table 3.39: Used Authors, Data and Programs per Relative Patch Richness (RPR)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.6.4. Shannon Diversity Index (SHDI) – Landscape Metrics

Shannon Diversity Index equals to minus the sum of the proportional abundance of each patch type multiplied by the ln of that proportion (Schindler et al., 2008), which is given by *Equation 3.4*:

Equation 3.4: Shannon Diversity Index (1) $SHDI = -\sum_{k=1}^{s} P_i \ln P_i$

Where s is the number of habitat types, Pi is the proportion of the area in habitat cover k (Kim and Pauleit, 2007).

Another way of representation of *Shannon Diversity Index (H)* is shown in *Equation 3.5*. *SHDI* is a measure which informs on the structural composition of the communities (Pielou, 1975).

Equation 3.5: *Shannon Diversity Index (2)* $H^{/} = \sum p_i \log_2 p_i$

Where p_i is the relative frequency of species in a record (Aubert et al., 2003). The used authors, data and programs per Shannon Diversity Index (SHDI) are represented in the *Table 3.40*.

Table 3.40: Used Authors, Data and Programs per the Shannon Diversity Index (SHDI)

Authors	*Data*	*Program*
Aubert et al. (2003)	Species data	ADE software; CCA
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Dogan and Dogan (2006)	LANDSAT TM image	UNIX & PC Arc/Info (ESRI 1994; ESRI 1997); Erdas Imagine 8.5 (ERDAS 1997)
Dramstad et al. (2006)	Aerial Photographs	ArcViewTM (ESRI)
Dramstad et al. (2001)	Simulated data	3Q programme
Kim and Pauleit (2007)	Topographic maps; Aerial photographs	GIS
Lasanta et al. (2006)	Landsat TM and ETM	MiraMon Software; Fragstat
Pelorosso et al. (2009)	Cartographic data; Landsat 5 TM & 7 ETM; Digital vegetation photographs	GIS; Fragstat version 3.3
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Storkey et al. (2008)	Ecological data	Statistical analyses
Uuemaa et al. (2008)	Soil data are derived from the Soil Map	Idrisi Kilimanjaro; Fragstat
Venturelli & Galli (2006)	Regional Technical Map	GIS
Zhang and Wang (2006)	Landsat TM	ArcView 3.2; Fragstat

3.2.6.5. Simpson Diversity Index (SIDI) – Landscape Metrics

Simpson diversity index is diversity measure, which equals 1 minus the sum of the squared proportional abundance of each patch type (Schindler et al., 2008). SIDI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared (McGarigal and Marks, 1995). The used authors, data and programs per Simpson Diversity Index (SIDI) are represented in the *Table 3.41*.

Table 3.41: Used Authors, Data and Programs per the Simpson Diversity Index (SIDI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Cushman et al. (2008)	Aerial photography	Fragstat version 3.2
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.6.6. Modified Simpson Diversity Index (MSIDI) – Landscape Metrics

Diversity measure, which equals minus the ln of the sum of the squared proportional abundance of each patch type (Schindler et al., 2008). MSIDI equals minus the logarithm of the sum, across all patch types, of the proportional abundance of each patch type squared (McGarigal and Marks, 1995). The used authors, data and programs per Modified Simpson Diversity Index (MSIDI) are represented in the *Table 3.42*.

Table 3.42: Used Authors, Data and Programs per the Modified Simpson Diversity Index (MSIDI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.6.7. Shannon Evenness Index (SHEI) – Landscape Metrics

Diversity measure, which considers only evenness of patch sizes, not the number of patches (Schindler et al., 2008). SHEI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types. In other words, the observed Shannon's Diversity Index divided by the maximum Shannon's Diversity Index for that number of patch types (McGarigal and Marks, 1995). The used authors, data and programs per the Shannon Evenness Index (SHEI) are represented in the *Table 3.43*.

Table 3.43: Used Authors, Data and Programs per the Shannon Evenness Index (SHEI)

Authors	*Data*	*Program*
Aubert et al. (2003)	Species data	ADE software; CCA
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Li and Wu (2004)	RS and map data	GIS
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.
Zhang and Wang (2006)	Landsat TM	ArcView 3.2; Fragstat

3.2.6.8. Simpson Evenness Index (SIEI) – Landscape Metrics

Simpson evenness index is diversity measure, which considers only evenness of patch sizes, not the number of patches (Schindler et al., 2008). SIEI equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared, divided by 1 minus 1 divided by the number of patch types. In other words, the observed Simpson's Diversity Index divided by the maximum Simpson's Diversity Index for that number of patch types (McGarigal and Marks, 1995). The used authors, data and programs per Simpson Evenness Index (SIEI) are represented in the *Table 3.44*.

Table 3.44: Used Authors, Data and Programs per the Simpson Evenness Index (SIEI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Dogan and Dogan (2006)	LANDSAT TM image	UNIX & PC Arc/Info; Erdas Imagine 8.5
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.2.6.9. Modified Simpson Evenness Index (MSIEI) – Landscape Metrics

Modified Simpson evenness index is diversity measure, which considers only evenness of patch sizes, not the number of patches (Schindler et al., 2008). MSIEI equals minus the logarithm of the sum, across all patch types, of the proportional abundance of each patch type squared, divided by the logarithm of the number of patch types. In other words, the observed modified Simpson's diversity index divided by the maximum modified Simpson's diversity index for that number of patch types (McGarigal and Marks, 1995). The used authors, data and programs per Modified Simpson Evenness Index (SIEI) are represented in the *Table 3.45*.

Table 3.45: Used Authors, Data and Programs per the Modified Simpson Evenness Index (MSIEI)

Authors	*Data*	*Program*
Bailey et al. (2007)	Digitized from true color orthophoto	ArcGIS 8.1 (ESRI); Fragstat
Schindler et al. (2008)	IKONOS	Fragstat version 3.3.

3.3. SUMMARIES AND PROPOSALS

A great variety of different landscape metrics based on remote sensing data (RS), for monitoring ecosystems and also different programs for their calculation (Fragstats, metrics, GIS) are considered in the current chapter. The investigation identified subsets of metrics, enabled scientists to recognize main aspects of landscape pattern, facilitated the compilation of groups of landscapes with similar characteristics and indicated which metrics are frequently useful in landscape studies. The frequency of used papers per each metric has been taken into account. In the current paper, there are six main categories of metrics. The most used to the least used metrics have the following order:

- Area / Density / Edge (All types of RS data, 10 subcategories, 22 papers);
- Isolation Proximity (All types of RS data, 2 subcategories, 15 papers);
- Diversity (All types of RS data, 9 subcategories, 20 papers);
- Contagion Interspersion (VHR and HR RS data, 8 subcategories, 12 papers);
- Shape (VHR RS data, 13 subcategories, 17 papers);
- Connectivity (VHR and HR RS data, 2 subcategories, 5 papers).

It can be seen from the aforementioned list that the three last categories of metrics use only VHR and/or HR remote sensing data. Particularly, only very high resolution (VHR) remote sensing data is used in the Shape Metric. This constraint can explain their limited use.

Furthermore, the frequency of used papers is divided into five groups. The frequency of used papers equals to the number of used papers per subcategory over the number of used papers per main category. It has been found that min=1/17=0.059 and max=12/15=0.8. The range from min to max has been divided into five equal pieces accordingly representing five groups, i.e. from Group A till Group E. To have a better idea of each group appearance per subcategory and main categories according to the frequency of used papers per each index, the first three before-mentioned groups has the following order:

(a) Group A:

- Euclidean Nearest Neighborhood (12/15=0.8) from Isolation Proximity main category;
- Shannon Diversity Index (13/20=0.65) from Diversity main category;
- Shape Index (11/17=0.647) from Shape main category;
- Patch Density (13/22=0.591) from Area / Density / Edge main category (Exception).

(b) Group B:

- Patch Cohesion Index (3/5=0.6) from Connectivity main category;
- Connectance Index (3/5=0.6) from Connectivity main category;
- Contagion Index (7/12=0.583) from Contagion Interspersion main category;
- Proximity Index Distribution (8/15=0.533) from Isolation Proximity main category;
- Number of Patches (11/22=0.5) from Area / Density / Edge main category;
- Interspersion Juxtaposition Index (6/12=0.5) from Contagion Interspersion main category.

(c) Group C:

- Largest Patch Index (9/22=0.409) from Area / Density / Edge main category;
- Edge Density (9/22=0.409) from Area / Density / Edge main category;
- Class Area (8/22=0.364) from Area / Density / Edge main category;
- Patch Richness (7/20=0.35) from Diversity main category.

An explanation of the above results, regarding to the four (4) proposed indices of group A and two (2) proposed indices from the group B, leads to the following:

- Euclidean Nearest Neighborhood (ENN) distance is the proximity of patches to neighbors of the same class, based on the area-weighted average distance between nearest neighbors (Cushman et al., 2008). According to the results of Bar and Loffler (2007), the number of patches increased while ENN between forest patches decreased. This illustrates that widespread forests were under fragmentation into smaller units. In other words, ENN underlies an assumption of habitat configuration (Quine and Watts, 2009). ENN was also chosen by Lee & Thompson (2005) because it was possible to measure a range of important changes in the spatial pattern of landscapes, without incurring significant inter-correlation between the indices. This index is one of the chosen indices (Miyamoto & Sano, 2008), which quantifies fundamental landscape characteristics and is found to be useful in several other landscape structural analyses. At last, the Euclidean Nearest Neighborhood Distance is used by 12 authors out of 15, as the current index is chosen because it is possible to measure a range of important changes in the spatial pattern of landscapes.

- As a global estimator of landscape structure, Shannon Diversity Index (SHDI), which gives more importance to the richness component and rare cover types, is calculated. In addition, SHDI does not only reflect the richness of habitats but also their relative importance in a given area (Kim and Pauleit, 2007). According to The Ecological Society of America Committee on Land Use (Dale et al., 2000), SHDI has greater sensitivity to rare cover types and it needs to be given greater importance during interpretation. SHDI might be useful to detect the area where rare and endangered species in focus (Dogan and Dogan, 2006). In the end, Shannon Diversity Index is used by 13 authors out of 20 because it is relatively simple to use and to interpret (Dramstad et al., 2006).

- Shape is a difficult parameter to quantify concisely in a metric. This shape index measures the complexity of patch shape compared to a standard shape (McGarigal and Marks, 1995). According to Weiers et al. (2004), the shapes of semi-natural patches are defined by the surrounding agricultural land use. This index is one of the chosen indices (Miyamoto & Sano, 2008), which quantifies fundamental landscape characteristics and is found to be useful in several other landscape structural analyses. Finally, despite the Shape Index is used by 11 authors out of 17, the current index stays to be difficult parameter to quantify concisely in a metric.

- Patch Density (PD) index identified as a potential discriminator of landscape pattern has been observed to provide more information. Based on the results of Bailey et al. (2007) paper, they suggested the inclusion of PD and a landscape composition parameter for the study of landscape of low thematic resolution. According to McGarigal and Marks (1995), the density of patches in the entire landscape mosaic could serve as a good heterogeneity index because a landscape with greater patch density would have spatial heterogeneity. Miyamoto & Sano (2008) may easily monitor the future landscape condition using a PD index. In their analysis, the increase of patch density for young conifer plantations reflects the addition of many newly planted areas by extensive afforestation, whereas the increase of patch density for secondary forests reflects the dissection of patches by cutting across large areas of study. Finally, PD, which is an exception in Group A, is used by 13 authors out of 22, as this metric not only provides more information, but also may be easily monitored for landscape conditions.

- The proximity index is dimensional (has no units), and therefore the absolute value of the index has a little interpretive value; instead it is used as a comparative index (McGarigal and Marks, 1995). According to the results of Wenguang et al. (2008), the value of the proximity index for forest in all periods exceeded that of other patch types, but with an obvious decrease over time, is suggesting a forest fragmentation process over this period. The proximity index was suggested by Bailey et al. (2007) because although it has limitations, it has low correlations with other indices. However, due to the apparent sensitivity to the thematic resolution it has probably only suited for use in the complex defined landscape. Finally, Proximity index is used by 8 authors out of 15 because the proximity index may provide a useful indicator for the potential of a landscape to capture resources (Bastin et al., 2002).

- Number of Patches (NP) index was chosen because it is commonly implemented in forms of landscape monitoring and is relatively simple to use and to interpret (Dramstad et al., 2006). Furthermore, NP is probably most valuable, however, as the basis for computing other, more interpretable metrics (McGarigal and Marks, 1995). The NP is a measure of fragmentation of a given class within a landscape since the landscape size is constant (Lasanta et al., 2006; Sivrikaya et al., 2007). According to Olsen et al. (2007)'s results, the NP associated with each land cover class increased dramatically for the given period but thereafter fluctuated for bare areas and deciduous and mixed forest and continued to increase for pine and non-forested areas. In other words, NP underlies an assumption of habitat composition (Quine and Watts, 2009). At the end, NP is used by 11 authors out of 22, as the current metric is not only probably most valuable but also relatively simple for the use and interpretations.

In this chapter, Landscape Metrics retrieved using Remote Sensing Data. These metrics can become the inputs of the Environmental Indicators pointed to *Section 4.13 – The Combined / Composite Sustainable Development Index of* **Chapter 4 – The Sustainability Indices**, nevertheless the last index, i.e. Composite Sustainable Development Index is the most useful index of the current work.

CHAPTER 4

THE SUSTAINABILITY INDICES

The current chapter refers to the Sustainability Indices, where the attention is given to twelve (12) sustainability indices, which play an important role to the sustainable development. These twelve indices will be discussed in order support their roles in the sustainable development.

1. Ecological Footprint (EF):

At the heart of the ecological footprint concept is the recognition that closed-loop ecological systems provide the productivity needed to support human society (Rees and Wackernagel, 1996). Whereas this indicator is appealing and widespread, it is not perfect. Nourry (2008) presents below three main limitations:

(1) The ecological footprint construction is problematic because heterogeneous data are transformed into land units. Conversion methods are criticized (Neumayer, 2004b).

(2) The ecological footprint can be seen as an indicator of weak sustainability whereas proponents present it as a measure of strong sustainability. Although this indicator focuses on the environmental constraint on development, it does not include irreversibility or threshold effects. Furthermore, it should not be regarded as an indicator of strong sustainability.

(3) The last but not the least limit, is the lack of specific policy proposals based on ecological footprint analysis. If the goal is to reduce the ecological footprint to fit within the carrying capacity of the land, advocates of this indicator do not propose detailed policy advice.

2. Human Development Index (HDI):

United Nations (1990) developed an index called HDI which is a summary measure of human development in three basic dimensions:

- A long and healthy life;
- Knowledge;
- GDP per capita.

There are several limitations which are as follows:

- Dasgupta and Weale (1992); Hicks (1997); Sen (1997) are pointing to the idea that the HDI is not reflecting human development accurately;
- Mac Gillivray (1991); Srinivasan (1994); Noorbakhsh (1998) are criticizing the construction and technical properties of the index.
- Critics of Nourry (2008) also apply to the “green HDI”, which is an attempt to incorporate an ecological measure into the HDI (Desai, 1994; Lasso de la Vega and Urrutia, 2001; Costantini and Monni, 2004).
- Indeed, since economic and social variables are included, an environmental measure is missing in the HDI to be interpreted as a sustainable development indicator.
- HDI covers only a minor part of all aspects of sustainable development (Neumayer, 2001).
- Van de Kerk and Manuel (2008) concluded that HDI is very suitable for giving a rough idea of the level of development, though not on the sustainability of the development, particularly in developing countries.

3. Environmental Sustainability Index (ESI):

As WEF (2002a) described that the core components of the ESI include:

- Environmental systems;
- Reducing stress;
- Reducing human vulnerability;
- Social and institutional capacity;
- Global stewardship.

Despite the ESI has advanced the debate and available information, at the level of measurement, it does not provide a complete picture of environmental sustainability. Perhaps the biggest challenge to global comparisons, and the most serious weakness of the ESI, is the existent of relevant data (Johnson, 2002).

4. Index of Sustainable Economic Welfare (ISEW):

The Index of Sustainable Economic Welfare (ISEW) has been developed by C.W. Cobb (1989) to integrate environmental and social externalities in national welfare accounting. The ISEW is set to control the inflation-adjusted consumption of households. The time series of consumption values is adjusted by five categories to obtain a "GDP" which is more appropriate for measuring social welfare:

- Distribution of income;
- Economic activities not counted in the conventional gross national income;
- Time adjustments;
- Damage caused by economic activity;
- The consideration of net capital endowment of foreign investors.

Although the ISEW is calculated for some countries, these calculations were done by very different institutions and are hardly comparable (Cobb and Cobb, 1994; Cobb et al., 1995). Moreover, the ISEW is available for a limited number of countries only (Van de Kerk and Manuel, 2008).

5. Well Being Index (WI):

The Well-Being Assessment by Prescott-Allen (2001) is based on the assumption that a healthy environment is necessary for healthy humans and is the arithmetic mean of two (2) indices:

(i) Human Well-being Index (HWI):
  - Population and Health;
  - Welfare;
  - Knowledge;
  - Culture and Society;
  - Equity Index

(ii) Ecosystem Well-Being Index (EWI):
  - Index for the land deployment;
  - Index for the water deployment;
  - Index for the air deployment;
  - Index for the species deployment;
  - Index for the genes deployment.

The results and discussions of Distaso (2007) are that Greece, Ireland and Portugal present many values below the mean and are at the bottom of the range.

As a disadvantage, an excellent, therefore, rather comprehensive index was published only once to date (Van de Kerk and Manuel, 2008).

6. Gross Domestic Product (GDP):

The common usage of gross domestic product (GDP), which is suggested in the paper of Wilson et al. (2007), is for a broad measure of economic performance and progress. Very few people still consider GDP per capita to be a useful indicator for sustainable development. In that respect, other indicators, such as the ISEW (Daly and Cobb, 1989; Bleys, 2007) or the Dutch DNI (Duurzaam Nationaal Inkomen, Sustainable National Income) (Hueting, 1980), are far more indicative. Unfortunately, they cannot be used for the sustainable development, since these two indicators are available for no more than a couple of countries (Van de Kerk and Manuel, 2008).

7. Genuine Savings Index (GS):

Pearce and Atkinson (1993) put forward an index, which is based on the Hicksian income concept (see **Chapter 2 - Economic valuation of Biodiversity Loss** for the *Hicksian Demand Curve* and refer to *Figure 2.10*). In 1997 this index has been enhanced by Hamilton et al. (1997) using the Hartwick rule (Hartwick, 1977), which defines the level of re-investment from resource rents that are reinvested to assure that the societal capital stock will never decline. The societal capital stock includes:

- ➢ The capital produced in the industries;
- ➢ The capital of human skills and knowledge;
- ➢ The capital of natural resources.

However, the Genuine Savings (GS) Index is considered as an indicator for a weak Sustainable Development.

8. Sustainability Performance Index (SPI):

The Index of sustainable performance (SPI), as Singh et al. (2009) emphasized, is based on an operationalized form of the principle of sustainable development. Only process data is not used for the presumable unknown influence, but is used to know an early stage of planning and data of natural concentrations of the substances. The weakness of the present index is to evaluate the SPI from the underneath, i.e. to calculate the area needed to embed a process completely into the biosphere (Narodoslawsky and Krotscheck, 2004).

9. Sustainable Society Index (SSI):

For many people, the major concept of sustainable development focuses greatly on depletion of resources (Van de Kerk and Manuel, 2008). Others consider that sustainable development covers also irreversible pollution, conservation of nature and other environmental and ecological aspects. Some authors include the aspects of quality of human well-being and life. From an anthropocentric point of view, sustainability includes all three (3) elements:

1. The depletion of resources → not to leave future generations empty-handed;
2. Environmental and ecological aspects → to enable present and future generations to live in a clean and healthy environment;
3. The quality of life → to ensure present and future generations' life.

The weakness of the current index covers the concept, based on papers of (Van de Kerk and Manuel, 2008), where the created indicator rationale per five existent categories for the sustainable society index gives more power to the society rather than to the environment/ecology or to the natural balance.

10. The Sustainability Index (SI):

The weakness of the sustainability index is that the concept of what is meant by sustainability varies considerably. Even among scientists there are numerous definitions of sustainable development (Pearce, 1996). To be able to support a sustainable way of our planet's creatures, a clear definition of sustainable development is required. Moreover, one has to be able to measure the present level of sustainability and refer how deep is a need for the complete sustainable development (Lawn, 2004). Moreover, the concept of sustainability applies to integrated systems comprising humans and nature. The structures and operation of the human component (namely society, economy, government etc.) must be such that these reinforce or promote the persistence of the structures and operation of the natural component (namely ecosystem trophic linkages, biodiversity, biogeochemical cycles, etc.) and vice versa (Cabezas et al., 2005).

11. The Sustainable Development Index (SDI):

The deceptively simple definitions raise many issues, but the two of them are the followings (Escobar, 1996):

- How can we take a rational view of what future generations might need?
- How can we monitor our progress towards a sustainable future?

As Owens and Cowell (2002); Stimson et al. (2006); Sagoff. (2007) mentioned that the proper balance among what is often referred to as the "three Es":

- Environment;
- Equity—is central to the achievement of a sustainable future;
- Economy

12. The Combined / Composite Sustainable Development Index (CSDI):

The paper of Krajnc and Glavic (2005a) presents a designing of a composite sustainable development index (CSDI) that would assess performance as a function of time. The focus of the paper is a consideration how to integrate indicators in order to determine SD in a relevant and useful manner for decision-making. It concentrates on sustainability and it tends to move from trying to define SD towards developing a concrete model for promoting and measuring sustainability achievements. The paper organizes sustainability assessment for:

- The social performance.
- The economic performance;
- The environmental performance.

All twelve indices were described in the **Chapter 4**. Each index separately has its own significant role in sustainable development. However, the last index, i.e. Combined / Composite Sustainable Development Index (CSDI), is the most important in the evaluation of Sustainable Development. The core idea of the current thesis is based on the Combined / Composite Sustainable Development Index (CSDI).

4.1. INTRODUCTION

Few trends in society have been growing more steadily over the latest decades than society's concerns about current non-sustainable development, and society's increasing willingness to deal with this situation. This has led to an increased interest in the subject of ecology in general. The development of various concepts for efficient management and monitoring of sustainable development has gained worldwide acceptance (Robert, 2000). Ecological sustainability and implications of human consumption levels are two (2) aspects of global environmental change that many believe are not well-represented in money-based metrics of global environmental change (Senbel et al., 2003).

Interesting studies about the development of indices to evaluate the sustainability of countries had been published in the journal Ecological Economics (Pearce and Atkinson, 1993; Gilbert and Feenstra, 1994; Nilsson and Bergstrom, 1995; Azar et al., 1996; Stockhammer et al., 1997; Bicknell et al., 1998; Neumayer, 2001; Baloccoa et al., 2004; Siche et al., 2008) and other influential journals (Krotscheck and Narodoslawsky, 1996; Moser, 1996; Steinborn and Svirezhev, 2000; Barrera-Roldan and Saldıvar-Valdes, 2002).

Nourry (2008) used the widespread definition of the Brundtland Report (Our common Future, 1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It aims at assuring the on-going productivity of exploitable natural resources and conserving all species of fauna and flora". In Nourry (2008)'s view, two key ideas are expressed in this definition:

(i) Concern for the well-being of future generations;

(ii) Recognition of the bi-directional impacts between economic activity and the state of the environment and natural resources.

In this context, sustainable development takes into account human development and sustainability of such development. Within this broad definition, (Keiner, 2006) described two (2) main approaches as:

(a) *Weak sustainability* only requires a non-declining combined stock of all capitals. It is then possible to substitute between human, man-made and environmental capital. In this approach, natural capital is not different from other resources. The aim is to keep the stock of total capital constant or increasing, whatever the combinations of the three types of capital are.

(b) *Strong sustainability* gives an essential position to natural capital. It is a different form of capital without which human life cannot exist. Strong sustainability requires the maintenance of environmental functions and critical natural capital needed for the life of ecosystems. Therefore, models

> of strong sustainability incorporate real world constraints on the possibility of substitution between man-made, human and environmental capital. Contrary to weak sustainability that focuses on maintaining a combined stock of capital intact, strong sustainability deals with specific environmental functions that ought not to be undermined by economic activity and possible ecological limits to growth (Nourry, 2008).

According to Kates et al. (2001), the purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature–society systems in short- and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable. The need for an integral systematic approach to the indicators definition and measurement is recognized (Bossel, 1999) in order to give well-structured methodologies, easy to reproduce and to assure that all-important aspects are included in the measurement. However, before developing the methodology and the indicators what is needed is the clear definition of the policy goals towards sustainability (Jepson, 2007). This appears to be even more difficult since in most cases the development of indicators has started while there are still arguments over what constitutes sustainable development (Singh et al., 2009).

This article reviews the explanatory power of 12 sustainability indices (see *Table 4.1 – Twelve Sustainability Indices*) applied in policy practice. Different authors' opinions are provided to each index. The paper also compiles the information related to sustainability indices formulation strategy, scaling, normalization, weighting and aggregation methodology. It is shown that some of these indices fail to fulfill the fundamental scientific requirements making them rather useless if not misleading with respect to policy advice.

Table 4.1: Twelve Sustainability Indices

Index	*Authors*	*Scale / Normalization*	*Weighting*	*Aggregation*
1. *Ecological Footprint (EF)* *(Section 4.2)*	Barrett and Scott (2001) Bicknell et al. (1998) Bohringer and Jochem (2007) Fiala (2008) Finco and Nijkamp (2001) Gasparatos et al. (2008; 2009) Gnegne (2009) Hanley et al. (1999) Hong et al. (2007) Mitchell (1996) Moran et al. (2008) Nourry (2008) O'Regan et al. (2009) Rees and Wackernagel (1996) Robert (2000) Rosenstrom & Lyytimaki (2006) Scotti et al. (2009) Senbel et al. (2003) Siche et al. (2008) Singh et al. (2009) Tanzil and Beloff (2006) Van den Bergh & Verbruggen(1999) Van Vuuren and Smeets (2000) Wackernagel and Rees (1996) Wilson et al. (2007) WWF (2004)	Area	Equal	Summation $\sum_{i=1}^{N} x_i$
2. *Human Development Index (HDI)* *(Section 4.3)*	Bohringer and Jochem (2007) Fiala (2008) Gasparatos et al. (2009) Gnegne (2009) Halme et al. (2006) Moran et al. (2008) Morse (2004a ; 2004c) Nourry (2008) Ronchi et al. (2002) Singh et al. (2007; 2009) UNDP (2001) Van de Kerk and Manuel (2008) Wilson et al. (2007)	$\frac{x_i - \underline{x}}{\overline{x} - \underline{x}}$	Equal	The arithmetic average of the scaled indicators $\frac{1}{N}\sum_{i=1}^{N} x_i$

Index	*Authors*	*Scale / Normalization*	*Weighting*	*Aggregation*
3. *Environmental Sustainability Index (ESI)* *(Section 4.4)*	Bohringer and Jochem (2007) Fraser et al. (2006) Pan and Kao (2009) Rosenstrom & Lyytimaki (2006) Siche et al. (2008) Singh et al. (2007; 2009) Van de Kerk and Manuel (2008) Wilson et al. (2007) Zidansek (2007)	Mean subtraction and division by the standard deviation	Equal weights	The arithmetic average of the normalised indicators $\frac{1}{N}\sum_{i=1}^{N} x_i$
4. *Index of Sustainable Economic Welfare (ISEW)* *(Section 4.5)*	Bohringer and Jochem (2007) Cobb (1989) Gasparatos et al. (2008; 2009) Gnegne (2009) Halme et al. (2006) Hanley et al. (1999) Lawn (2003) Mitchell (1996) Nourry (2008) Ronchi et al. (2002) Singh et al. (2009) Van de Kerk and Manuel (2008)	Sub-indicators are expressed in monetary terms.	Equal. Allow the user to change the weightings and assumptions used in the index	Summation $\sum_{i=1}^{N} x_i$
5. *Well Being Index (WI)* *(Section 4.6)*	Bohringer and Jochem (2007) Distaso (2007) Prescott-Allen (2001) Singh et al. (2009) Van de Kerk and Manuel (2008) Wilson et al. (2007)	Best=100 worst=0	Subjective (not derived)	Weighted average $\frac{1}{N}\sum_{i=1}^{N} (w_i) x_i$
6. *Gross Domestic Product (GDP)* *(Section 4.7)*	Barrera-Roldan & Saldıvar-Valdes (2002) Fiala (2008) Khanna et al. (1999) Lawn (2003) Ledoux et al. (2005) Lin (2007) Mitchell (1996) Ronchi et al. (2002) Van de Kerk and Manuel (2008) Wilson et al. (2007) Zidansek (2007)	$I_{GDP} = \begin{cases} 0, if GDP \le GDP_{\min} \\ \frac{GDP - GDP_{\min}}{GDP_{\max} - GDP_{\min}}, if GDP_{\min} < \\ GDP < GDP_{\max} \\ 1, if GDP \ge GDP_{\max} \end{cases}$		
7. *Genuine Savings Index (GS)* *(Section 4.8)*	Bohringer and Jochem (2007) Hanley et al. (1999) Lin (2007) Nourry (2008) Randall (2008) Singh et al. (2009)	Monetized	Equal	Summation $\sum_{i=1}^{N} x_i$

Index	*Authors*	*Scale / Normalization*	*Weighting*	*Aggregation*
8. Sustainability Performance Index (SPI) (Section 4.9)	Singh et al. (2007; 2009)	Area	Equal	Total area per unit product divided by the area per capita
9. Sustainable Society Index (SSI) (Section 4.10)	Shi et al. (2004) Singh et al. (2009) Van de Kerk and Manuel (2008)	Mathematical formula for each indicator	Equal	Summation $\sum_{i=1}^{N} x_i$
10. The Sustainability Index (SI) (Section 4.11)	Bastida et al. (2008) Bene and Doyen (2008) Budd et al. (2008) Edum-Fotwe and Price (2009) Van de Kerk and Manuel (2008)	Mathematical formula for each indicator	Equal	Summation $\sum_{i=1}^{N} x_i$
11. Sustainable Development Index (SDI) (Section 4.12)	Barrera-Roldán & Saldıvar-Valdés (2002) Darton (2003) Noury (2008) O'Regan et al. (2009)	$SDI = \frac{1}{100}\sum_{i=1}^{3} WGC_j \frac{1}{n_j}\sum_{j=1}^{3} AG_{ji}$ Where WGC$_j$ is the weighting factor of the jth general criterion; AG$_{ji}$ grade obtained by the evaluated region corresponding to the ith attribute under the jth general criterion; n_j number of attributes under the jth general criterion.		
12. Combined / Composite Sustainable Development Index (CSDI) (Section 4.13)	Blanc et al. (2008) Gasparatos et al. (2008) Krajnc & Glavic (2005a; 2005b) O'Regan et al. (2009) Searcy et al. (2007) Singh et al. (2009) Tanzil and Beloff (2006)	Distance from max and min	Analytic hierarchy process (AHP)	Weighted average $\frac{1}{N}\sum_{i=1}^{N}(w_i)x_i$

4.2. ECOLOGICAL FOOTPRINT (EF)

The ecological footprint has its roots in the concept of the carrying capacity. As defined by biologists, carrying capacity is the number of individuals of a given species that a given habitat can support without being permanently damaged (Odum, 1989). If the population of a given species exceeds the carrying capacity of a given habitat, then either the resources required to meet the needs of that species will be depleted, or the wastes produced by that species will build up to the point of poisoning members of the species, or both and the population will crash (Senbel et al., 2003).

One of the most important contributions to the development of a sustainability indicator was given by Rees (1992) with the development of an index called "*Ecological footprint*" or *EF*. The original methodology consisted in the construction of a matrix "consumption/use of land". The objective of this index is to calculate the necessary land area for the production and the maintenance of goods and services consumed by a determined community (Wackernagel and Rees, 1996).

At the heart of the ecological footprint concept is recognition that closed-loop ecological systems provide the productivity needed to support human society (Rees and Wackernagel, 1996). The cycles may be geographically closer to people's daily lives, as in the case of a backyard vegetable garden fed by composted food wastes; or they may be far removed, as illustrated by the absorption of local CO_2 emissions by growing forests all over the world. The underlying premise of the ecological footprint is that the biophysical processes of the ecosphere support all human needs.

In the age of global trade, the closed-loop ecosystem affected by human activity is the entire globe. Hence, ecological footprint analysis estimates how much of the biophysical output of the earth is required to meet the resource consumption and waste absorption needs of a given community, region, state or continent (Vitousek et al., 1986; Rees, 1996, 2001). All measures are converted into hectares of land or water surface. Both the ecosystem areas required to produce consumable goods, and the ecosystem areas required to assimilate certain wastes associated with the production and consumption of these goods, are considered. Eco-footprint studies sometimes compare the estimated demand for land/water ecosystems with the readily available supply (e.g., Domestic Productive Land) to determine whether the study population and region could be self-sufficient (Rees, 1992, 1996; Wackernagel and Rees, 1996). Such analyses show that many high income countries (market-oriented consumer societies) are running significant 'ecological deficits' with the rest of the world.

A major contribution of EF as an index of consumption is to reveal the scale of such eco-deficits and to force explicit acknowledgement of how they are overcome. There are only two (2) ways to "support" a biophysical deficit. These two (2) ways are:

(i) The first is by over-exploiting and depleting domestic natural capital and thereby permanently is reducing local carrying capacity.

(ii) The second is by appropriating the biophysical surpluses of other regions either through commercial trade or by imposing on the global commons (e.g., by using the oceans or atmosphere as a waste dump or by exploiting open access fisheries) (Senbel et al., 2003).

Rees, Wackernagel and their colleagues have employed the EF as a simple metric for the study of human impact on nature in many different areas (Rees, 1992; Shawkat, 1995; Wackernagel and Rees, 1996; Wackernagel et al., 1999b; van den Bergh and Verbruggen, 1999; Chambers et al., 2000c; Costanza, 2000).

Measures of the potential productivity deficit or surplus of a region or state have been used in the EF analysis as potential measures of the degree of ecological risk, or, its obverse, ecological sustainability, of a given area. Implicit in this reasoning is the notion that the Earth as a whole cannot perpetually sustain ongoing ecological deficits, in which ecological productivity is mined and consumed rather than limited to the harvest of a regenerative yield. However, the EF in its current form does not have more specific indicators of the potential for ecological disaster such as the widespread loss of species and ecological services. Per capita ecological footprint calculations also do not include the provision of fresh water or the neutralization, storage or assimilation of toxic waste. Hence, the EF is only a crude indicator of the total ecological risk or the sustainability of a region. Other limitations in previous efforts at EF analysis have been the lack of attention to uncertainty in the estimates, and little attempt to determine how future scenarios of consumption and lifestyle choices may influence these measures. In the words of Rees, “Ecological Footprint analysis was not intended to provide a dynamic window on the future, but rather a snapshot in time. As such it can both help to assess current reality and to test alternative “what if” scenarios on the road to sustainability” (Rees, 2000).

Some writers have questioned aspects of the EF. One argument is that EF analysis has assumed greater certainty about waste absorption processes than is possible given current scientific knowledge (van Wooten and Bullet, 2000). Like any analysis, there are also many conceptual assumptions in the aggregation of different types of natural habitat (e.g., forest land, pasture land) and in the productivity of different land types in different parts of the world. Economists have questioned the lack of consideration of economic incentives in assessing the ecological productivity in different parts of the world. The output variation from country to country may have more to do with socioeconomic factors than purely biophysical or ecological factors (van Wooten and Bullet, 2000). While the study presented in this paper demonstrates that EF calculations can be made to reflect different socio-economic and management regimes, the lack of social or distributional considerations in EF models serve to distance them from the realities of Policy Development and Analysis.

On the other hand, the EF has several advantages that make it a potentially useful metric for integrated assessment (IA) and other simulation-modeling efforts.

(i) One advantage lies in what the EF does not assume, in contrast to what many other models take as a standard assumption. The EF does not assume the possibility of substituting ecological productivity for other outputs, such as capital or income. In contrast, economic models widely assume that substitution across different kinds of variables is widely achieved at the market-clearing price. Hence, the EF highlights the potential conflicts and difficulties that could arise when substitutability of capital or labor for ecological productivity proves impossible.

(ii) A second advantage is that, like other aggregate indicators, it reduces and simplifies complex resource use patterns to a single number (Costanza, 2000). The advantage over other aggregate indicators is that EF is easy to communicate and understand, as evidenced by the growing number of uses of and references to this concept. It considers if in only gross terms, the ecological issues associated with consumption and waste disposal, including waste in the form of CO_2 and other greenhouse gas emissions. It provides a graphic, tangible and conceptually simple unit for tracking sustainability. The higher the ecological deficit, the less sustainable the entity that is being measured. While the same relative simplicity is true of all aggregate indicators land area units are conceptually simpler than dollars or energy units.

The model presented by Senbel et al. (2003) is a synthesis of:

(i) The elements of integrated assessment, as captured through a simulation model;

(ii) The ecological footprint analysis in an uncertainty modeling environment.

Similar to other ecological footprint calculations, the model disaggregates different types of human consumption into land and ocean surface areas needed to produce the resources used in that consumption. It also separates factors influencing consumption and ecological production so that they can be independently manipulated to gain insight into their relative significance on EF calculations. The ecological footprint simulation model (EFSM) uses a 10-year temporal increment and takes advantage of the simplifying homogeneity of ecological footprint inputs. All inputs, with the exception of population and income, are in hectares.

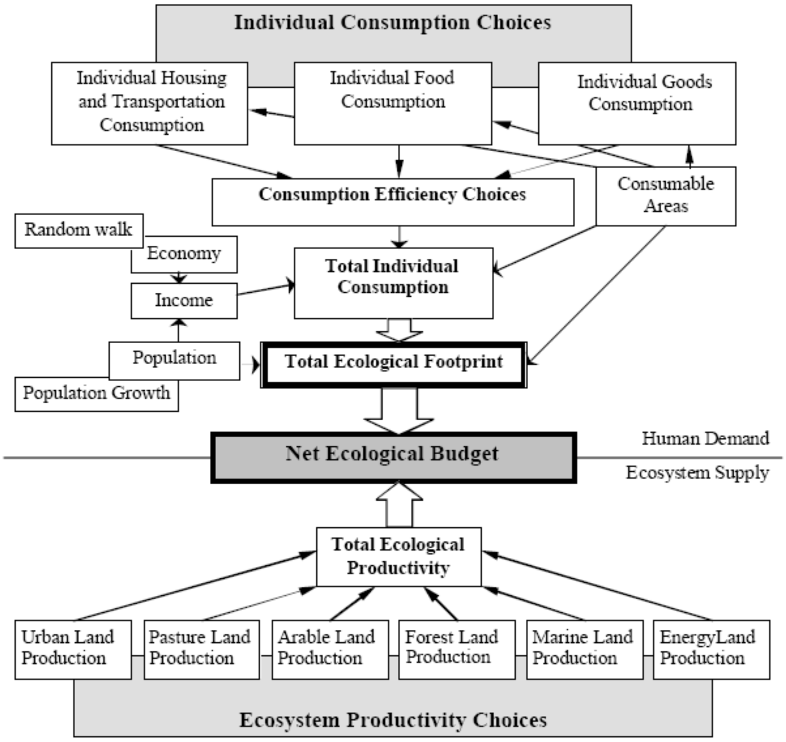
As summary of Structure of the EFSM model is depicted in *Figure 4.1*, where the basic concept of the model is a supply and demand system of accounting with the sum being the net ecological surplus or deficit in the study region. On the demand side (e.g., the top half of Structure of EFSM *in Figure 4.1*), human consumption comprises three distinct categories:

- ➢ Housing and transportation;
- ➢ Food and consumer goods;
- ➢ A categorization used by Wackernagel and Rees (1996).

Individual consumption in each of the categories is then aggregated and multiplied by a projected population in any given year. The supply side of the model uses information about the land area categories and their respective productivity within North America. Senbel et al. (2003) adapted a classification borrowing from both Wackernagel and Rees (1996) and Wackernagel et al. (1997). Senbel et al. (2003) used Wackernagel et al.'s ecosystem types:

- ❖ Urban land; developed to house humans and human institutions;
- ❖ Arable land, used for crop production;
- ❖ Pasture land, grazing land for raising livestock;
- ❖ Forestland, logged for the production of timber products.

Figure 4.1: Structure of the EFSM. Note: Arrows indicate the influence of one variable on the next. An independent variable has no arrows going into it and the model output, the ecological budget, is dependent on all others.



Source: Senbel et al. (2003)

The EF can be compared with the productive biological capacity of the available land and the sea to this population (WWF, 2005). The EF measures the demand for natural resources. For its creators, the EF is a measure of the impact of the population expressed in terms of the appropriate area; it is the surface of ecologically productive territory in the diverse categories:

- Arable lands;
- Pastures;
- Forests;
- Sea;
- CO_2 absorption area.

These categories are necessary to supply the resources of energy and matter that a population consume and to absorb its wastefulness considering its current technology (Wackernagel and Rees, 1996).

One characteristic term of this methodology is the bio-capacity or interest from natural capital. Thus, the bio-capacity measures the bio-productivity or biological productivity in an area. The average biological productivity of a hectare of the earth's productive surface area is called "global hectare" (gap) and is used as the common unit of comparison. Bio-productivity is the ability of a biome (e.g., arable land, pasture land, forest land, productive sea) to produce biomass, which is defined as the weight of organic matter, including animals, plants and micro-organisms (living and dead), above or below the soil surface. Thus, the biomes have different levels of bio-productivity. Some of it is built or degraded land. Bio-capacity is dependent not only on natural conditions but also on prevailing land use (e.g., farming use, forest use). The use of bio-productive area as an aggregate unit is a powerful and resonant means of measuring and communicating environmental impact and sustainability. It is crucial to note that the bio-capacity represents the theoretical maximum sustainable capacity for a year. While ecological overshoot by definition reveals the degradation of natural capital, the ecological remainder does not guarantee the sustainability of production. Rather, as the Footprint of production approaches the bio-capacity and the ecological remainder narrows, the likelihood that the country will experience environmental stress or degradation escalates, at least over longer periods of time (Siche et al., 2008).

In the EF, by comparing the demand with the available supply it is possible to estimate the ecological sustainability of territories or countries. A nation's ecological footprint correspond to the aggregate land and water area in various ecosystem categories to produce all the resources it consumes, and to absorb all the waste it generates on a continuous basis, using prevailing technology.

The calculation of the EF for a country implies basically:

(a) Calculation of the footprint (= Consumption × Equivalence Factor / Global Yield), considering categories of products (e.g., cropland, forestland, and fishing);

(b) Calculation of the Bio-capacity (= Bio-productive Area × Yield Factor × Equivalence Factor) for each category. Finally, it is possible to calculate the Ecological Balance (= Bio-capacity − Footprint).

According to Monfreda et al. (2004) a Footprint greater than total Bio-capacity indicates that demands exceed the regenerative capacity of existing natural capital. For example, the products from a forest harvested at twice its natural regeneration rate have a Footprint twice the size of the forest. They call the amount of overuse “ecological deficit”. Ecological deficits are compensated in two (2) ways:

(a) Either the deficit is balanced through imports, resulting in “ecological trade deficit” or, as in this forest product example;

(b) The deficit is met through the overuse of domestic resources, leading to natural capital depletion (“ecological overshoot”) (Siche et al., 2008).

A detailed description of this index can be found in Wackernagel and Rees (1996); Wackernagel and Rees (1997b) and Monfreda et al. (2004), some recent modifications by the calculation in Wiedmann et al. (2006), Venetoulis and Talberth (in press), and the calculation for 149 countries in the Living Planet Report 2006 (Hails et al., 2006). In addition, global results were released as part of Living Planet Report at 2000, 2002 and 2004. An update was also released in 2004 by the environmental think-tank Redefining Progress as part of their Footprint of Nations report. Data used for this study was based on findings from that update. The Global Footprint Network currently maintains the global ecological footprint accounts. Updates are released annually as part of the Living Planet Report series (Wilson et al., 2007; Cocciufa et al., 2006; Loh et al., 2005).

The ecological footprint quantifies the total area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate its wastes (Rees and Wackernagel, 1996). According to Wackernagel et al. (1999b) the ecological footprint methodology assumes that it is possible to keep track of all the materials and human services required to sustain a human population and assimilate its wastes by converting most of them to a corresponding biologically productive area. Since different productive lands produce different commodities and to differing degrees a common denominator, the global hectare (gha), is employed in its calculations (Gasparatos et al., 2009).

According to Van den Bergh and Verbruggen (1999), convert everything a person consumes (house, mobility, energy, food, recreation, etc.) and what is needed to produce all these items, in the required area on earth, the number of hectares per capita. The Ecological Footprint only partly covers sustainability in its wider sense. There is still quite some discussion about the calculation methodology used.

Van de Kerk and Manuel (2008) concluded that a valuable index for providing a quick and inspiring idea about the seriousness of the present lack of sustainability.

They encourage people to take action. However, the Footprint is not suited for giving a good idea of sustainability in its broadest sense.

Ecological footprints (Gnegne, 2009) are a measure of the amount of carrying capacity appropriated by human activity, with carrying capacity being the maximum population size that can be supported by a given set of resources. Material flow accounts (MFA) sum, with weights and on an annual basis, all the material inputs and outputs of an economy; and other hybrid indicators (combine physical capital and monetary policy) are among the strongest sustainable development indicators. Each of these weak and strong sustainable development indicators has its limits. For further discussion, refer to Dietz and Neumayer (2007).

Ecological Footprint (EF) was calculated and expressed as per capita, per settlement. Component footprints were aggregated to provide a total footprint per capita, per settlement. For ease of comparison, settlement footprints were normalized to the value of the settlement with the smallest footprint. Ecological footprints were adopted as the metric for calculating sustainability as it measures resource use intensity and includes energy consumption, and is effective in communication with non-technical stakeholders (O'Regan et al., 2009).

The ecological footprint (EF) measures the demands humans place in nature. It provides a quantitative assessment of the biologically productive area (the amount of nature) required to produce the necessary resources (food, energy, and materials) and to absorb the wastes of a given population (Wackernagel and Rees, 1996). If the human load exceeds the productive capacity of the biosphere then consumption patterns are clearly not sustainable given current circumstances. The human load can vary depending on the population, technology and eco-efficiency. The ecological footprint therefore, ultimately measures the sustainability of human consumption patterns (Wilson et al., 2007).

The Ecological Footprints (EF) (Wackernagel and Rees, 1997a) are based on the quantitative land and water requirements to sustain a (national) living standard into infinity thereby assuming certain efficiency improvements. The ratio of required resources of available resources is interpreted as a measure of ecological sustainability: ratios exceeding one are seen as unsustainable, i.e. contemporary living standards would violate the principles of sustainable development. Calculation of the EF is based on data from national consumption statistics. Thus, the EF primarily relies on normalization (as any consumption has converted for land use). Weighting is rather implicit in the conversion parameter and aggregation is done by adding up all land and water requirements (Bohringer and Jochem, 2007; Singh et al., 2009). There are several approaches similar to the EF, e.g. the MIPS (Material-Input-Per-Service) concept (Schmidt-Bleek, 1994), the Sustainable Process Index (Narodoslawsky and Krotscheck, 2004; Gassner and Narodoslawsky, 2004) or the Ecoindex™ (Chambers and Lewis, 2001).

The Ecological Footprint, (henceforth EF) measures the biologically productive area needed to sustain a certain human community (Rees, 1996; Wackernagel and Rees, 1996; Chambers et al., 2000b; Wackernagel and Silverstein, 2000) or process (De Leo et al., 2001). Because of its intuitive meaning and ease of computation it has rapidly taken ground as a tool for assessing the human pressure on natural resources and ecosystem services. Its recent inclusion in the European Common Indicators Programme (ECIP) confirms the importance assigned to this index (Simmons, 2003). In Italy EF has been calculated for regions, provinces and municipalities (Ambiente Italia, 2001a,b; WWF Italia, 2000, 2002a,b). EF has become a matter of interest because the impacts it measures, identified as exploited areas, may help define targets for remedial actions. Accordingly, it is perceived as a tool that helps to set up an agenda for local policies. However, its potential in this respect remains to be clarified. EF, in fact, is usually computed using the household Ecological Footprint scheme (Wackernagel et al., 2000, 2003) and this makes assessing certain impacts difficult. Consider, as an example, the impact due to electricity consumptions. EF quantifies the intensity at which the citizens use electricity, which, in turn, depends on everyone's lifestyle. Electricity is produced by power plants which emit CO_2, and a certain amount of forested land is thus required to absorb these emissions. In principle, this land requirement is shared among all the citizens who use electricity, and contribute to building up their EF. In general, they belong to different communities. However, the administrations which govern the territories that host the power plants are politically responsible for the emissions produced. To curb them they must take action and cannot rely on educational programs launched by other local administrations whose communities use the energy produced by the power plants (Scotti et al., 2009).

While Scotti et al. (2009) present our methodological approach to EF, the authors discuss also some important issues concerning its calculation. If this index has to be usefully employed in support of local policies, which imply decisions and effects at the different layers of the administrative hierarchy, homogeneity is required in the way it is calculated so that information can be shared about constraints and priorities for action. Presently, there are studies based on the spreadsheet of Ecological Footprints of Nations (Wackernagel et al., 1997, 1999 a,b; Loh et al., 1999, 2000, 2002, 2004; Monfreda et al., 2004), others that use the household Ecological Footprint (Chambers et al., 2000a; WWF Italia, 2000, 2002a,b) and projects combining both approaches (Wackernagel, 1998). Moreover, within the same scheme of calculation there are differences as for type of categories considered and conversion factors adopted to transform impacts into global hectares (gha). Undoubtedly, a unique approach to calculation is prerequisite for EF to become an effective tool of governance.

Wackernagel and Monfreda (2004) pointed to the land requirement that makes up the EF is apportioned to six (6) main area types:

(i) Cropland (crops for food, animal feeding, fiber and oil);
(ii) Grazing land (to produce meat, hides, wool and milk);

(iii) Forest area (e.g. harvesting trees for timber or paper making and gathering fuelwood);
(iv) Fishing ground (fish for human consumption);
(v) Built up land (e.g. areas occupied by infrastructures for industrial activities, transportation and housing);
(vi) CO_2 area.

The extension of each area type required to sustain consumptions of resources or goods is obtained dividing their amount by specific coefficients of production:

$$Area_i(ha) = \frac{Consumption(t)}{Yield(tha^{-1})}$$

In Equation above, i stands for the ith area type and Yield is the number of tonnes per hectare (tha^{-1}) used to compute the area required to get each Consumption (t) from the land type i. Then, any Are a_i calculated corresponds to a consumption pattern.

Area types are summed up to obtain the EF value. To make this calculation consistent on a global scale, the value obtained for each land type is converted into global hectares (gha), a standardized unit of biologically productive area that is characterized by an ideal productivity equal to the average of the whole 11.4 billion bio-productive hectares (ha) on earth. This is done by using specific Ecological Footprints and known as Equivalence Factors and represented in *Equation 4.1*:

Equation 4.1: Ecological Footprint

$$EF(gha) = \sum_{i=1}^{n} Area_i(ha) \cdot EquivalenceFactor_i(ghaha^{-1})$$

Where n stands for the total number area types (n=6).

Equivalence Factor for cropland is 2.17 $ghaha^{-1}$, meaning that 1 world average cropland hectare produces 2.17 times more than 1 global average bio-productive hectares ($gha\ ha^{-1}$) (Wackernagel and Rees, 1996).

Bio-capacity (B) quantifies productive land at the disposal and it is computed as in *Equation 4.2.*

Equation 4.2: Bio-capacity

$$B(gha) = \sum_{i=1}^{n} Area(ha) \cdot EquivalenceFactor_i(ghaha^{-1}) \cdot YieldFactor$$

In which the Yield Factor (Wackernagel and Rees, 1996), specific for each area type, relates local productivity to world average productivity (i.e. Yield Factor bigger than 1 means that local productivity is lower than global average productivity). The ecological footprint is then subtracted from Bio-capacity to establish whether the community runs an Ecological Deficit which is computed in *Equation 4.3*.

Equation 4.3: Ecological Deficit

$$Eco\log icalDeficit(gha) = Biocapacity(gha) - EF_{Consumption}(gha)$$

The ecological footprint's objective is "to translate all the ecological impacts of human activity into the area required to produce the resources consumed and assimilate the wastes generated under the predominant management and production practices in any given year" (Neumayer, 2004b). The ecological footprint is a physical indicator of sustainability expressed in land units. It compares human consumption of natural resources with planet Earth's ecological capacity to regenerate them and absorb the corresponding waste. The ecological footprint is defined as the amount of biologically productive land area required supporting the consumption of a given population. If the ecological footprint is higher than the existing land area, current consumption is not sustainable since the carrying capacity of the land is exceeded. In other terms, economic activity, responsible for the ecological footprint, is unsustainable. Empirically, energy, food and timber consumption per capita are transformed in terms of land area needed to produce these amounts. The sum is then compared with the amount of available productive land area per capita (Nourry, 2008).

Whereas this indicator is appealing and widespread, it is not perfect. Nourry (2008) presents below three main limitations.

(1) The ecological footprint construction is problematic because heterogeneous data are transformed into land units. Conversion methods are criticized. For example, not all the aspects of economic activity can be integrated into the index because of the lack of means of conversion into physical units (Neumayer, 2004b).

(2) The ecological footprint can be seen as an indicator of weak sustainability whereas proponents present it as a measure of strong sustainability. Although this indicator focuses on the environmental constraint on development, it does not include irreversibility or threshold effects. In fact, even if the ecological footprint is lower than the carrying capacity of the ecosystem, it is possible that some critical ecological thresholds have been exceeded. There are no constraints on the substitution between different kinds of natural capital. In this context, it should not be regarded as an indicator of strong sustainability.

(3) The last but not the least limit, is the lack of specific policy proposals based on ecological footprint analysis. If the goal is to reduce the ecological footprint to fit within the carrying capacity of the land, advocates of this indicator do not propose detailed policy advice.

Nevertheless, the ecological footprint gives a general policy recommendation that is to reduce the rate of resource throughput. This could lead to more precise policy proposal concerning resource use efficiency and means to respect regenerative and waste assimilative capacities of resource stocks.

4.3. HUMAN DEVELOPMENT INDEX (HDI)

The Human Development Index (HDI) of the United Nations is a summary measure of human development in three basic dimensions:

(ii) A long and healthy life;
(iii) Knowledge;
(iv) GDP per capita (United Nations, 1990).

Essentially, HDI is a measure of current well-being, which measure in three dimensions:

(i) Health by life expectancy at birth;

(ii) Education by adult's literacy before 1991, mean years of schooling for 1991–94, and a combination of adult literacy rate and an enrollment rate thereafter;

(iii) Access to resources needed for an acceptable standard of living, by real per capita GDP in purchasing power parity dollars. GDP has been criticized because it's more a measure of economic capability and ignores the other dimensions of human well-being.

Human deprivations have 3 sources:

- Natural disasters;
- Human vices;
- Institutional factors.

The problem is that many deprivations are not quantifiable. Amartya Sen worked on and showed the different forms of human deprivations and their causes. That allowed the UNDP to construct the three (3) deprivation indices that enter into the calculation of HDI. HDI has the general merit of being an aggregate measure of welfare calculated every five year on a consistent basis, and available for a large number of countries over the period 1970–2009 (UNDP, 2002; UNDP, 2004; Morse, 2004a; Gnegne, 2009).

The human development index (HDI) was first developed in 1990 and has been released annually thereafter. Data used for this study are from the 2004 Human developments reporting entitled Cultural Liberty in Today's Diverse World. It is used as a proxy of sustainability based on the rationale that high human development facilitates sustainable development (Wilson et al., 2007).

The HDI has a strong focus on the social dimension of SD. Each sub-index of Development Index (*DI_i)* is calculated as *Equation 4.4.*

Equation 4.4 Development Index: $DI_i = (x_i - \underline{x}) / (\overline{x} - \underline{x})$

Where x_i denote the country i and $\overline{x}(\underline{x})$ are Bohringer maximum (minimum) values per I region (Bohringer and Jochem, 2007). The indices are formulated based on minimum and maximum values (goal posts) for each indicator and performance in each dimension is expressed as a value between 0 and 1 (Singh et al., 2009).

Methodological limits while weighing/aggregating the indicators have attracted some attention within the literature. Munda and Nardo (2005a) have shown that the weights do not always retain their status as value judgements within a composite index. This is particularly evident in composite indices utilizing linear aggregation where the assigned weights end up gaining a trade-off status which implies complete substitutability between the indicators of the composite index (Gasparatos et al., 2009). A characteristic example of such composite indices is the Human Development Index (UNDP, 2006). In such a composite index an indicator (e.g. economic output) has the ability to compensate for a lower performance of another indicator (e.g. depletion of natural resources). The substitutability between the components of the DI implies the existence of tradeoffs and renders aggregated DI weak sustainability tools. The existence of a perfect aggregation technique for ranking alternative options (e.g. alternative designs, policies, etc.) has been questioned by Arrow (1963) as quoted by Munda and Nardo (2005b).

Critics are related either to the idea that the HDI is not reflecting human development accurately (Dasgupta and Weale, 1992; Hicks, 1997; Sen, 1997) or to the construction and technical properties of the index (Mac Gillivray, 1991; Srinivasan, 1994; Noorbakhsh, 1998). In this context, such critics also apply to the “green HDI”. Nourry (2008) refers “green HDI” to the attempts of incorporation of an ecological measure into the HDI (Desai, 1994; Lasso de la Vega and Urrutia, 2001; Costantini and Monni, 2004). Indeed, since economic and social variables are included, an environmental measure is missing in the HDI to be interpreted as a sustainable development indicator.

HDI covers only a minor part of all aspects of sustainable development (Neumayer, 2001). Van de Kerk and Manuel (2008) concluded that HDI is very suitable for giving a rough idea of the level of development, though not on the sustainability of the development, particularly in developing countries. For developing countries the HDI is less valuable due to the limited information it contains.

4.4. ENVIRONMENTAL SUSTAINABILITY INDEX (ESI)

The environmental sustainability index (ESI) is a composite index targeting environmental, socioeconomic and institutional indicators as a means to assess sustainability. As WEF (2002a) described that the core components of the ESI include:

- Environmental systems;
- Reducing stress;
- Reducing human vulnerability;
- Social and institutional capacity;
- Global stewardship.

The environmental sustainability index was first developed in 1999 by the World Economic Forum’s (WEF’s) Global Leaders for Tomorrow Environment Task Force, the Yale Centre for Environmental Law and Policy (YCELP) and the Columbia University Centre for International Earth Science Information Network (CIESIN) (Wilson et al., 2007).

The ESI was developed by a group of researchers of the universities of Yale and Columbia and presented formally in 2000 in World Economic Forum (Annual meeting 2000, Davos Switzerland) for Kim Samuel-Johnson and Daniel C. Esty. The ESI, first published in 2001 and subsequently in 2002 and 2005, has seen increasing popularity at least in the popular media (Morse, 2004b; Morse and Fraser, 2005) and has been overtly linked in the press to the rule of law (Economist, 2002). The increasing popularity of the ESI is in part related to the fact that it is promoted by the powerful World Economic Forum (WEF), and its release coincides with high-profile WEF meetings. Sutton and Costanza (2002) mentioned in their paper, that the ESI is by no means the only index or indicator of sustainability and an approach also gaining in interest is the estimation of Critical Natural Capital.

“The ESI score quantifies the likelihood that a country will be able to preserve valuable environmental resources effectively over the period of several decades” (Esty et al., 2005). Up to now, the ESI has been calculated three times (ESI, 2001, 2002, and Esty et al., 2005). Since the composition of the indices has been changed from calculation to calculation, it is hardly possible to compare the three rankings on the sustainable performance of countries. The actual ESI 2005 consists of five components which are based on 21 indicators. The 21 indicators are again derived from 76 variables. While normalizing those variables, the standard deviation is calculated of each (normal distributed) variable. The three aggregation steps consist of arithmetic means with equal weights (Bohringer and Jochem, 2007).

The 2002 environmental sustainability index (ESI) is a measure of the overall progress towards environmental sustainability developed for 142 countries (Singh et al., 2009). The ESI is based upon a set of 68 basic indicators. These are then aggregated to construct 21 core indicators. The Environmental Sustainability Index value for each economy is simply the average value of the 21 factors. For every variable in our data set we created a normalized range and scaled values from 0 (low sustainability) to 100 (high sustainability) (WEF, 2002b).

Siche et al. (2008) consider the five dimensions of the ESI-2005, namely:

1. Environmental systems:

    - Air;
    - Water;
    - Land;
    - Biodiversity.

2. Stresses:

    - Situations of very critical of pollution;
    - Any excessive level of exploration of natural resources.

3. Human vulnerability:

    - Nutritional situation;
    - The environmental illnesses.

4. Social and institutional capacity

    - Capacities that allows the dealing with of problems;
    - Capacities that allows the dealing with of environmental challenges.

5. Global stewardship:

    - Efforts of the international cooperation of the global responsibility;
    - Representative projects of the international cooperation of the global responsibility.

ESI covers the whole range of aspects of sustainable development in its broadest context. However, the Gender-Related Index is absent in the ESI and Good Governance receives only minor attention. ESI supplies a lot of relevant and valuable information, but is not very transparent due to the great amount of data (Williams et al., 2002). It is uncertain whether an update will be made (Van de Kerk and Manuel, 2008).

To assess the progress of improving the environmental sustainability, indicators are frequently used to measure that progress (Hezri and Hasan, 2004; Wilson et al., 2007). For instance, the Environmental Sustainability Index (Esty et al., 2005) is a typical example of these indicators (Pan and Kao, 2009).

According to ESI, environmental sustainability is a fundamentally multi-dimensional concept. Environmental sustainability is the ability to maintain valued environmental assets over the next several decades and to manage problems that emerge from changing environmental conditions (Esty et al., 2005).

The ESI is an index applied in the evaluation of nations' sustainability, being its main objective to establish a way of comparison of the sustainability of countries. To assist in the comparisons across countries with similar profiles, a cluster analysis is used. Cluster analysis provides a basis for identifying similarities among countries across multiple dimensions.

Siche et al. (2008) represented the method for the calculation of the ESI is the following one:

(a) Election of the countries (based in the country size, variable coverage and indicator coverage);
(b) Standardization of the variables for cross-country comparisons;
(c) Transformation of the variables (for imputation and aggregation procedures);
(d) Substitution of missing data using the multiple imputation algorithm;
(e) Winsorization of the data;
(f) Aggregation of the data to indicator scores i.e. the final ESI score.

In the web site of ESI (http://sedac.ciesin.columbia.edu/es/ESI/) historical data, reports, methodology and detailed descriptions of this index can be found.

Though the ESI has advanced the debate and available information, at the level of measurement, it does not provide a complete picture of environmental sustainability. Perhaps the biggest challenge to global comparisons, and the most serious disadvantage of the ESI, is the availability of relevant data (Johnson, 2002).

4.5. INDEX OF SUSTAINABLE ECONOMIC WELFARE (ISEW)

There is an overwhelming volume of literature commenting on the use of economic analysis for measuring a shift towards sustainability, e.g. (Pearce, 1993; Goldin and Winters, 1995; Pezzey and Toman, 2002a; Neumayer, 2004a). Only key ethical and methodological criticisms of certain commonly used monetary tools will be discussed by Gasparatos et al. (2009) in order to explain both some of the boundaries of economic valuation/aggregation and the discontent that has arisen over the validity of economic analysis in sustainability assessments. A detailed analysis of economic tools such as the Contingent Valuation Method, the Cost Benefit Analysis and the

Index of Sustainable Economic Welfare (ISEW), particularly concerning their methodological limitations, are included in Gasparatos et al. (2008).

The Index of Sustainable Economic Welfare (ISEW) has been developed by C.W. Cobb (1989) to integrate environmental and social externalities in national welfare accounting. With some modifications to the original accounting method (among others Cobb and Cobb, 1994), the ISEW has been relabeled to the Genuine Progress Indicator (Cobb et al., 1995). Although the ISEW is also calculated for some countries, these calculations were done by very different institutions and are hardly comparable.

The starting point for the ISEW is the inflation-adjusted consumption of households. The time series of consumption values is adjusted by five categories to obtain a "GDP" which is more appropriate for measuring social welfare:

(i) Distribution of income;
(ii) Economic activities not counted in the conventional gross national income;
(iii) Time adjustments;
(iv) Damage caused by economic activity;
(v) The consideration of net capital endowment of foreign investors.

As all adjustments are monetarized (normalization and weighting), the sum is used for aggregation (Bohringer and Jochem, 2007).

The index of sustainable and economic welfare (ISEW) is one of the most advanced attempts to create an indicator of economic welfare, developed by the Centre for Environmental Strategy (CES) and the New Economics Foundation (NEF). The main objective is to measure the portion of economic activity that delivers welfare to people (Singh et al., 2009). It aims further to replace GDP as an indicator of progress, because GDP is likely to lead in the wrong direction given that it does not distinguish between activities that improve or directly damage the quality of life (CES, 2000). The set of 20 sub-indicators includes seven economic activities that deliver welfare to people, such as adjusted consumer expenditure, services from domestic labor, from consumer durables, from streets and highways, public expenditure on health and education, net capital growth and net change in the international position. On the other hand, Guenno and Tizzi (1998) described the thirteen (13) indicators that ''reduce'' the welfare. These thirteen (13) indicators are defined as:

- Consumer durables (difference between expenditure and value of services);
- Defensive private expenditures on health and education;
- Cost of commuting;
- Cost of personal pollution control;
- Cost of automobile accidents;
- Cost of water pollution;
- Cost of air pollution;

- Cost of noise pollution;
- Loss of natural habitats;
- Loss of farmlands;
- Depletion of non-renewable resources;
- Cost of ozone depletion;
- Costs of climate change.

The idea of the ISEW is to adjust the Gross Domestic Product of a country for costs that are currently not included in the GDP and/or are consciously accelerated to the future, namely:

- The environmental pollution costs;
- The resources depletion;
- The traffic accidents cost;
- Domestic and voluntary labor matters.

Results are expressed in dollars. Conclusion: very valuable as a correction on the GDP. While taking GDP as a standard, it misleads the computation of sustainable development in a clear way. ISEW does not include the main aspects of quality of life and does not offer a clear insight into the level of sustainability of a country. The ISEW is available for a limited number of countries only (Van de Kerk and Manuel, 2008).

4.6. WELL BEING INDEX (WI)

The Well-Being Assessment by Prescott-Allen (2001) is based on the assumption that a healthy environment is necessary for healthy humans. Accordingly, the Well-Being Index (WI) is the arithmetic mean of two (2) indices:

(i) Human Well-being Index (HWI):

  - Population and Health;
  - Welfare;
  - Knowledge;
  - Culture and Society;
  - Equity Index

(ii) Ecosystem Well-Being Index (EWI):

  - Index for the land deployment;
  - Index for the water deployment;
  - Index for the air deployment;
  - Index for the species deployment;
  - Index for the genes deployment.

Not only HWI but also EWI are constructed from five (5) sub-indices are above presented. While, thirty six (36) indicators are grounds for HWI, fifty one (51) indicators are considered as a base of the EWI (Bohringer and Jochem, 2007). The aggregation of these dimensions is conducted by a weight of 10 for arithmetic means of further sub-indices or variables which are normalized again by a proximity-to-target approach using related indicators' targets (Prescott-Allen, 2001).

The wellbeing index (WI) is a composite index evaluating human and ecosystem wellbeing. This metric is based upon the philosophy that assessing the combination of these two elements offers insight into how close a country is to becoming sustainable (Wilson et al., 2007). Robert Prescott-Allen in collaboration with the International Development Research Centre (IDRC) and the World Conservation Union developed the Wellbeing Index in 2001. Comprehensive results of WI are released for 180 countries by them.

The results and discussions of Distaso (2007) are that Greece, Ireland and Portugal present many values below the mean and are at the bottom of the range. Greek National Committee for Combating Desertification (2002) wrotes that the case of Greece, whose big effort to enter the EU needs to be recognized is like an emblem. Greece, as a full EU member, must integrate and fully implement the laws formulated by the EU.

Only three (3) variables are above the mean:

- Consumption;
- Boys and girls expectancy;
- Health, which indicate a better lifestyle.

These three (3) variables are referred as above the means for countries as Italy, Spain and France. In short, the analysis of the ranges allows Distaso (2007) to assert that the number of countries with a negative score (below the mean and therefore less sustainable) is less than the number of the countries a positive score (above the mean and therefore more sustainable). This issue can be expressed as a positive sign in terms of human and sustainable development.

The Human Well-being Index and the Ecosystem Well-being Index cover the whole field of sustainable development and give an enormous amount of information, which makes it rather complicated. The way of presentation hampers its existent and therefore its use. At the end, an excellent, though the rather complicated index, published only once to date (Van de Kerk and Manuel, 2008).

4.7. GROSS DOMESTIC PRODUCT (GDP)

The common usage of gross domestic product (GDP) is for an economic productivity measure widely (Wilson et al., 2007). The GDP measure is considered to be a proxy with which to assess the economic performance and progress. Specifically, the GDP represents: "The sum of the gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Purchase power parity (PPP) GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States" (World Bank, 2005b).

Barrera-Roldan and Saldıvar-Valdes (2002) constructed the utility function of the economic general attributes the *Per Capita Gross Domestic Product (GDP) in Equation 4.5*, which is shown below:

Equation 4.5: Gross Domestic Product (GDP)

$$I_{GDP} = \begin{cases} 0, if GDP \leq GDP_{\min} \\ \dfrac{GDP - GDP_{\min}}{GDP_{\max} - GDP_{\min}}, if GDP_{\min} < GDP < GDP_{\max} \\ 1, if GDP \geq GDP_{\max} \end{cases}$$

The most well-known indicator — *GDP Per Capita (Gross Domestic Product Per Capita)* suggested by Van den Bergh (2007) to be left out, for obvious reasons. This is not surprising, since Economy is not explicitly included in the definition. Very few people still consider GDP per capita to be a useful indicator for sustainable development. In that respect, other indicators, such as the ISEW (Daly and Cobb, 1989; Bleys, 2007) or the Dutch DNI (Duurzaam Nationaal Inkomen, Sustainable National Income) (Hueting, 1980), are far more indicative. Unfortunately, they cannot be used in the SSI, since these two indicators are available for no more than a couple of countries (Van de Kerk and Manuel, 2008).

4.8. GENUINE SAVINGS INDEX (GS)

Pearce and Atkinson (1993) put forward an index, which is based on the Hicksian income concept (see **Chapter 2** **- Economic valuation of Biodiversity Loss** for the *Hicksian Demand Curve* and refer to *Figure 2.10*). In 1997 this index has been enhanced by Hamilton et al. (1997) using the Hartwick rule (Hartwick, 1977), which defines the level of re-investment from resource rents that are reinvested to assure that the (societal) capital stock will never decline. The Genuine Savings (GS) are thus an indicator of weak SD. The societal capital stock includes:

- The capital produced in the industries;
- The capital of human skills and knowledge;
- The capital of natural resources.

All values are monetarized, such that aggregation is again achieved by simply adding up (Bohringer and Jochem, 2007; Singh et al., 2009).

Genuine Savings (GS) stem from a theoretical model of maximization of a social welfare function, discounted at a constant rate, under the hypothesis of constant population and perfect substitution between all kinds of capital (Hamilton and Clemens, 1999; Neumayer, 2004b). Within this framework, it can be shown that the economy is unsustainable if its GS is inferior to zero (Pezzey and Toman, 2002b). Pearce and Atkinson (1993) refer to GS as to an extension of the Hartwick rule, i.e. if savings are superior to the aggregated depreciation of human, man-made and natural capital, an economy is sustainable. Based on the following operating specification, the World Bank computed GS in 2004 for 140 countries (Nourry, 2008):

GS = Gross national savings − fixed capital consumption + education expenditures − value of natural resources depletion − value of damages caused by pollutants (carbon dioxide and particulate matters).

Empirical results show that, during the period 1980–2000, OECD countries, as well as, East and South Asia never had negative GS; whereas many African nations and the Middle East had negative value of GS (World Bank, 2005a). Therefore, according to GS, the results for developed nations do not indicate unsustainability, whereas the most developing countries are dependent on exploitation of the natural resources.

Note that this indicator is a measure of weak sustainable development. Indeed, the condition for sustainability of the theoretical model is non-declining consumption and the total stock of capital on the optimal development path. Therefore, a constraint on natural capital is considered as a requirement. The substitution between human, man-made capital and environmental capital is out of boundaries. In this context, this indicator does not take into account irreversibility or threshold effects. Moreover, problems appear during the move from the theoretical definition to the operational one.

(1) The theoretical model supposes that the economy follows an efficient growth path. Therefore, prices used in the GS computation must be the optimal and sustainable prices. However, only current prices are available for empirical work and these prices are neither optimal nor sustainable (Pezzey and Toman, 2005). Since empirical values of GS are evaluated with incorrect data, conclusions on national sustainability based on this indicator must be used carefully.

(2) The methods used to compute natural resource depletion and damages from pollution are questioned. Neumayer (2000) uses an alternative method to assess resource depletion and this change has an impact on the value of GS: for countries with substantial reserves, GS changes from a negative to a positive value, transforming conclusions on the sustainability of those countries.

(3) GS is overestimated because the only damage from carbon dioxide and particulate matter is subtracted. Other environmental fields like biodiversity, water and soil are not included because of a lack of data, although these fields are absolute to assess national sustainable development.

To conclude, GS seems to be a partless and a not useful indicator for a weak sustainable development.

4.9. SUSTAINABILITY PERFORMANCE INDEX (SPI)

The Index of sustainable performance (SPI), as Singh et al. (2009) emphasized, is based on an operationalized form of the principle of sustainable development. Only process data is not used for the presumable unknown influence, but is used to know an early stage of planning and data of natural concentrations of the substances.

The current concept of Lundin (2003) comprises:

- The production of raw material, process energy and provided installations is required per area;
- The staff is required per area;
- The accumulation of products is required per available area.

The weakness of the present index is to evaluate the SPI from the underneath, i.e. to calculate the area needed to embed a process completely into the biosphere (Narodoslawsky and Krotscheck, 2004).

4.10. SUSTAINABLE SOCIETY INDEX (SSI)

“Consequences are all around us, as everything we do has a consequence. How can a more sustainable society with a different type of culture be growing?” As Hill (2001) asked “Maybe humans should live in and with, not “off” or beside the land and its creatures?”

The recently developed Sustainable Society Index, the SSI, has integrated for the sustainability and quality of life. At a glance of Singh et al. (2009), the SSI shows the sustainable development of a country, process and urgent required improvements.

For many people, the major concept of sustainable development focuses greatly on depletion of resources (Van de Kerk and Manuel, 2008). Others consider that sustainability covers also irreversible pollution, conservation of nature and other environmental and ecological aspects. Some authors include the aspects of quality of human well-being and life. From an anthropocentric point of view, sustainability includes all three (3) elements:

1. The depletion of resources → in order not to leave future generations empty-handed;

2. Environmental and ecological aspects→ in order to enable present and future generations to live in a clean and healthy environment;

3. The quality of life → in order to ensure present and future generations' life.

All three (3) elements are important while developing towards a sustainable society. The reason of those elements is that the IUCN, UNEP and WWF defined sustainable development as "To enhancing the quality of life and to live with the carrying capacity of the ecosystems" (IUCN/UNEP/WWF, 1991). The reason is clear that the sustainable development without quality of life makes no sense and quality of life without sustainable development has no perspective.

Another element, economy, is not explicitly included, though politicians often use the term "sustainable economy". However, the development of an economy is certainly not a condition for sustainability or a goal. The economy of a country has to be developed within the limits set of sustainability.

The core elements to assess the society sub-system are a sustainable progress for a quality of life and a sustainable change in population for a social welfare. The reflectance of the population status is to select population and natural birth rate. The regional education level and the population characteristics are referred as the number of students per thousand people. The target of sustainable development is sustainable improvements for quality of life and social welfare. Some factors, as to make better the human life, to care for the health of the people and to educate persons, are assessed by the quality of life and are based on the sustainable enhancement of social welfare and (Kretser et al., 2008).

As noted by Shi et al. (2004), the ground levels of infrastructures are affected by the people's quality of life are reflected from:

- Passenger transportation per thousand people;
- Telephone occupation per thousand of people;

- ➢ Water consumption per head;
- ➢ Power consumption per head.

The first level bears the society sustainability index (SSI). The current index is very general and shows the situations of general developments. The second level carries only 5 sub-references, which gives further knowledge of the first level index and leads to the categories of the third level references. The second level keeps no quantitative values. There are 9 reasonable references at the third level that reflect the features of the three sub-systems. The Reference System for Sustainable Society Index shows the system' references per three (3) levels *(See Table 4.2).*

Table 4.2: The Reference System for Sustainable Society Index

Level one	*Level Two*	*Level three*
Society sustainability index (SSI)	Population index	Number of population
		Natural birth rate
	Infrastructure level	Passenger transportation per thousand people
		Telephone occupation per thousand people
		Water consumption per head
		Power consumption per head
	Living standards	Income per head
	Health care	Number of hospital beds per thousand people
	Educational level	Number of students per thousand people

Source : Shi et al. (2004)

The well-known and worldwide respected definition of the Brundtland Commission (WCED, 1987) has been interpreted in more than two hundred ways (Pezzey, 1989; Solow, 1993a; Mebratu, 1998). To make explicitly clear that sustainable development includes all the three (3) aforementioned elements, the definition of Brundtland have extended by the concept that the qualitative aspects of human life are included. Van de Kerk and Manuel (2008) have the formulated Brundtland definition by Van de Kerk and Manuel (2008) as follows:

(1) A sustainable society is a society:

- That meets the present generation's needs,
- That does not compromise the ability of future generations to meet their own needs;
- Where each human has the chance to be developed freely, to be good everywhere and to grow the society properly.

(2) A sustainable society is a society where everyone can:

- Be developed in a healthy manner;

- Be educated properly;
- Live in a clean environment;
- Live in a well-balanced and safe society;
- Use non-renewable resources in a responsible manner so that future generations won’t be left empty-handed;
- Contribute to the sustainable world.

Van de Kerk and Manuel (2008); Singh et al. (2009) shows that the framework of the Index for a Sustainable Society carries several indicators per five (5) categories, refer to *Table 4.3*.

Table 4.3: Each Indicator Rationale per Category of Sustainable Society Index

Category	*Indicator*	*Rationale*
(1.) Personal Development	1. Healthy Life	Condition for development of each individual in a healthy way
	2. Sufficient Food	Condition for the development of an individual
	3. Sufficient to Drink	Condition for the development of an individual
	4. Safe Sanitation	Condition for the prevention and spread of diseases that would severely hamper a person's development
	5. Education Opportunities	Condition for a full and balanced development of children
	6. Gender Equality	Condition for a full and balanced development of individuals and society at large
(2.) Clean Environment	7. Air Quality	Condition for human and ecological health
	8. Surface Water Quality	Condition for human and ecological health
	9. Land Quality	Condition for production of crops, livestock and timber
(3.) Well-balanced Society	10. Good Governance	Condition for the development of all people in freedom within the framework of (international) rules and laws
	11. Unemployment	Access to the labor market is a condition of well-being for all people
	12. Population Growth	Limitation of population pressure on earth is a condition for sustainability
	13. Income Distribution	Fair distribution of prosperity is a condition for sustainability
	14. Public Debt	The measure of a country's ability to make independent decisions with respect to budget allocation

Category	*Indicator*	*Rationale*
4. Sustainable Use of Resources	15. Waste Recycling	A measure of sustainable use of raw materials in order to prevent depletion of resources
	16. Use of Renewable Water Resources	A measure of sustainable use of water resources in order to prevent depletion of resources
	17. Consumption of Renewable Energy	A measure of sustainable use of energy resources in order to prevent depletion of resources
(5.) Sustainable World	18. International Cooperation	The measure of a country's willingness to take up its responsibility for the world at large with respect to sustainability
	19. Ecological Footprint	A measure of people's (un)sustainable usage of the earth's resources
	20. Preservation of Biodiversity	Condition for perpetuating the function of nature, in all its aspects
	21. Emission of Greenhouse Gases	A measure of the main contribution to climate change, causing unsustainable effects
	22. Forest Areas	Preservation of forest area is a condition for sustainable development

Source: Van de Kerk and Manuel (2008)

The weakness of the current index represents the concept, based on the afore-created each indicator rationale per five existent categories, where the sustainable society index gives more power to the society rather than to the environment or to the natural balance.

4.11. THE SUSTAINABILITY INDEX (SI)

Development needs biodiversity and the services it delivers to be sustainable. Biodiversity and development are so intrinsically interrelated that it makes no sense to suppose that progress can be achieved separately (IUCN, 2006). The complexity and uncertainty underlying the functioning of biodiversity further contribute to the difficulty of the assessment. On the ecological side, Hooper and Vitousek (1997); Tilman et al. (1997); Borrvall et al. (2000); Tilman et al. (2005) actively investigated the incompleteness of scientific knowledge on relationships and interdependencies among species and the effects of biodiversity on the productivity, stability and sustainable development of ecosystems.

Bene and Doyen (2008) assume a proportional relation between these outputs H(t) and the extraction rate e, in the sense that *Equation 4.6*.

Equation 4.6: A Proportional Relation between These Outputs H(t) and the Extraction Rate e

$$H_i(t) = e_i N_i(t)$$

Been and Doyen (2008) then adopted a direct-use valuation framework (See Chapter 2 - **Economic valuation of Biodiversity Loss**, *Section 2.3 – Economic Foundations for Biodiversity Analysis and Valuation*) so that *the Total Utility Derived From the Exploitation of the Ecosystem E_n* is defined by the constant elasticity substitution (CES) function *Equation 4.7*:

Equation 4.7: The Total Utility Derived From the Exploitation of the Ecosystem E_n

$$U(H_1(t),H_2(t),...,H_n(t)) = (\sum_{i=1}^{n} \alpha_i H_i^{\beta})^{\frac{1}{\beta}} \, where \beta > 0$$

This CES function is a generalized form of the utility function. It includes in particular the linear case (β=1) and the Cobb Douglass case (β→+∞).

Bene and Doyen (2008) proposes to define the economic sustainability of the ecosystem E_n by the existence of a minimum guaranteed threshold measured in terms of utility U_{lim} under which the ecosystem E_n is said to be not economically viable, namely:

E_n is economically sustainable if $U(H(t)) \geq U_{lim}$; t=0,...,T

When accounting for uncertainty, the economic sustainability of ecosystem E_n is the probability that the total utility U(H(t)) derived from E_n's direct-uses remain above the guaranteed utility U_{lim}:

Definition: Consider a probability P on a set of scenario Ω. Assume that the parameters of the ecosystem En = (g, d, w, K, α) defined in the system (1) are a random vector on Ω. Assume further that initial conditions N_0 and R_0 and the economic parameters $\alpha€R^n$ are also defined randomly. The economic sustainability of ecosystem E_n is measured through the *Probability that the Ecosystem E_n Remains Sustainable* with respect to the minimal guaranteed utility U_{lim}, namely (*Equation 4.8*).

Equation 4.8: The Probability that the Ecosystem E_n Remains Sustainable

$$P_U(n,U_{\lim}) = P_{(E_n,N_0,R_0,\alpha)}\left[\min_{t=0,...,T} U(H(t)) \geq U_{\lim} \right]$$

Drawing upon aforementioned Definition above, Bene and Doyen (2008) define the marginal contribution of utility of the biodiversity level n as follows:

Definition: Consider any guaranteed utility U_{lim}. The marginal contribution $C_U(n,U_{lim})$ of biodiversity level n (n≥2) with respect to U_{lim} is defined by

$$C_U(n,U_{\lim}) = P_U(n,U_{\lim}) - P_U(n-1,U_{\lim})$$

Sustainability indexes $P_U(n,U_{lim})$ and marginal contributions $C_U(n,U_{lim})$ of E_n are computed through numerical simulations for different levels of species richness $n \leq 150$ and minimum guaranteed utility levels U_{lim}. For each simulation the initial conditions N_0 and R_0 and the system's parameters (g, d, w, K, α) are chosen randomly within [0,1]. Additional economic parameter α_i (which would correspond 1 to the prices in the case of a linear CES function) are also chosen randomly within [0,1]. Bene and Doyen (2008) use the intermediate case β=2 to run the simulations to show Economic Sustainability:

- Economic Sustainability: Probability P_U (n,U) in *Figure 4.2*, shows the sustainability indexes $P_U(n,U_{lim})$ as a function of the species richness n and the minimal guaranteed utility level U_{lim}. Furthermore, the Economic Sustainability: Probability P_U (n,U) shows that for any given minimal guaranteed level U_{lim} the sustainability index $P_U(n,U_{lim})$ increases with n, suggesting that species richness promotes economic sustainability.

- Economic Sustainability: Marginal Contribution C_U (n,U) in *Figure 4.3*, displays the associated marginal contributions $C_U(n,U_{lim})$. Moreover, Economic Sustainability: Marginal Contribution C_U (n,U), confirms that the marginal contributions $C_U(n,U_{lim})$ of the species is positive or zero for any combination (n,U_{lim}).

Conjecture: Ecosystem sustainability increases with species richness, and the marginal contribution of biodiversity is positive or nil for all n, in the sense that

$$C_U(n,U_{\lim}) \geq 0, \forall n \geq 2, \forall U_{\lim} > 0$$

Figure 4.3 – Economic Sustainability: Marginal Contribution C_U (n,U), also shows that the marginal contribution of biodiversity $C_U(n,U_{lim})$ is characterized by a maximum value with respect to guaranteed utility U_{lim} for any level of species richness n:

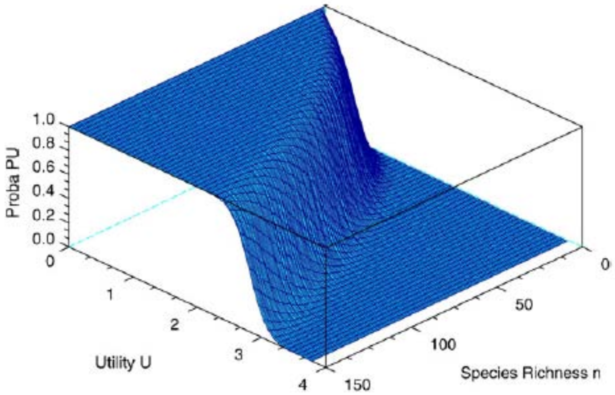
$$C_U^*(n) = \max_{U_{\lim} \geq 0} C_U(n,U_{\lim})$$

This maximum value, however, decreases with n, suggesting a decreasing marginal contribution of species richness to economic sustainability.

Conjecture: The marginal contribution of biodiversity $C_U(n,U_{lim})$ exhibits a maximum value $C_U^*(n)$ with respect to guaranteed utility U_{lim}. This maximum contribution decreases with the species richness level n, in the sense that:

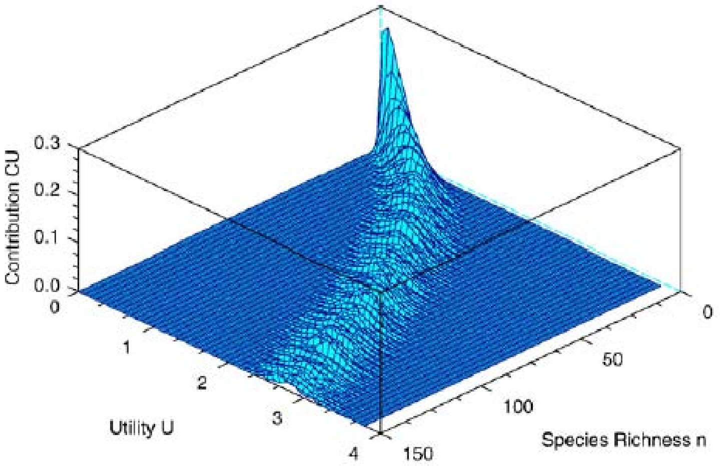
$$\frac{C_U^*(n+1)}{C_U^*(n)} < 1$$

Figure 4.2: Economic Sustainability: Probability P_U (n,U) as a function of utility of catch U and the species richness n for a CES utility function β=2



Source: Bene and Doyen (2008)

Figure 4.3: Economic Sustainability: Marginal Contribution C_U (n,U) as a function of utility of catch U and species richness n for a CES utility function β=2



Source: Bene and Doyen (2008)

The ecosystem is then assumed to be exploited and its performances are measured through its economic sustainability, that is, its capacity to generate direct-use values greater than a minimum utility level U_{lim}. A probabilistic framework is adopted and performances of the system are examined through numerical simulations mentioned above. The analysis of the numerical simulations suggests that biodiversity promotes conjointly the ecological and economic performances of the ecosystem as both ecological viability and economic sustainability increase with species richness (Conjectures). These results add pertinent elements to the current literature of biodiversity as they confirm the positive effect of biodiversity on ecosystem performances. While this conclusion in itself is not totally new (see e.g. Kinzig et al., 2002; Loreau et al., 2002; Tilman et al., 2005), the innovative part of work of Bene and Doyen (2008) comes from the fact that these conclusions are observed in parallel for ecological and economic criteria, using one single analytical framework.

Reducing the many different specific goals to a small set of general goals resulted in a synthesis into five broad categories, which subsume the various sustainable development goals identified by stakeholders (Gustavson et al., 1999):

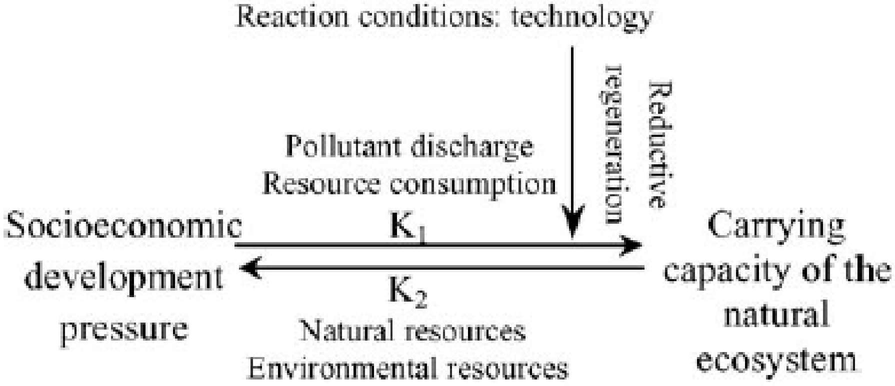
1. Maintain ecosystem integrity and diversity;
2. Meet the basic human needs for social and economic development;
3. Maintain intergenerational distribution and options;
4. Improve intra-generational distribution and entitlements;
5. Improve local decision making and empowerment.

The ecosystem approach is an inclusive framework that covers the natural environment including all relevant futures and constraints; population demographics and associated economic activities, resources use and development; the market forces governing economic development; public service institutions and facilities; and the existing regulation controlling all previous activities and population growth as well (Hannoura et al., 2006).

Moreover, according to Zhang et al. (2006), the goal of measuring and evaluating the interactions within the ecosystem is to optimize the relationship between man and nature. Unfortunately, the demands of socioeconomic development sometimes conflict with the need for environmental protection, as illustrated in *Figure 4.4* by An Equilibrium Model.

Furthermore, according to Kenzheguzin and Yessekina (2004), in the last 20–25 years the economic load on natural complexes dramatically increased and created a sharp problem of environmental protection from the excessive anthropogenic press. In the opinion of Feoli et al. (2002), to develop environmental protection strategies, it is necessary to have, among other things, a clear understanding of the relationships between the environmental variables influencing and constraining the availability of natural resources and the human population pressure in the rural system. In other words, it is essential to understand the rural system in its total complexity by integrating the information related to its environmental system with the information related to its socio-economic system.

Figure 4.4: An Equilibrium Model to represent social and economic development pressures and the support capacity of the ecological environment



Source: Zhang et al. (2006)

Two key factors must be addressed in creating a model to describe the many relationships within the ecosystem. Economic growth, especially at the present immature stage of the economy, often leads to resource shortages, puts enormous pressure on the natural environment, weakens the environment's capacity to support economic growth, and accelerates the rate of increase of pressure (*K*1) caused by socioeconomic development. In contrast, enhancing the capability of the environment to support socioeconomic growth can increase the natural environmental resources available to the socioeconomic system and can thus improve the natural ecosystem's ability to sustain socioeconomic development (*K*2). At the same time, technological factors should be addressed by the model. Technology can mitigate the impact of urban development and change the socioeconomic development pressure, leading to a new dynamic equilibrium between *K*1 and *K*2. According to Skidmore (2002) in any definition of sustainability a key element is changing; for example, Fresco and Kroonerberg (1992) define sustainability as the "… dynamic equilibrium between the input and output." In other words they emphasize that dynamic equilibrium implies change and that in order for a land to be sustainable. In the same way, Clementh (2000) discussed the equilibrium between the economic development and environmental gain.

By analyzing the feasible signals from the environment, it is possible to identify six fundamental properties of system environments (Bossel, 1999; 2000):

- *Normal environmental state:* The actual environmental state can vary around this state in a certain range.
- *Resource scarcity:* Resources (energy, matter, information) required for a system's survival are not immediately available when and where needed.
- *Variety:* Many qualitatively very different processes and patterns of environmental variables occur and appear in the environment constantly or intermittently.

- *Variability:* The state of the environment fluctuates around the normal environmental state in random ways, and the fluctuations may occasionally take the environment far from the normal state.

- *Change:* In the course of time, the normal environmental state may gradually or abruptly change to a permanently different normal environmental state.

- *Other actor systems:* The environment contains other actor systems whose behavior may have system-specific (subjective) significance for a given actor system.

The maintenance of soil quality is critical for ensuring the sustainability of the environment and the biosphere (Smith et al., 1993; Arshad and Martin, 2002), although this is a complex theme due to the importance of the climate, soil, plants, anthropic factors and their interactions. Indeed, soils are subject to natural or environmental degradation, often accompanied by erosion, leaching, even without human intervention (Popp et al., 2000).

Table 4.4: The Soil Quality Sustainability Index in Agro-Ecosystems

Authors	*Objective*	*Indicators used*
Kang et al. (2005)	Sustainability Index: Comparison of long-term effect of organic amendments in systems for cultivating maize and rice.	Organic C, total N, extractable K, extractable nitrates and ammonium content, microbial biomass C and N, mineralizable N, respiration, bacterial counts, mycchorhizal infection, dehydrogenase activity.

Source : Kang et al. (2005)

Despite the steps proposed on soil quality indices of Karlen et al. (1994a,b) and Andrews et al. (2002a,b) that have been the most widely used in establishing indices at both agronomic and environmental levels, some authors have looked at other alternatives. Kang et al. (2005) used a trigonometric approach based on three sub-indices (nutritional, microbiological and crop-related) to establish the Soil Quality Sustainability Index in Agro-Ecosystems (see *Table 4.4*).

From an environmental point of view, but taking into account the effects of soil management, Burguer and Kelting (1999) elaborated a soil quality index for pinewoods, using different soil functions and a method similar to that of Karlen et al. (1994a,b). The result was an index suitable for evaluating the sustainability of a forest soil in different management systems. These authors established a threshold above whose certain practices are sustainable and also discuss a series of considerations on the spatial scale, which is important for obtaining a model that functions on a larger scale. This index was subsequently applied by Kelting et al. (1999) to demonstrate the effect of different management practices on a forest to help choose the most suitable index for the sustainable development of a forest soil. For these authors, maintaining soil productivity was a criterion of sustainability initiatives (Bastida et al., 2008). An interesting approach to for the strategic environmental assessment is used by Marull et al. (2007), where giving an emphasis to the land suitability index (LSI).

Sustainability is very much in the spotlight these days. The mission of Al Gore and his film An Inconvenient Truth has contributed greatly to the present, the widespread sense of urgency. However, this feeling is mainly confined to climate change. But sustainability is more than climate change, however dramatically climate change might affect our future. Few people experience the same sense of urgency with respect to sustainability in its wider sense (Van de Kerk and Manuel, 2008). Adriaanse (1993) defines sustainability as either a ‘no-effect level’ or a ‘no-major-effect level’ of environmental impact. His approach involves aggregating measures of environmental stress into ‘theme equivalent units’ for different environmental themes, and normalizing these units of stress in terms of sustainability standard (Ekins and Simon, 2001).

The concept of what is meant by sustainability varies considerably. Even among scientists there are numerous definitions of sustainability (Pearce, 1996). To be able to support a sustainable way of living on our planet, a clear definition of sustainability is required. Moreover, one has to be able to measure the present level of sustainability and indicate how far removed we are from complete sustainability (Lawn, 2004). This need was clearly recognized by Hales and Prescott-Allen (2002) when they stated: “Achieving sustainability requires defining its components in measurable terms and clearly fixing the responsibility to assess progress comprehensively.” Moreover, the concept of sustainability applies to integrated systems comprising humans and nature. The structures and operation of the human component (in terms of society, economy, government etc.) must be such that these reinforce or promote the persistence of the structures and operation of the natural component (in terms of ecosystem trophic linkages, biodiversity, biogeochemical cycles, etc.), and vice versa (Cabezas et al., 2005).

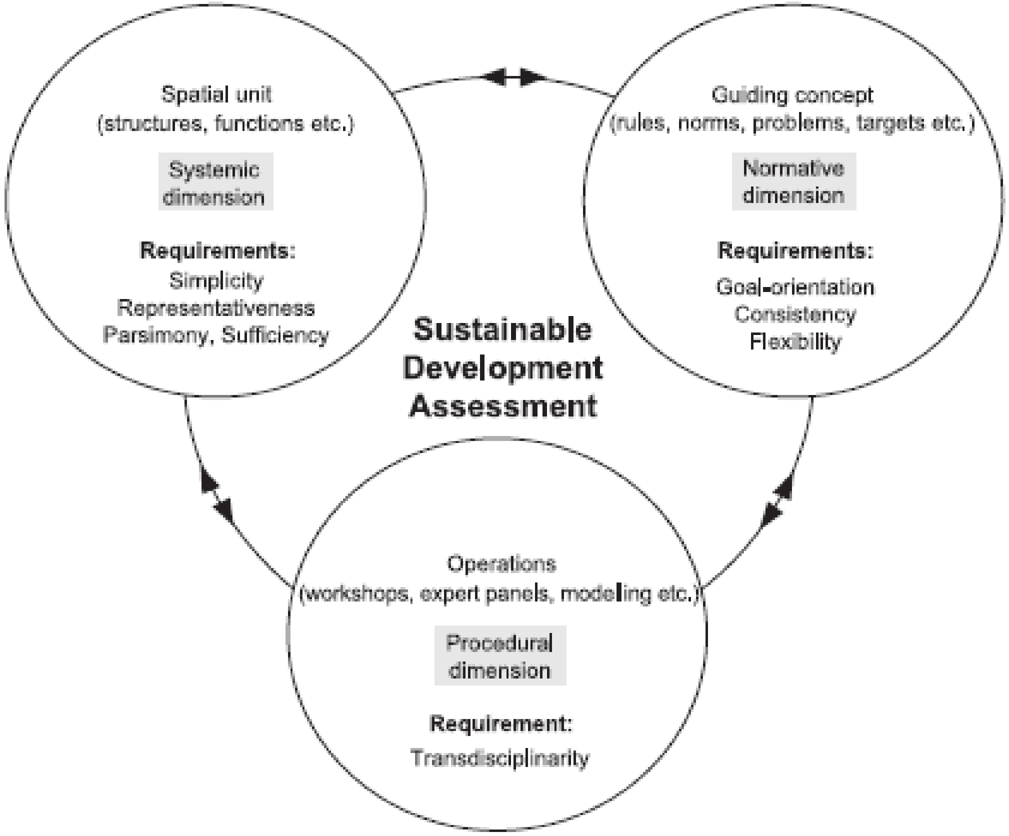
Sustainable development is focused on developing a mutually beneficial relationship between economic development and the environment. In practice SD focuses on finding methods to promote growth that do not damage the environment, or compromises future generations’ access to natural resources. Some authors propose that ecologically sustainable economic development “calls for an economic development within the limits imposed by the natural system, or at least within the limits imposed by the maintenance on the biological basis of human beings” (Bithas and Nijkamp, 2006). Moreover, ecologically sustainable economic development implies that “material and energy natural resources should be sufficient to ‘support’ economic development now, as well as in the future” (Bithas and Nijkamp, 2006). According to Nijkamp and Vreeker (2000); Wiek and Binder (2005), a multidimensional sustainability assessment tool is needed to address the issue. The tool should include:

(1) *The Normative Dimension*: A normative guiding concept operationalized in specific targets;

(2) *The Systemic Dimension:* A target-related model of the system to be assessed;

(3) *The Procedural Dimension:* An appropriate procedure to integrate the relevant stakeholders and to bridge normative and systemic aspects as the Requirements for Assessing the Sustainability (*Figure 4.5*).

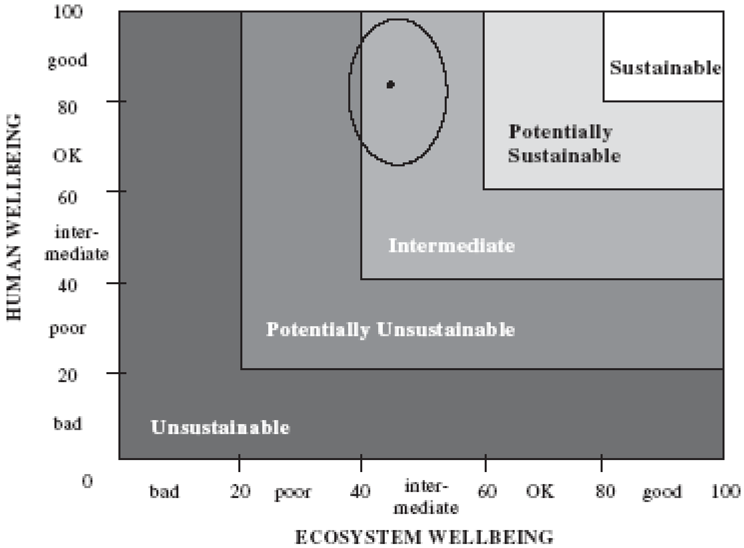
Figure 4.5: Requirements for Assessing the Sustainability by including normative, systemic, and procedural aspects



Source: Nijkamp and Vreeker (2000); Wiek and Binder (2005),

The core of sustainability refers to the manner in which the physical, social, economic, and environmental needs of a community are met without compromising the ability of future generations to meet their own needs (WCED, 1987). To be sure, early approaches to addressing sustainability have placed rather differing emphases on these various needs (e.g., Pearce and Turner, 1990; Pezzoli, 1997; Rees, 1999; Sachs, 1999; WBCSD, 2000). Nonetheless, the most sustainability efforts are directed to meet environmental concerns, especially those that project significant or health-threatening deterioration of natural resource availability or the quality of public life (e.g., Rees, 1999; White and Ellis, 2007). Moreover, Becker (2004) uses a graphical representation of sustainability, which is another way of displaying results effectively. An example of this is the Barometer of Sustainability (see *Figure 4.6*) used to assess British Columbia's progress.

Figure 4.6: Barometer of Sustainability



Source: Becker (2004)

"… A man who wishes to profess goodness at all times will come to ruin among so many who are not good. Hence it is necessary for a prince who wishes to maintain his position to learn how not to be good, and to use this knowledge or needs" (Machiavelli, 1998; Hezri and Hasan, 2004).

Diener and Oishi (2000) have shown that happiness is related to a relative importance that a person assigns to either money or love. People, who believe money is very important, are less happy, while people who believe love is more important are happier. If post-materialistic values like valuing love instead of money are beneficial for sustainability and if happiness is positively correlated with post-materialistic values, it is reasonable to expect that happier people are beneficial for sustainability (Zidansek, 2007). At the same time, sustainability efforts also address important issues related to individual and population based conditions other than those that are clearly environmental, such as public health (Prescott-Allen, 2001), social and economic equity (Sachs, 1999) and the promotion of widespread civic engagement (Boston Indicator Project, 2000). The assumption underlying these efforts is that the preservation of a quality environment, the use of renewable or highly efficient energy resources, the maintenance of a healthy population with ready access to health services, the presence of economic vitality, the active pursuit of social equity, and the creation of an engaged citizenry will characterize urban areas with sustainable futures (Parris and Kates, 2003; Kates et al., 2005). As noted by the

Development Assistance Committee of the Organization for Economic Cooperation and Development [OECD],

> … we have learned that successful development strategies must integrate a number of key elements: they require a sound and stable policy framework; an emphasis on social development; enhanced public participation by the local population, and notably by women; good governance, in the widest sense; policies and practices that are environmentally sustainable; and better means of preventing and resolving conflict and fostering reconciliation (1996, p. 4).

Sustainability measures the degree of the consistency of present and future needs in an economy, which is a dynamic process (Phillis and Andriantiatsaholiniaina, 2001). Sustainability does not represent the endpoint of a process; rather, it represents the process itself (Shearman, 1990). Sustainability implies an ongoing dynamic development, driven by human expectations about future opportunities, and is based on present ecological, social and economic issues and information (Cornelissen et al., 2001). Gale and Cordray (1994) in an effort to sharpen the concept of sustainability identified four questions for the classification into several types of resource sustainability. The four questions are as follows (Kelly, 1998):

1. What is sustained?
2. Why sustain it?
3. How is sustainability measured?
4. What are the politics?

At the same time, Macnaghten et al. (1997) suggested that the current state of research, which was entirely overviewed by Ford (2000), into sustainability illustrates that the desired state of the concept can be achieved through a three-stage process (Diamantis, 1999):

(1) The present unsustainable situation;

(2) The new mechanism and relations based on the utilization of environmental indicators to maintain the current position;

(3) The sustainable state, which can be achieved through the mechanism cited within the latter category.

Bagheri and Hjorth (2008) argue that sustainability is neither a state of the system to be increased or decreased, nor a static goal or target to be achieved. Sustainability is a difficult concept, because one can never really measure it (Korhonen, 2003). Sustainability is “sustainable development” (Bossel, 1999). In other words, sustainable development of landscapes demands that: the landscape structure supports the ecological, social and economic processes required, so it can deliver its goods and services to present and future generations; the landscape can change over time without losing its key resources; stakeholders are involved in decision-making about landscape functions and patterns (Opdam et al., 2006).

Sustainable development is an umbrella concept that puts equal emphasis on economic vitality, protecting the environment, managing growth, building healthy communities and enhancing the well-being of residents. Similar to sustainability, sustainable development is used to mean different things by different communities. But the concepts are not the same, and it is worth taking note of several aspects of sustainable development that distinguish it from sustainability (Mitra, 2003). Concluding**,** recent studies clearly distinguish the terms “sustainable development” and “sustainability” (Dovers and Handmer, 1993). Brundtland’s commission report on sustainable development refers it as “the development, which meets the needs of the present without compromising the ability of future generations to meet their own needs”. Contrarily, Prasad and Badarinath (2005) referred to sustainable development as the “the ability of a human, natural, or mixed system to withstand or adapt to endogenous or exogenous changes indefinitely”.

4.12. SUSTAINABLE DEVELOPMENT INDEX (SDI)

The Brundtland (WCED, 1987) definition of sustainable development is “... development which meets the needs of the present without compromising the ability of future generations to meet their own needs”. According to Morse (2008), the Brundtland report, indeed the entire sustainable development movement, has an attempt at resigning nature , resources , the earth , human life itself , at a scale perhaps not been witnessed since the rise of empirical sciences (Escobar, 1996). These deceptively simple definitions raise many issues, but the two of them are the followings:

(1.) How can we take a rational view of what future generations might need?

(2.) How can we monitor our progress towards a sustainable future?

As Holden (2006) wrote, that the learning from a case of failed consensus-building around a sustainable development initiative in Greece. Sapountzaki and Wassenhoven (2005) encapsulate the wicked problem within participation in sustainable development this way: “Sustainable development and planning assumptions, objectives and content are not always understood by the public at large, especially their comprehensiveness and global nature. Inversely, the community of academics, researchers, government officials and professionals engaged in the study, planning and implementation of sustainable development . . . does not always have a satisfactory grasp of the view of the citizens, which, quite naturally, tends to focus on the level of everyday life and experience.”

The sustainable development issue in the economic literature is often tackled in the way: “Something must be kept constant, or at least not decreasing”, and the debate is about the ‘thing’ to be preserved Dobson (1996). Solow (1993b) claimed that if the sustainability means anything more than a vague emotional commitment, it must require that something be conserved for the very long run.

The approach of Martinet and Rotillon (2007) consists in wondering if there are invariant quantities endogenous to the representation of the economy. Such invariants will give a significance to the ‘thing’ Martinet and Rotillon (2007) can and perhaps want to preserve. The authors thus wonder what it is possible to sustain in a production–consumption economy. They adopt a general approach to find criterions of the form (Heal, 1998):

$$\max \int_0^\infty Z(t)U(t)\,\mathrm{d}t$$

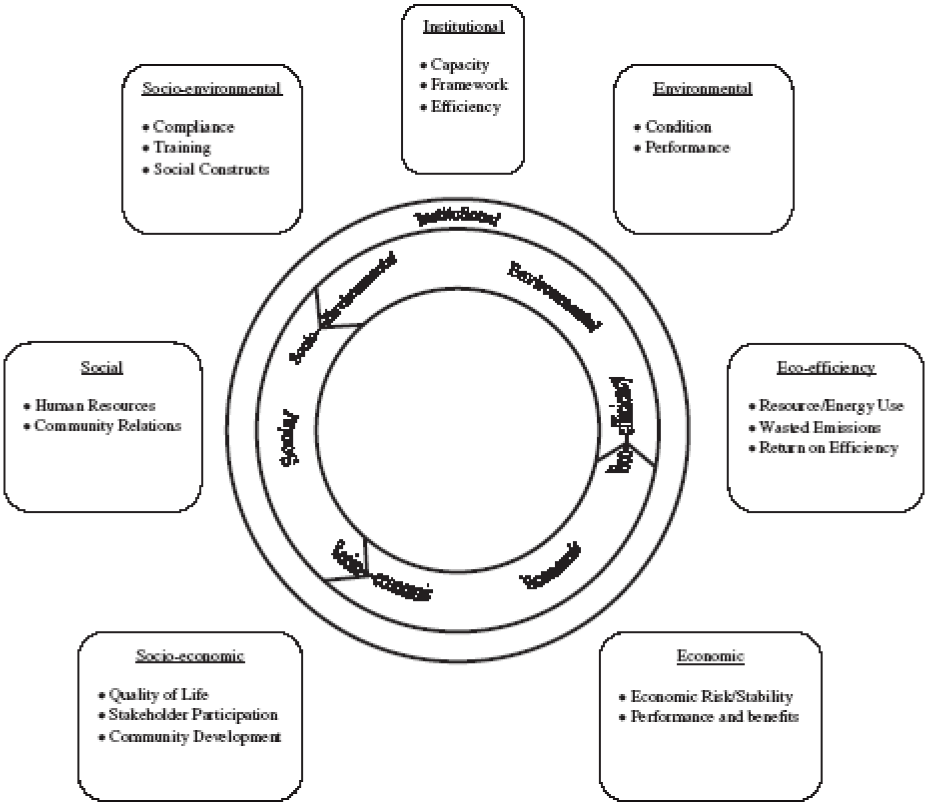
that leads to such invariant quantities. It is the general formulation of a program that maximizes some intertemporal sum of utilities. Z(t) is a weighting function of any form (not necessarily of the usual exponential form).

Gustavson et al. (1999); Spangenberg et al. (2002); Spangenberg (2004; 2008); Vera et al. (2005); Comim et al. (2007); Lee and Huang (2007) speak about policies must achieve by integrating four dimensions towards sustainable development:

- The economic objectives;
- The social objectives;
- The environmental objectives;
- The institutional objectives

Mediterranean Action Plan (2008) refers to the Mediterranean strategy for Sustainable Development. Adams and Ghaly (2007) discuss also a recent framework for sustainability where the aim is to integrate the various aspects of sustainability by considering indicators that provide a description of the systemic nature of the industry. It includes two-dimensional indicators (where possible), instead of solely focusing on indicators that provide a one-dimensional, reductionist evaluation of economic, environmental, social and institutional sustainability. Evaluating the linkages at the boundaries of each area provides a more comprehensive understanding of the system, as the Integrated Sustainability Evaluation Framework (see *Figure 4.7*).

Figure 4.7: The Integrated Sustainability Evaluation Framework



Source: Adams and Ghaly (2006)

As Owens and Cowell (2002); Stimson et al. (2006); Sagoff (2007) mentioned that the proper balance among what is often referred to as the “three Es”:

- Environment;
- Equity—is central to the achievement of a sustainable future;
- Economy.

There are, of course, inevitable trade-offs associated with attempts to achieve these goals simultaneously, as ably illustrated by Campbell (1996). Viewed as a triangle with each “E” goal at each corner, Campbell notes conflicts along each axis. The tension between promoting economic growth and the equitable sharing of opportunities that arises from the claims on the use of property as both a private resource and public good creates property conflict. The tension that arises from the competitive claims on the use of natural resources creates a resource conflict. And the challenge of improving the situation of the poor through economic growth while protecting the environment creates a development conflict. Resolving these tensions and conflicts is an ongoing process for all communities.

Identification of appropriate measures of sustainability has been an ongoing challenge around the world for some time (Cartwright, 2002). Indeed, the literature on this topic is so great that King et al. have noted that. . . “it has become an industry unto its own” (King et al., 2000). Budd et al. (2008) have selected measures that are relatively objective and available, and that fit a model of sustainability reflecting the intersection of environment, economy, polity, and society. The author’s review of the sustainability literature leads to the identification of five positively distinct dimensions of the sustainability concept:

(1) The environmental quality;

(2) The economic vitality;

(3) The public health;

(4) The countermeasures to urban sprawl;

(5) The official planning activities and policies directly supportive of sustainable development.

Budd et al. (2008) do recognize that other researchers may opt for alternative/additional sustainability dimensions as well as alternative/additional indicators of the dimensions on which the authors have focused. Nonetheless, Budd et al. (2008) believe that the indicators employed in the current paper provide a valuable starting reference for the assessment.

The SUE-MoT Project is a publicly funded research project by the UK EPSRC and forms part of a bigger research agenda on Sustainable Urban Environment (Edum-Fotwe and Price, 2009). Within this bigger research platform, the SUE-MoT Project addresses Metrics, Models and Toolkits for Whole Life Sustainable Urban Development. The primary aspiration of the SUE-MoT Project was to identify existing capabilities and gaps in the current assessment of urban sustainability. The gaps in assessment should provide an opportunity to develop an inclusive, holistic, multi-dimensional instrument that can be employed as a toolkit by key decision-makers and related stakeholders involved at various stages of the development process (Syms, 2001). The vision of the research project is to develop this toolkit as a comprehensive and transparent framework that encourage key decision-makers to systematically assess the sustainability of the urban environment by taking account of the scale, life cycle, location, context and all stakeholder values. Such an undertaking will require decision-makers confront not only the environmental factors, but equally so, the social and economic factors that attend development projects. The Underlying Concept of Sustainable Development *(See Figure 4.10)* presents the underlying concept of the multi-dimensional view of sustainability on which the SUE-MoT project is based. The rationale of the SUEMoT concept is that for sustainable development to be effectively attained, the social, economic, as well as the environmental aspects need to be appropriately addressed. The factors that would need to be addressed will be represented by the concurrent overlap of the three dimensions of environment, economic, and social. The extent of the overlap between the various dimensions will be governed by the nature of the development and its socio-economic circumstances and context. The context can be defined by global, national, regional, local, and project factors, and is subsequently described as the spatial scale within the SUE-MoT programme (Walton et al., 2005).

Lyytimaki and Rosenstrom (2008) presented a holistic illustration of the sustainable development framework (See *Figure 4.8*). Levett (1998) discusses the (proposed) Russian dolls model of sustainability (*Figure 4.9*). The Underlying Concept of Sustainable Development (See *Figure 4.10*) also shows the different states of sustainability that could exist for any development. Sustainability is usually discussed as a state or, better, a development in which three kinds of interests are met simultaneously:

(1) The interest of the present generation to generally improve their actual living conditions (i.e. economic sustainability);

(2) The search for an equalization of the living conditions between rich and poor (i.e. social sustainability);

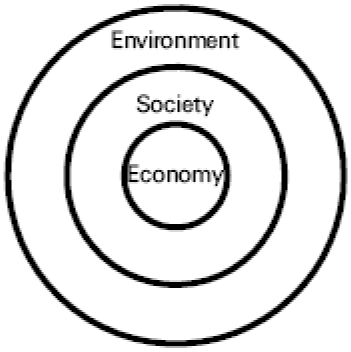
(3) The interest in an intact natural environment that is capable of supporting the needs of future generations (i.e. ecological sustainability) (Sartorius, 2006; Ledoux et al., 2005).

The first order state reflects only economic, social, or environmental issues separately. Any project thus executed can only attain a single state sustainable status. Traditionally, projects in the construction sector often explore such a single state sustainability within the economic dimension. The second order state describes a partial overlap between two dimensions, such as economic and environmental optimization at the expense of the social dimension. Its generic form is the optimization of any two dimensions at the expense of the third dimension. The third order of sustainability refers to an optimization of all three dimensions, and is a state that is rarely attained in the most urban development projects in isolation. The ability to establish optimization of the third order relies on the awareness of the issues and dominant requirements that are each of the principal dimensions within a generic as well as a specific spatial context. The social dimension presents the aspect of sustainability that is difficult to define. This is because of a greater proportion of subjective factors that are reflected as dominant requirements for consideration. As such, defining generic social factors that would require attention in the assessment of sustainability should present an opportunity for conducting a more systematic appraisal of the issues that would need to be addressed (Edum-Fotwe and Price, 2009).

Figure 4.8: Holistic Illustration of the Sustainable Development Framework

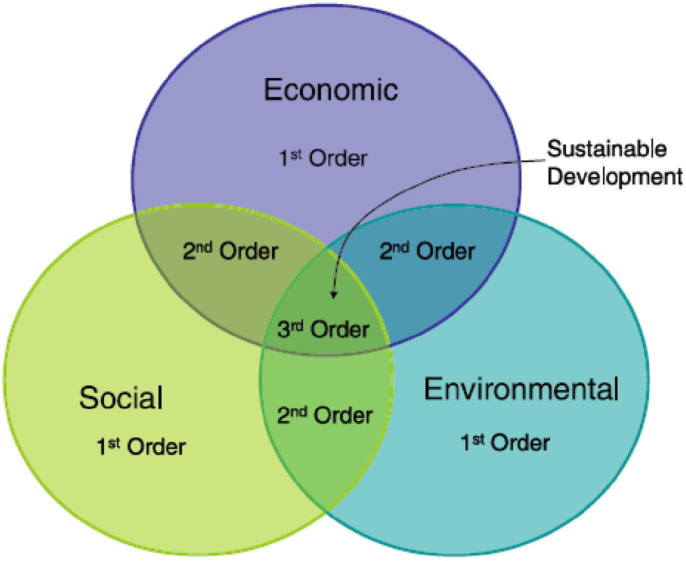
Source: Lyytimaki and Rosenstrom (2008)

Figure 4.9: (Proposed) Russian Dolls Model of Sustainability



Source: Levett (1998)

Figure 4.10: Underlying Concept of Sustainable Development



Source: Walton et al. (2005)

The wish to progress towards a more sustainable future raises the issue of measurement. We must be able to measure sustainability in order to check whether a new policy or decision or technical innovation is making things better or worse. All these changes *might* affect future generations in some way, but by how much, and are there alternatives which will have a lesser and perhaps negligible effect? Without some measuring system, we can neither identify areas of concern nor direct our actions. This need for measurement, which is common to all attempts to apply sustainability thinking, has given rise to the concept of *sustainability indicators*, or *metrics* (Bell and Morse, 1999).

The sustainable development indicator is a measure of the degree of sustainability of some particular feature of our world. In some cases the indicator is an indirect or surrogate measure, because the feature in which we are really interested cannot be quantified. Sustainability is a holistic property involving the three aspects of economic, environmental and social development, so these indicators are generally considered in sets, and to be a true measure of sustainability, the set must include indicators of all three aspects (otherwise you are measuring something else).

There are clearly a great many ways of deriving metrics and using them. For example the UK government defines sustainable development (Anonymous, 1999) as “the achievement of a better quality of life for everyone, now and for generations come”, and has identified the four primary requirements, social progress, environmental protection, prudent resource use and high/stable economic growth and employment. Some fifteen-headline indicators chart progress in these four major areas, and for each headline indicator there are many individual quantified indicators, some 147 in total. *The Fifteen Headline Indicators* can be grouped, as suggested in *Figure 4.11*. The positioning of some headline indicators in this chart is arguable. For example, it might be thought that education is valuable for social development, and thus should appear in that quadrant. However, the paper makes clear that this indicator is designed to measure progress towards the government’s stated objective “To equip people with the skills to fulfill their potential” and this suggests a utilitarian view of education as an investment providing training for the labor market, perhaps in line with the Bologna accord. So for this particular set, education is put into the quadrant devoted to economic benefit (Darton, 2003).

Figure 4.11: The Fifteen Headline Indicators Used by the UK Government (http://www.sustainable-development.gov.uk/indicators/index.htm)

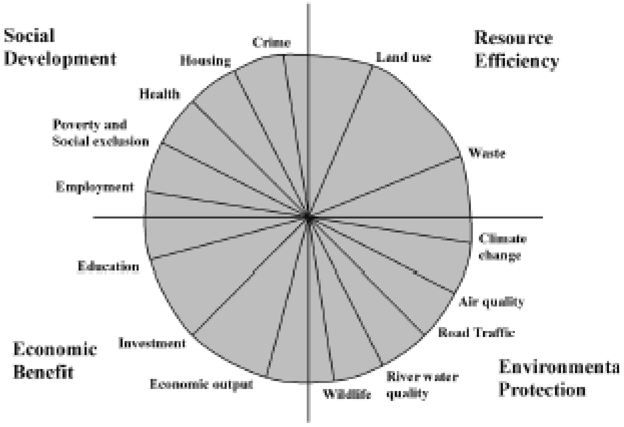
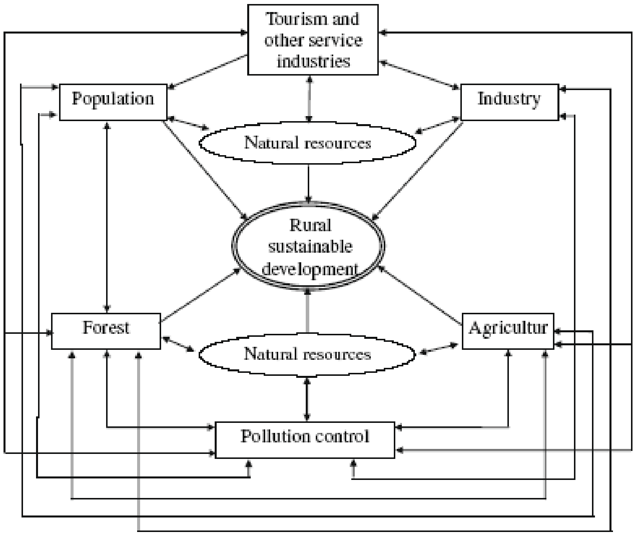


Figure 4.12: Interrelationships Among Various System Components of Rural Sustainable Development



Source: Cai et al. (2009)

The paper of Cai et al. (2009) shows interrelationships among various system components, i.e. themes, of rural sustainable development (See *Figure 4.12*).

Supported by available relevant indicators, and in accordance with the Commission on Sustainable Development, Barrera-Roldan and Saldıvar-Valdes (2002) propose that the number of core indicators should be flexible, and determined in accordance with the level of information and the specific situation of the region under study, as well as the country’s conditions. To integrate these indicators a modified multi--attribute decision theory methodology was chosen. Within the philosophy of the methodology a tree was formed with 21 indicators representing the production, social and natural systems of the studied region (main branches or general attributes). The number of indicators used was defined by the availability of data and by their potential to represent an important characteristic of the region (EUROSTAT, 2007; INBO, 2007). For the tree representing the sustainable development index see *Figure 4.13*.

Figure 4.13: The Tree Representing the Sustainable Development Index

Source: Barrera-Roldan et al. (1998) and EUROSTAT, 2007

A complete version of the final utility functions would be too long to include here, however it can be found elsewhere (Barrera-Roldan et al., 1998).

Once all the utility functions were designed, the Sustainable Development Index (SDI) (*Equation 4.9*) was defined as (Barrera-Roldan and Saldıvar-Valdes, 2002):

Equation 4.9: Sustainable Development Index (SDI)

$$SDI = \frac{1}{100}\sum_{i=1}^{3} WGC_j \frac{1}{n_j}\sum_{j=1}^{3} AG_{ji}$$

Where WGC$_j$ is the weighting factor of the jth general criterion; AG$_{ji}$ grade obtained by the evaluated region corresponding to the ith attribute under the jth general criterion; n_j number of attributes under the jth general criterion.

As a first approach, the three systems: production, social, and natural were considered equally important within the Sustainable Development philosophy, thus the WGC$_j$ for the general criterion representing them were defined.

A metric was generated through quantification of indicators and their aggregation to indices, selected to encompass environmental, social and economic dimensions of sustainability. Through stakeholder participation, analyses for data availability, skewness and normality, and sensitivity to settlement attributes, 40 indicators were selected, ten each representing environmental, socioeconomic, transport and the quality of life dimensions of sustainability. Indicators in each group were subsequently aggregated into four indices for each dimension, and these were further aggregated into a single Sustainable Development Index (SDI) (O’Regan et al., 2009).

4.13. COMBINED / COMPOSITE SUSTAINABLE DEVELOPMENT INDEX (CSDI)

To generate a combined metric, footprint values (first metric) and sustainability indices (second metric) were aggregated to create a Combined Sustainable Development Index (CSDI) for settlements: to achieve this, footprint values were transformed to create an index additional of environmental, quality of life, socioeconomic and transport indices and the five values were aggregated, an aggregation method also adopted by Wilson et al. (2007). This was undertaken to include all available data, but resulted in double counting of some environmental attributes, which was accepted on the assumption that social and economic sustainability are ultimately dependent on environmental quality. To allow comparis1on amongst settlements with differing population sizes, all sustainability values were calculated on a per capita basis (O’Regan et al., 2009).

Despite of Combined Sustainable Development Index (CSDI), Krajnc and Glavic (2005a) collected and developed a standardized set of sustainability indicators for companies covering all main aspects of sustainable development. A composite sustainable development index (CSDI) in order to track integrated information on economic, environmental, and social performance of the company with time. Normalized indicators were associated into three sustainability sub-indices and finally composed into an overall indicator of a company's performance. This was applied by determining the impact of individual indicator to the overall sustainability of a company using the concept of analytic hierarchy process (Singh et al., 2009). Blanc et al. (2008) points to the existence of four steps in constructing a composite index:

(1) The selection,

(2) The scaling,

(3) The weighting and

(4) The aggregation of the variables.

In all indicator frameworks no attempt was made to create an aggregate measure for easy comparison. In recent years, international research has focused on the development of composite indicators mostly for cross-national comparisons of economic, social, environmental and/or sustainable progress of nations in a quantitative fashion. Such indicators have been applied in a wide variety of application fields such as:

- *Environment:* pilot environmental performance index (WEF, 2002b), index of environmental friendliness (Statistics Finland, 2003), eco-indicator 99 (Pre Consultants, 2001);

- *Economy:* internal market index (JRC, 2002), composite leading indicators (OECD, 2002b), index of sustainable and economic welfare (Daly and Cobb, 1989);

- *Society:* human development index (UNDP, 1990–2003), overall health system attainment (Murray et al., 2001);

- *Sustainability:* Dow Jones sustainability index (DJSI, 2003), index of balanced sustainable development (Seljak, 2001).

Despite the indices developed, there is still no useful method for integrated sustainability assessment. To meet the challenges of sustainability, an approach to integrated assessment is required to provide a good guidance for decision-making. It has been foreseeable that aggregation of indicators to sustainability indices could provide a chance for new policy guiding instruments and better integration of decision-making, as well as public participation in sustainability discussion. Although the common principle to aggregate indicators for assessment has gained acceptance, it has also become evident that the methods for the aggregation of indicators are either not sufficiently well established yet, or are under development, or are not available with respect to all the sustainability aspects. As the credibility of aggregation methodologies is of crucial importance for the quality of new information categories, more research is needed on the aggregation methodologies and on the relevance of basic data for comprehensive assessments (Statistics Finland, 2003).

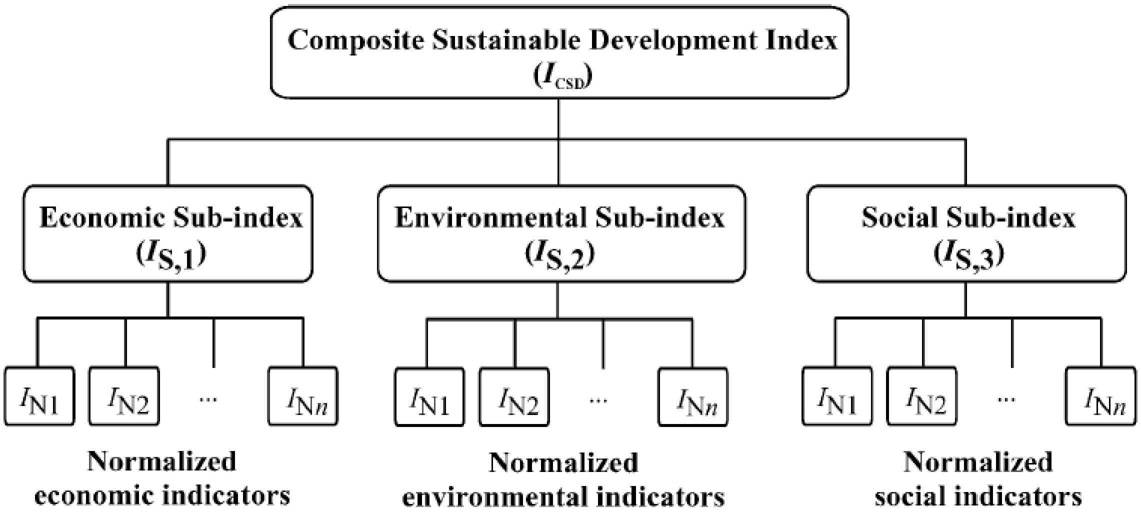
The paper of Krajnc and Glavic (2005a) presents a designing of a composite sustainable development index (CSDI) that would assess performance as a function of time. The focus of the paper is a consideration how to integrate indicators in order to determine SD in a relevant and useful manner for decision-making. It concentrates on sustainability and it tends to move from trying to define SD towards developing a concrete model for promoting and measuring sustainability achievements. The paper organizes sustainability assessment for:

- The social performance;
- The economic performance;
- The environmental performance.

The current structure has been chosen because it reflects what is currently the most widely accepted approach to defining sustainability (GRI, 2002). The main aim is to raise the quality of sustainability reporting to a higher level of consistency. The paper discusses how economic, environmental, and social indicators can be associated into sustainability sub-indices and finally into an overall indicator. This is applied by determining the impact of individual indicator to overall sustainability using the concept of the analytic hierarchy process (AHP) (Saaty, 1980). The model uses normalized social, environmental, and economic indicators to incorporate them into a unique measure of performance.

Integrated information on sustainable development has been very essential for decision-making since it is very difficult to evaluate the performance on the ground of too many indicators. The proposed model reduces the number of indicators by aggregating them into a composite sustainable development index (CSDI). For the generic hierarchy scheme for calculation of the Composite Sustainable Development Index see *Figure 4.14*. ISO 31 used as a guide to terms used in names and symbols for (physical) quantities (ISO, 1993).

Figure 4.14: The Generic Hierarchy Scheme for Calculation of the Composite Sustainable Development Index



Source: Krajnc and Glavic (2005a)

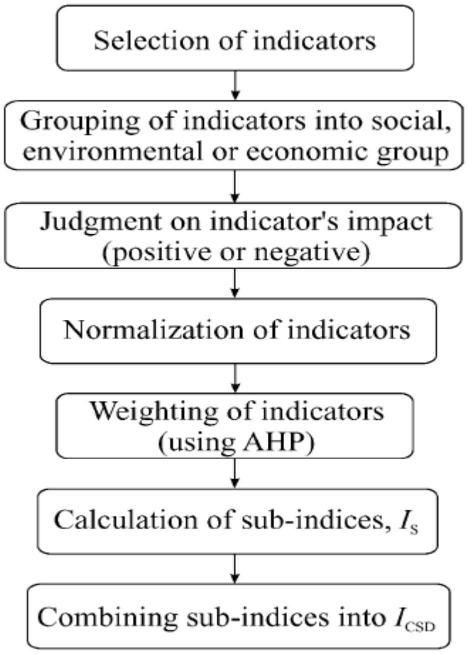
For procedures of calculating the CSDI, which is divided into several parts (Krajnc and Glavic, 2005a), see *Figure 4.15*, and for scheme for calculation of the Composite Sustainable Development Index (Krajnc and Glavic, 2005b) (see *Figure 4.16*). At first, the *proper indicators* are selected in the economic, environmental, and social *group of indicators* according to the main aspects of sustainability (Social, j = 1; Economic, j = 2; and Environmental, $j=3$ group of indicators) is determined. For each group j, indicators whose increasing value has a positive *impact* (I^{+}_{A}) and indicators whose increasing value has a negative impact (I^{-}_{A}) in the perspective of sustainability are considered (see *Table 4.5*).

Table 4.5: Notation Used in the Definition of Sustainability Indicators

Group of indicators	*Group notation, j*	*Indicators with positive impact*	*Indicators with negative impact*
Social group	1	$I^{+}_{A,1i}$ $i = 1, \dots, n$	$I^{-}_{A,1i}$ $i = 1, \dots, n$
Economic group	2	$I^{+}_{A,2i}$ $i = 1, \dots, n$	$I^{-}_{A,2i}$ $i = 1, \dots, n$
Environmental group	3	$I^{+}_{A,3i}$ $i = 1, \dots, n$	$I^{-}_{A,3i}$ $i = 1, \dots, n$

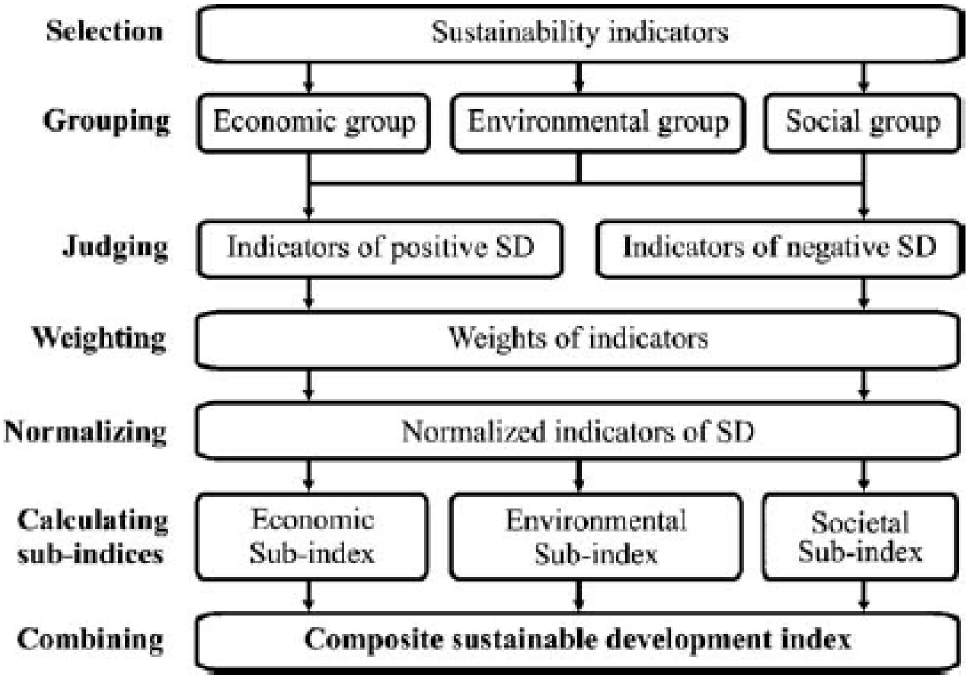
Source: Krajnc and Glavic (2005b)

Figure 4.15: The Procedure of Calculating the CSDI



Source: Krajnc and Glavic, 2005a

Figure 4.16: Scheme for Calculation of the Composite Sustainable Development Index



Source: Krajnc and Glavic (2005b)

4.14. SUMMARIES AND PROPOSALS

The current chapter reviews twelve sustainability indices (see *Table 4.1 – Twelve Sustainability Indices*) applied in policy practice are as follows:

1. *Ecological Footprint (EF) (Section 4.2)*
2. *Human Development Index (HDI) (Section 4.3)*
3. *Environmental Sustainability Index (ESI) (Section 4.4)*
4. *Index of Sustainable Economic Welfare (ISEW) (Section 4.5)*
5. *Well Being Index (WI) (Section 4.6)*
6. *Gross Domestic Product (GDP) (Section 4.7)*
7. *Genuine Savings Index (GS) (Section 4.8)*
8. *Sustainability Performance Index (SPI) (Section 4.9)*
9. *Sustainable Society Index (SSI) (Section 4.10)*
10. *The Sustainability Index (SI) (Section 4.11)*
11. *Sustainable Development Index (SDI) (Section4.12)*
12. *Combined / Composite Sustainable Development Index (CSDI) (Section 4.13)*

Each index is separately discussed taking into consideration the huge range of overviews of the authors on diverse topics of sustainability. In general, overviews of different authors are kept to show not only the precise opinions of the authors but also their diverse thoughts on the same metrics. It is illustrated that some of these indices fail to fulfill the fundamental scientific requirements making them rather useless if not misleading with respect to policy advice. For instance, the Ecological Footprint is one of the main metrics for evaluation of Sustainable Development. Whereas this indicator is appealing and widespread, it is not perfect (Nourry, 2008). In addition, it presented three main limitations, which are discussed at the end of Ecological Footprint *(Section 4.2).*

Despite of the main purpose of this article which is to emphasize authors' review of the 12 chosen indices. These indices have been chosen on the following basis and works:

1. Hundreds of articles with the keywords of sustainable development, sustainability indices, sustainability metrics were taken into consideration;
2. A table of authors and metrics was created;
3. The most repeated indices were chosen;
4. The indices including "sustainability" were chosen.

All twelve indices have their own limitations while are assessing sustainable development. However, the last index, i.e. *Combined / Composite Sustainable Development Index (CSDI)*, is proposed as the most appropriate metrics for the calculation of Sustainable Development. O'Regan et al., (2009) and Wilson et al., (2007) aggregated two Sustainable Development Indices to derive the *Combined Sustainable Development Index (CSDI)*. Besides, the papers of Krajnc and Glavic (2005 a, b) present a designing of a *Composite Sustainable Development Index*

(CSDI) that would assess performance as a function of time. The focus of that paper is a consideration how to integrate indicators (refer to **Chapter 5 – The Indicators for the Sustainable Development** to choose Sustainable Development in a relevant and useful manner for decision-making. It concentrates on sustainability and it tends to move from trying to define Sustainable Development towards developing a concrete model for promoting and measuring sustainability achievements. Unfortunately, the main limitation of the papers of Krajnc and Glavic (2005 a, b) is that *the Composite Sustainable Development Index (CSDI)* is calculated only for the company level. The latter limitation is taken as an advantage, where *Composite Sustainable Development Index (CSDI)* is proposed not for the company level but for all levels of sustainable development. The latest index is proposed to be the current Dissertation’s core.

CHAPTER 5

SUSTAINABLE DEVELOPMENT INDICATORS

The current chapter represents as a preamable to the indicators for the sustainable development. Furthermore, the subsequent angles will be confabulated as:

1. What are the aspects of indicators?
   The surveys of Gallopin (1997) and Rigby et al. (2001) are on a wide range of literature and reports and are aknowledged as:

   - A parameter;
   - A variable;
   - A measuring instrumentl;
   - A fraction;
   - An index;
   - An empirical model;
   - A sign;
   - A statistical measure;
   - A meter;
   - A value;
   - A proxy;
   - A measure

2. What are the broad goals to account for the above adverted indicators' aspects?
   Varma et al. (2000); Bell and Morse (2004); Simianer (2005) enhanced the three sub-goals as:

- An aspect of sustainability that recognizes its ecological, economic and social underpinning, i.e. what is the objective?
- To trove ways to measure sustainability with due regard to its spatial and temporal dimensions, i.e. what are the elected spaces?
- The effects of the sustainability to acknowledge strategies to improve management, wherever needed, i.e. how the goals can be chosen ?

3. What is the Design Process for the Sustainable Development Indicator?

Boyd and Charles (2006) the overall process for the set of indicators of sustainable development for community-level is shown as:

- To start the participant identification stage;
- To proceed through visioning;
- To specify a suitable framework;
- To specify the sustainability characteristics;
- To specify an iterative series of steps to develop;
- To classify and evaluate the indicators involved.

4. What are the Criteria for Sustainable development?

De Kruijf and Van Vuuren (1998); Ravetz (2000); Spangenberg et al. (2002); The Energy & Biodiversity Initiative (2002); Yuan and James (2002); Ledoux et al. (2005) have developed a number of additional criteria to determine the quality of selected or proposed measurables as:

(1) Sole, so that each indicator must be meaningful;
(2) Declaratory, so that each indicator must be truly representable of the phenomenon to be earnmarked;
(3) General, so that not dependent on a concrete modes, society or culture, but be momentous for several concepts of truth;
(4) Robust, so that the behest should be safe and no severe changes in case of minor changes in the methodology or improvements in the data base;
(5) Sensitive, i.e. they have to react early and sensibly to changes in what they are observable, to allow to observe the trends or the successes of methods.

5. What are the indicators to model the framework?

By the words of Potts (2006), the sustainable development indicator system encompasses an assortment of policy contexts, frameworks, dimensions, criteria, indicators, real strategies and targets. The conceptual model of the the sustainable development indicator system displays the core processes that underline sustainability indicator systems. The current approach focuses on the core indicator system as dependent upon a series of inputs, so that involve updates to construct the indicators and to develop an apprehend structure for the policy need, and of outputs, so that involve to use the the indicator results, to operate effectively. Hilden and Rosenstrom (2008) emphasize that the different uses and the indicators' development are thus abstrusely connected. To keep the connectance, one can ensure that the indicators of sustainable development stay observable, secure and lawfull while the world is in a stage of changes. Some clear challenges related to the indicators use have been identified to develop indicators of sustainable development.

1. There has been a lack of clear and simple frameworks.
2. Developers of indicators often neglect to engage those who are earmarked to well advantages from the indicators in the process.
3. Many real indicators stay unknown to the atlantean users due to unsuccesses to make them accessible (Morrone and Hawley, 1998).

6. What are the types of Indicators Categories and Principles?

According to the UK Biodiversity Partnership (2007), the indicators for assessing the 2010 targets are grouped under focal areas based on those identified by the Convention on Biological Diversity and the European Council:

- Status and trends in the components of biodiversity;
- Sustainable use;
- Threats to biodiversity;
- Ecosystem integrity and ecosystem goods and services;
- Status of resource transfers and use;
- Public awareness and participation.

Moreover, Korhonen (2007b) mentioned the four sustainability principles which are as follows:

1. In the sustainable society, nature is not subject to systematically increasing concentrations of substances extracted from the Earth's crust,
2. Concentrations of substances produced by society,
3. Degradation by physical means,
4. In a sustainable society, human needs are met worldwide in the short- and long-term.

The latter definition was not applicable in the literature survey of Palme and Tillman (2008), as the presence or lack of a connection between an indicator and a vision, target, or goal was not always evident in the texts studied. Furthermore, inconsistencies in the indicators in the micro-level do not help policy makers in formulating and implementing sustainable strategy at the macro-level. Therefore, standardization of indicators is the next step that may aid identification and comparison of options for more sustainable development (Azapagic and Perdan, 2000).

7. How top-down and bottom-up approaches are accorded in Sustainable Development?
   The chosen indicators are expected to help political decision-makers evaluate alternatives, make policy choices, and adjust policies and objectives based on actual performance (Rosenstrom and Kyllonen, 2007).

   Reed et al. (2006) has shown as a two methodological paradigms for developing and applying sustainability indicators at local scales and how each method approaches four basic steps (Blue Plan - Regional Activity Centre, 2006). Furthermore, Hartmuth et al. (2008) shows the linkage of the top-down (↓) and bottom-up (↑) approaches in the integrative concept of sustainable development.

8. How is the composite indicator construed?
   The development of a sustainable development reference system involves five steps (Garcia et al., 2000):

   1. Specifying the scope of the sustainable development reference system;
   2. Developing a framework to agree on components within the system;
   3. Specifying criteria, objectives, potential indicators and reference values;
   4. Choosing the set of indicators and reference values;
   5. Specifying the method of aggregation and visualization.

   The composite indicator can be simply defined as an aggregation of different indicators under a well-developed and pre-determined methodology. Thus the composite indicator lies on the top of an “Information Pyramid” (Hammond et al., 1995b).

9. What are the arguments of the Pressure State Response (PSR) indicator framework?
   Putting indicators in an appropriate context or framework can increase their usefulness (IISD, 1997). The driving force-pressure-state-impact-response (DPSIR) indicator framework is a general framework for organizing systems of indicators of sustainable development (Turner, 2000; Bellini, 2005; EEA, 2006b; Zavadskas and Antucheviciene, 2006; Nuissl et al., 2009). The framework assumes cause–effect relationships between interacting components of social, economic and environmental systems (Smeets and Weterings, 1999). The systems according Amajirionwu et al. (2008) proposes five types of indicators:

(1) Driving force indicators, which refer to human activities, processes and patterns that impact on sustainable development.
(2) Pressure indicators, which refer to activities having a direct effect on a given issue.
(3) State indicators, which describe the observable changes as a result of the earlier mentioned pressures.
(4) Impacts indicators, which show the effect of the impact on the population, economy, ecosystems.
(5) Response indicators which show the actions taken by the society in response to the changes in the state of sustainable development.

Although the DPSIR framework has been criticized for over-simplifying reality and ignoring many of the linkages between issues and feedbacks within the socio-ecological system, the framework is nevertheless a useful conceptual system (Smeets and Weterings, 1999).

Pressure–State–Response (PSR) methodology was developed by the OECD, for the categorization of environmental indicators, and is based on the "stress–response" model (OECD, 1993).

The key point of the current chapter is the definition of a composite indicator, which can be simply defined as an aggregation of different indicators under a well-developed and pre-determined methodology. The current indicator system is proposed to interlink the current chapter with **Chapter 4 – The Sustainability Indices**, where the Composite Sustainable Development Index (CSDI) was proposed for the evaluation of sustainable development. To meet the challenges of sustainability, an approach to integrated assessment is required to provide a good guidance for decision-making. Decision-makers had a very difficult task for the assessment of sustainable development per region. Meanwhile, it is proposed that decision-makers combine indicators into one while referring to society. It is suggested that they merge into the other group of indicators while referring to the economy. In the same way, the environmental indicators are joined as another composite indicator. Therefore, three composite indicators, i.e. social, economic and environmental indicators, are proposed to highlight the concept of sustainable development. To review and define each composite indicator, refer to **Chapter 6 – Theoretical Framework**.

5.1. INTRODUCTION

Since its launch with the World Conservation Stategy (IUCN, 1980), sustainable development has steadily risen in status to assume a central position in writing and discussion throughout the 1990s (Clement, 2000). Sustainable development is development that meets the needs of the present without comprising the ability of future generations to meet their own needs (WCED, 1987). Sustainable development is people-centered in that it aims to improve the quality of human life, and it is conservation-based on that it is conditioned by the need to respect nature's ability to provide resources and life-supporting services. In this perspective, sustainable development means improving the quality of human life while living within the carrying capacity of supporting ecosystems (Reed, 1996).

Earlier approaches to addressing sustainability have placed rather differing emphases on these various needs (e.g., Pearce and Turner, 1990; Pezzoli, 1997; Rees, 1999; Sachs, 1999), which in turn lead to variations in the types of indicators used to measure the success of these sustainability efforts. As noted by Segnestam (2002), indicators can be a more useful analytical tool than the data from which they are derived. They assist in the assessment of conditions and trends, facilitate informed discussion among diverse groups within the community because indicators are often easier to understand that the statistics that underlie them, and provide input into the policy process. Indicators help communities identify important tradeoffs they may face in all sorts of decisions that affect sustainability (Olewiler, 2006).

While the *PSR* (*Section 5.9*) system provides an overall framework for indicator selection, it does not clarify the different roles of indicators in the sustainability (Huang et al., 2009; Rudd, 2004; Ronchi et al., 2002). Furthermore, in many existing sustainability indicator systems, the most often used "indicator lists" are deficient with respect to the accurate representation of the system and its problems (Wiek and Binder, 2005). They consider neither all dimensions of sustainability nor the inter-linkages among the indicators nor the interdependency with other systems (Vester, 1988; Scholz and Tietje, 2002). This suggests that a systematic analysis including the linkages between specific indicators and the dynamics of these indicators at various levels is needed (Malkina-Pykh, 2000; Wiek and Binder, 2005).

In the current chapter the following topics will be further pointed out concerning *Definition and Goals of Indicators* (*Section 5.2*); *The Sustainable Development Indicator Design Process* (*Section 5.3*); *The Criteria of Sustainable Develepment* (*Section 5.4*); *The Indicators to Model the Framework* (*Section 5.5*); *Categorization and Principles of Indicators* (*Section 5.6*); *Top-down and Bottom-up Approaches in Sustainable Development* (*Section 5.7*); *The composite indicator* (*Section 5.8*); *The Pressure State Response (PSR) indicator framework* (*Section 5.9*).

5.2. DEFINITION AND GOALS OF INDICATORS

Today's decision-makers are living in a strange paradox: there are both too much and too little information. In other words, the vast amounts of information available are not meeting the needs of the decision-makers. In any country, specifying the indicators and metrics according to the regional situation would make them even more helpful for political decision-making (Spangenberg and Lorek, 2002). Varma et al. (2000); Bell and Morse (2004) and Simianer (2005) highlighted that decision-making involves three following sub-goals:

- A definition of sustainability that recognizes its ecological, economic and social underpinning, i.e. what is the objective?
- Finding ways to measure sustainability with due regard to its spatial and temporal dimensions, i.e. what is the decision space?
- Operationalising sustainability in terms of identifying strategies to improve management, wherever needed, i.e. how can we decide?

Both insufficient and excessive data can be problems in selecting indicators (Finco and Nijkamp, 2001). In addition, problems are perceived as more complex than ever, and more sophisticated tools are needed to feed information into decision-making. Indicators are seen as one solution to bridge this gap (Atkinson and Hamilton, 1996; Mickwitz et al., 2006) and improve the availability of information (McAlpine and Birnie, 2006). Indicators are “signals which allow data to become available for decision-making”. Since decision-making is an intellectual process, the decision-maker should have the opportunity to consider all the available and necessary information:

- ➢ What is the necessary information?
- ➢ How much information is necessary?

The answer to these questions is the object of the research line carried out by our team in the present study (Peris-Mora et al., 2005). To develop a valid indicator the question being addressed should be clear and agreed between users of the indicator and the method used to address the question must validly assess the answer (Connolly et al., 2001).

The surveys of Gallopin (1997) and Rigby et al. (2001) are on a wide range of literature and reports and are aknowledged as:

- ➢ A parameter;
- ➢ A variable;
- ➢ A measuring instrumentl;
- ➢ A fraction;
- ➢ An index;
- ➢ An empirical model;
- ➢ A sign;
- ➢ A statistical measure;
- ➢ A meter;
- ➢ A value;
- ➢ A proxy;
- ➢ A measure

Further accounts on the indicators are that they are pieces of information which simplify complex phenomena and highlight the trends of system functioning, through summarizing or typifying the characteristics of particular systems (Pagina, 2000). Another trend sees indicators as a means of enhancing learning with a “multi-level governance” paradigm, enhancing “steering”, “mapping” and “weaving” (Parsons, 2004; Lehtonen, 2008). Such “steering” towards sustainability necessitates multiple, appropriate information flows (Brodhag, 2000), for wider communication of sustainability values (Paehlke, 2001). Furthermore, the three basic functions of indicators are simplification, quantification and communication (OECD, 1997). Liu and Ou (2007) mention that indicators in Canadian research are based on simplicity, measurability, accurateness, relatedness, timing. At the same time indicators in Australian research are based on science, accessibility, acceptability and easy monitoring. Sustainability indicators aim to monitor key aspects of the interactions between society and nature, to generate information regarding the current state and drivers. Indicators are useful tools to communicate simplified, concise and scientifically credible information on problems of sustainable development, which are too complex to measure directly (Smith, 2002; Haberl et al., 2004; Moles et al., 2008).

An indicator is an empirical and an indirect interpretation of reality, but not the reality itself (Merkle and Kaupenjohann, 2000; Diamantini and Zanon; 2000). It is the result of a selection of data (for instance, the follow up of the population as a demographic indicator) or of an aggregation of data that reduce the information (Repetti and Desthieux, 2006). An indicator is a synthetic and a representative reflection of a greater, more complex sum of phenomena, preferably made measurable on a quantitative scale (OECD, 2001b). Probably the most significant aspect of indicators, apart from the inherent monitoring possibilities, is the formulation of quantitative targets within sustainable development (Jung, 1997). SDIs have emerged as excellent communication tool aimed at making the concept of sustainable development measurable by quantifying and qualifying trends in society (Pastilles Consortium, 2002; Azapagic, 2004; Bell and Morse, 2004; Amajirionwu et al., 2008). Some of the indicators are hard to quantify, however, to assure the integrated and multidimensional character of the sustainability assessment it is better to include those indicators qualitatively rather than not at all (Balkema et al., 2002). By providing information relevant to sustainability in comprehensive and quantitative form, SDIs have become powerful aids for decision-making (IISD, 1997). As the United Nations Conference on Environment and Development (1992) states, “indicators of sustainable development need to be developed to provide a solid basis for decision-making at all levels and to contribute to the self-regulating sustainability of integrated environment and development systems”. Furthermore, according to Gustavson et al. (1999), “using sustainable development as a planning goal or tool necessitates the identification of indicators that will assist policy-makers in identifying appropriate policies and in monitoring the effectiveness of policy interventions.” (Jollands and Harmsworth, 2007). Bell and Morse (2001), Kuik and Verbruggen (1991), and Peterson (1997) affirm that there has been a worldwide attention to the generation and utilization of information in the form of SDIs.

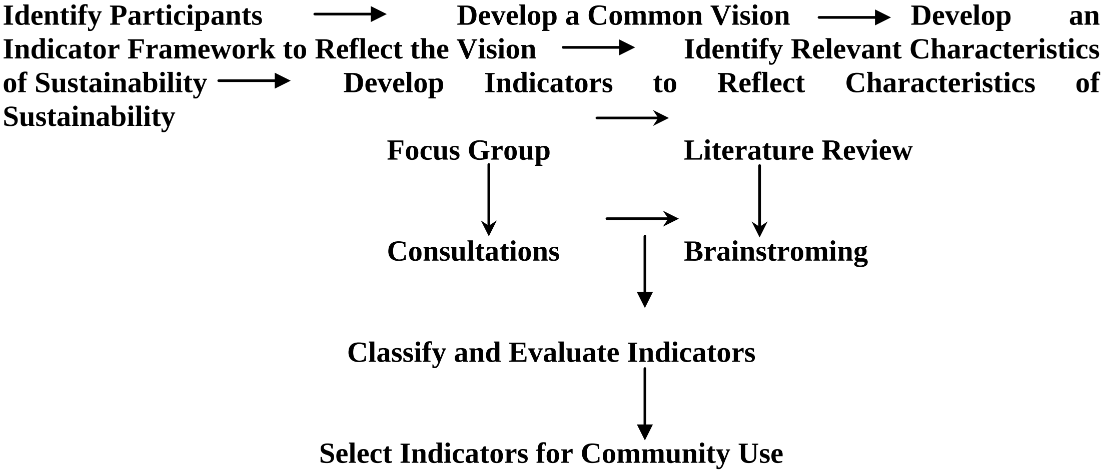
5.3. THE SUSTAINABLE DEVELOPMENT INDICATOR DESIGN PROCESS

The aspects of Azapagic et al. (2005) are to the arrangment more sustainable processes is an respectable part to perform sustainable development. Approaches to design vary and no two designers will design a complex process in exactly the same steps. However, regardless of the approach, the design process normally involves the sequenced steps:

1. Project Initiation;
2. Preliminary Design;
3. Detailed Design;
4. Final Design.

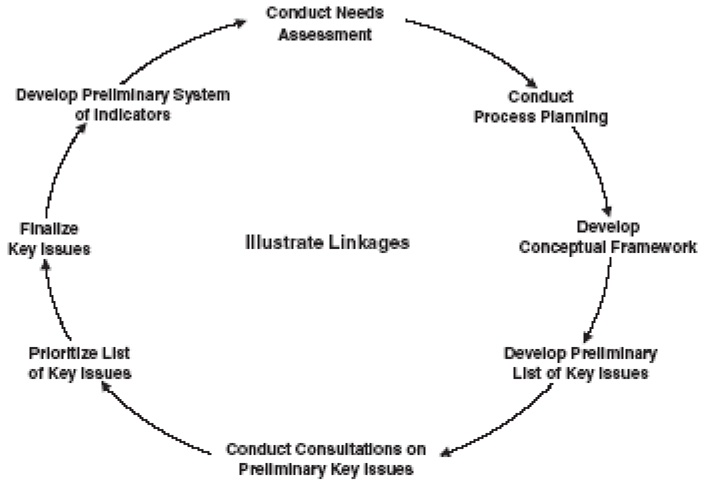
The overall process for developing a set of indicators for community-level is indicated in the sustainable development indicator design process (see *Figure 5.1)*, starting at the participant identification stage, proceeding through visioning, specifying a suitable framework and the sustainability characteristics, then following an iterative series of steps to develop, classify and evaluate the indicators involved (Boyd and Charles, 2006). Later on, Searcy et al. (2008) shows the process used to identify the key sustainable development issues and develop a preliminary system of indicators is depicted in the indicator design process (see *Figure 5.2*).

Figure 5.1: The Sustainable Development Indicator Design Process



Source: Boyd and Charles (2006)

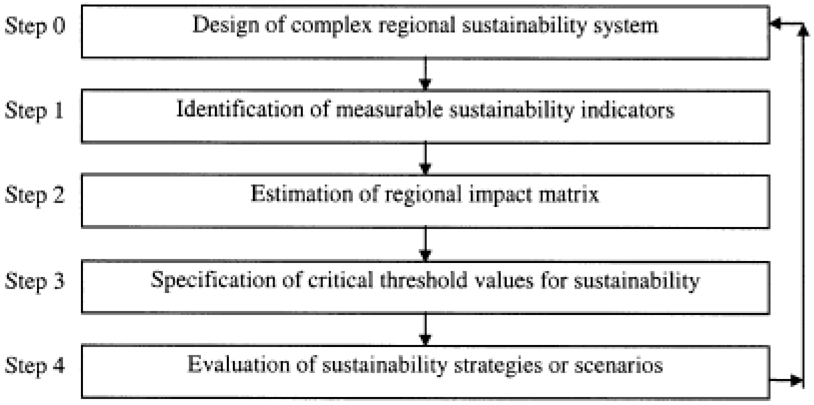
Figure 5.2: The Indicator Design Process



Source: Searcy et al. (2008)

Furthermore, Nijkamp and Vreeker (2000) distinguished the following steps for a sustainable development assessment procedure (see *Figure 5.3*).

Figure 5.3: Steps for a Sustainable Development Assessment Procedure



Source: Nijkamp and Vreeker (2000)

Current integrated frameworks to assess sustainability, whether nationally, internationally, locally or company-focused, have been reviewed to determine relevant aspects (or criteria) that should be considered when assessing sustainability (Labuschagne et al., 2005). The reviewed selection frameworks are based on the prospects:

(1) The indicator framework includes a set of measurables.
(2) The indicator framework addresses all three dimensions of sustainable development, i.e. environmental, social, and economic indicators are part of the framework.
(3) The indicator framework has a wide focus, i.e. at a national, community or company level.

5.4. THE CRITERIA FOR THE SUSTAINABLE DEVELOPMENT

A good meadurable should satisfy a number of criteria (Tate, 2002). Further, Ekins et al. (2008) seaks for the attendaces:

(1) What are the criteria for the sustainable development?

(2) What are the fatefull thresholds, that could be applied across these dimensions to facilitate judgments;

(3) What are the degrees for the sustainable development?

De Kruijf and Van Vuuren (1998); Ravetz (2000); Spangenberg et al. (2002); The Energy & Biodiversity Initiative (2002); Yuan and James (2002); Ledoux et al. (2005) have developed a number of additional criteria to determine the quality of selected or proposed measurables as:

(1) Sole, so that each indicator must be meaningful;

(2) Declaratory, so that each indicator must be truly representable of the phenomenon to be earnmarked;

(3) General, so that not dependent on a concrete modes, society or culture, but be momentous for several concepts of truth;

(4) Robust, so that the behest should be safe and no severe changes in case of minor changes in the methodology or improvements in the data base;

(5) Sensitive, i.e. they have to react early and sensibly to changes in what they are observable, to allow to observe the trends or the successes of methods.

5.5. THE INDICATORS TO MODEL THE FRAMEWORK

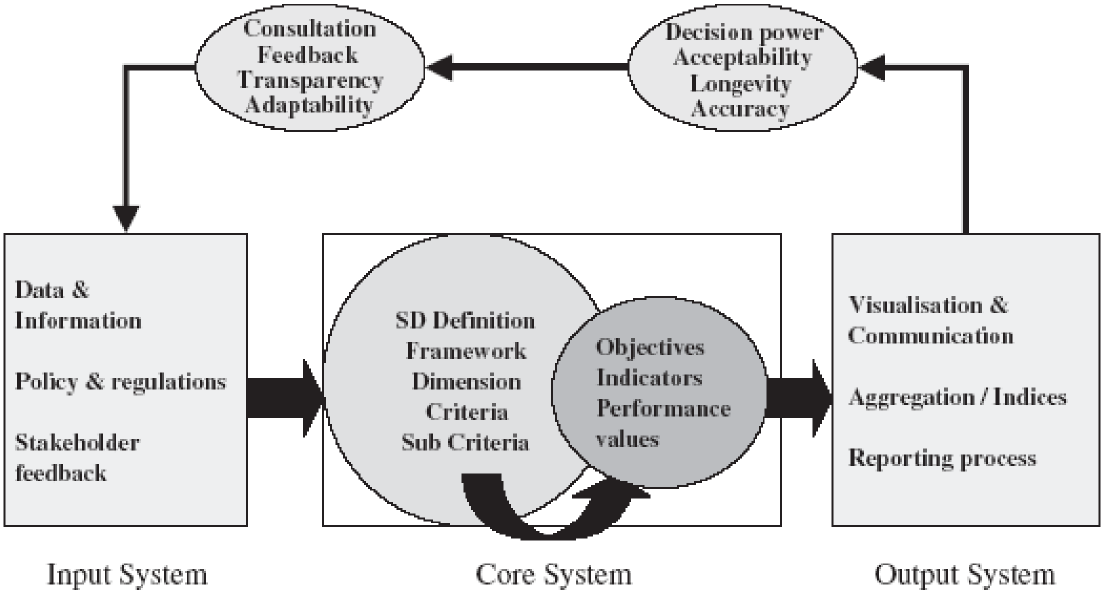
By the words of Potts (2006), the sustainable development indicator system encompasses an assortment of policy contexts, frameworks, dimensions, criteria, indicators, real strategies and targets. The conceptual model of the the sustainable development indicator system (see *Figure 5.4*) displays the core processes that underline sustainability indicator systems. The current approach is based on the peer-reviewed literature and useful evidence from and indicator practice. The approach focuses on the core indicator system as dependent upon a series of inputs and outputs to operate effectively. Inputs involve updates to construct the indicators and to develop an apprehend structure for the policy need when outputs involve to use the indicator results. Hilden and Rosenstrom (2008) emphasize that the different uses and the indicators' development are thus abstrusely connected. To keep the connectance, one can ensure that the indicators of sustainable development stay observable, secure and lawfull while the world is in a stage changes. Some clear challenges related to the indicators use have been identified to develop indicators of sustainable development.

1. There has been a lack of clear and simple frameworks.

2. Developers of indicators often neglect to engage those who are earmarked to well advantages from the indicators in the process.

3. Many real indicators stay unknown to the atlantean users due to unsuccesses to make them accessible (Morrone and Hawley, 1998).

Figure 5.4: The Sustainable Development Indicator System



Source: Potts (2006)

Once a sufficiently corroborated pretense model appears, momentous indicators are easy to acknowledge — the state changeables of the system are supposed to challenge the "state" of the system and are therefore perfect indicators expectants (Brang et al., 2002). By the words of Malkina-Pykh (2002), the central advantages of connectance to a set of indicators to model the framework are shown as:

1. To show how the unequal indicators are connected (connectances of the cause-effect shakle of an issue (up-and-down embedment) and between different issues (west-to-east embedment);

2. To attach the sharpness to the relevance and effectual way of indicators (effectual patterns of social, economic and environmental systems);

3. To enable launches for sustainable development (long-term trends' indicators for the society, economy and environment);

4. To choose fateful system changeables and to offer a steerage to select and aggregate the measurables;

5. To have results for the set of indicators to be more well-rounded, where model changeales to be as a pass stage for trend launches are not yet part of the real set;

6. To serve as a leader for the further development of the completed modeling framework.

5.6. THE CATEGORIZATION AND PRINCIPLES OF INDICATORS

Braat (1991) distinguished two types of sustainability indicators: predictive and retrospective. The predictive indicator provides direct information about the future state and the development of relevant socioeconomic and environmental variables. The retrospective indicator provides information about the effectiveness of existing policies or about autonomous developments (Huang et al., 1998). Tils (2007) can now analyze and assess the German SD strategy and its implementation by identifying five following categories: horizontal and vertical integration, participation, implementation mechanism, monitoring and evaluation. At the same time on the basis of literature review of Patlitzianas et al. (2008), several kinds of indicators have been developed which are categorized as follows:

- Descriptive indicators;
- Basic normalized indicators;
- Comparative indicators;
- Structural indicators;
- Intensity indicators;
- Decomposition indicators;
- Causal indicators;
- Consequential indicators;
- Physical indicators.

According to UK Biodiversity Partnership (2007), the indicators for assessing the 2010 targets are grouped under focal areas based on those identified by the Convention on Biological Diversity and the European Council:

- Status and trends in the components of biodiversity
- Sustainable use
- Threats to biodiversity
- Ecosystem integrity and ecosystem goods and services

- Status of resource transfers and use
- Public awareness and participation

In general, the above-mentioned indicators can be put into two categories (Pittman and Wilhelm, 2007; Devkota, 2005):

(a) Those that adopt a “weak sustainability” standpoint. These indexes calculate (in monetary terms) the natural capital depletion caused by national resources imports.

(b) Those adopting a biophysical or “strong sustainability” perspective. In this case, the strategy is to estimate the foreign environmental physical pressures associated with a national consumption.

According to Osinski et al. (2003), the bio-indicator must:

1. Be, as far as possible, scientifically unquestioned;
2. Be accepted by all participants of the control system;
3. Be useful for all comparable agrarian eco-systems;
4. Always exist with the implementation of the measure;
5. Be recognizable without using a special control procedure;
6. Also be able to show the quality of the implemented measures.

Moreover, Korhonen (2007b) mentioned the four sustainability principles which are as follows:

1. In the sustainable society, nature is not subject to systematically increasing concentrations of substances extracted from the Earth’s crust,

2. Concentrations of substances produced by society,

3. Degradation by physical means,

4. In a sustainable society, human needs are met worldwide in the short- and long-term.

When the four principles are achieved in the global society within the biosphere, sustainability is achieved. In addition, an indicator is validated if it is scientifically sound and if it meets the objectives for which it was created (Zahm et al., 2008). The path toward the objective is the process, which is termed as sustainable development, i.e., development that ensures that sustainability is achieved. Indicators have three key objectives (Veleva et al., 2001):

1. To raise awareness and understanding;
2. To inform decision-making;
3. To measure progress toward established goals.

The largest scientific effort to date has been the creation of indicators of sustainable development and to use them to track a transition toward sustainability. It sought to make more realistic the diverse meanings of sustainable development by attempting to develop indicators of the different values so implied (Kates, 2004). Sustainability being a multidimensional concept is not directly measurable and requires a set of indicators to enable performance toward its multiple objectives to be assessed (Lamberton, 2005). The indicators must be able to translate both internally-relevant and externally-important sustainability issues into the representative measures of performance (Azapagic, 2004). Performance indicators to be considered as SDIs must convey information concerning any of the dimensions of sustainable development except the purely financial ones; this would include indicators capturing sustainable development, sustainability, sustainable production, environmental performance, social performance, and eco-efficiency. SDIs are defined similarly in the field studies, though the definition is narrowed by adding the requirement that they be connected to a vision, a goal, or a target of sustainable development. The latter definition was not applicable in the literature survey of Palme and Tillman (2008), as the presence or lack of a connection between an indicator and a vision, target, or goal was not always evident in the texts studied. Furthermore, inconsistencies in the indicators in the micro-level do not help policy makers in formulating and implementing sustainable strategy at the macro-level. Therefore, standardization of indicators is the next step that may aid identification and comparison of options for more sustainable development (Azapagic and Perdan, 2000).

5.7. TOP-DOWN & BOTTOM-UP APPROACHES IN SUSTAINABLE DEVELOPMENT

The chosen indicators are expected to help political decision-makers evaluate alternatives, make policy choices, and adjust policies and objectives based on actual performance (Rosenstrom and Kyllonen, 2007). The general use of indicators in policy evaluation at various spatial scales is normally premised on the assumption that the outputs of (in this case) complex socioeconomic and biophysical systems can be reduced to a set of measurable indicators, which reflect their performance with respect to societal values about society, economy, biodiversity, etc. (Slee, 2007). In addition, the indicators can make the concept of sustainable development more comprehensible to the public. Concepts and definitions differ greatly and the indicators must be chosen to serve specific needs. The development of sustainable development indicators (SDIs) is often a challenging process. Two main approaches have emerged: a “top-down” or technocratic process, where experts set the agenda, or a more “bottom-up” approach with significant participation from the stakeholders affected by the SDIs (Macleod and Todnem, 2007; Bell and Morse, 2005). Reed et al. (2006) has shown as a two methodological paradigms for developing and applying sustainability indicators at local scales and how each method approaches four basic steps (see *Table 5.1*) (Blue Plan - Regional Activity Centre, 2006).

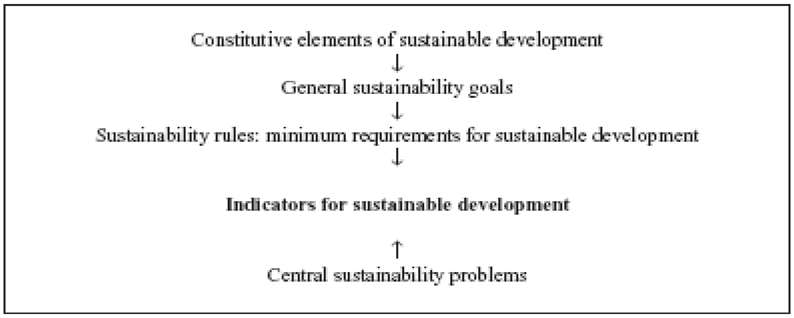
Furthermore, Hartmuth et al. (2008) shows the linkage of the top-down (↓) and bottom-up (↑) approaches in the integrative concept of sustainable development (see *Figure 5.5*).

Table 5.1: Two Methodological Paradigms for Developing and Applying the Sustainability Indicators at Local Scales and How Each Method Approaches Four Basic Steps

Methodological paradigm	**Top–down**	**Bottom–up**
Step 1: establish context	Typically land use or environmental system boundaries define the context in which indicators are developed, such as a watershed or an agricultural system.	Context is established through local community consultation that identifies strengths, weaknesses, opportunities and threats for specific systems.
Step 2: establish sustainability goals and strategies	Natural scientists identify key ecological conditions that they feel must be maintained to ensure system integrity.	Multi-stakeholder processes identify sometimes competing visions, end-state goals and scenarios for sustainability.
Step 3: identify, evaluate and select indicators	Based on expert knowledge, researchers identify indicators that are widely accepted in the scientific community and select the most appropriate indicators using a list of pre-set evaluation criteria.	Communities identify potential indicators, evaluate them against their own (potentially weighted) criteria and select indicators they can use.
Step 4: collect data to monitor progress	Indicators are used by experts to collect quantitative data which they analyze to monitor environmental change.	Indicators are used by communities to collect quantitative or qualitative data that they can analyze to monitor progress towards their sustainability goals.

Zource: Reed et al. (2006)

Figure 5.5: Linkage of the Top-Down (↓) and Bottom -Up (↑) Approaches in the Integrative Concept of SD



Source: Hartmuth et al. (2008)

5.8. THE COMPOSITE INDICATOR

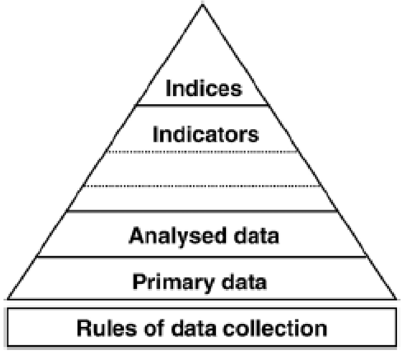
The development of a sustainable development reference system involves five steps (Garcia et al., 2000):

1. Specifying the scope of the sustainable development reference system;
2. Developing a framework to agree on components within the system;
3. Specifying criteria, objectives, potential indicators and reference values;
4. Choosing the set of indicators and reference values;
5. Specifying the method of aggregation and visualization.

The composite indicator can be simply defined as an aggregation of different indicators under a well-developed and pre-determined methodology. Thus the composite indicator lies on the top of an "Information Pyramid" (see *Figure 5.6*) (Hammond et al., 1995b). The aggregation of the diverse indicators in a single composite indicator, differs conceptually from other indicator-based techniques such as Multi-Criteria Assessments (MCA) where the constituent indicators are not aggregated into a single number. Composite indicators are becoming increasingly popular for sustainability assessments at various scales e.g. (Prescott-Allen, 2001; Krajnc and Glavic, 2005b; Tanzil and Beloff, 2006; van Dijk and Mingshun, 2006). Hardi and DeSouza-Huletey (2000) point out the reasons for applying statistical and econometric techniques to SD:

- To improve the empirical base of the results;
- To formulate an SD theory, policies or models adequately;
- To find and collect data on SD issues and identify gaps;
- To estimate the relationships between indicators;
- To provide criteria for determining conclusions that are supported by data;
- To influence decision-makers at all levels to turn SD principles into everyday practice.

Figure 5.6: The Information Pyramid.



Source: Hammond et al. (1995b)

5.9. THE PRESSURE STATE RESPONSE (PSR) INDICATOR FRAMEWORK

Putting indicators in an appropriate context or framework can increase their usefulness (IISD, 1997). The driving force-pressure-state-impact-response (DPSIR) indicator framework is a general framework for organizing systems of indicators of sustainable development (Turner, 2000; Bellini, 2005; EEA, 2006b; Zavadskas and Antucheviciene, 2006; Nuissl et al., 2009). The framework assumes cause–effect relationships between interacting components of social, economic and environmental systems (Smeets and Weterings, 1999). The systems according Amajirionwu et al. (2008) proposes five types of indicators:

(1) Driving force indicators, which refer to human activities, processes and patterns that impact on sustainable development.

(2) Pressure indicators, which refer to activities having a direct effect on a given issue.

(3) State indicators, which describe the observable changes as a result of the earlier mentioned pressures.

(4) Impacts indicators, which show the effect of the impact on the population, economy, ecosystems.

(5) Response indicators which show the actions taken by the society in response to the changes in the state of sustainable development.

Although the DPSIR framework has been criticized for over-simplifying reality and ignoring many of the linkages between issues and feedbacks within the socio-ecological system, the framework is nevertheless a useful conceptual system (Smeets and Weterings, 1999).

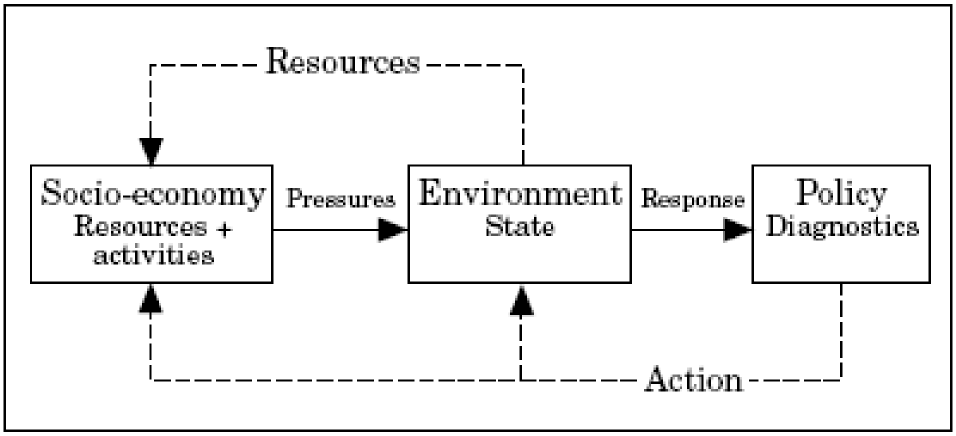
Pressure–State–Response (PSR) methodology was developed by the OECD, for the categorization of environmental indicators, and is based on the "stress–response" model (OECD, 1993). Since the layout echoes the well-known pressure–state–response framework, the structure might also aid the identification of causal links between metrics (Keirstead and Leach, 2008). The PSR methodology of the the conceptual framework for sustainability indicators (see *Figure 5.7*) does not try to determine the nature or to shape interactions between human activities and the situation of the environment but tried to express how the human activities exert pressures on the environment that can involve changes. The society then reacts through the changes with environmental and economic policies and programs, which is intended to prevent or to decrease pressure. The methodology's components according to Patlitzianas et al. (2008) and Buchs (2003) are described as follows:

- Pressure: It describes the direct and indirect pressures of human activities that are applied in the environment. (What is causing the environmental conditions to change?)

- State: It concerns the environmental conditions from the above-mentioned pressures. (What are the effects on the environment?)

- Response: It describes the actions taken to prevent or to decrease the environmental repercussions and to maintain the natural resources. (What actions are being taken in public and private sectors to respond to changes in the state of the environment?).

Figure 5.7: The Conceptual Framework for Sustainability Indicators



Source: Crabtree and Bayfield, 1998

Indicators should not only be derived considering pragmatical argumentations, but also referring to an optimal theoretical background. This demand is especially important because in many cases the indirect effects, chronicle interactions, accumulative reaction chains and complex interaction webs can lead to the most evident consequences for the performance of the particular system processes. Thus, a holistic approach is an important prerequisite for a reliable indication of complex systems with different scales (Wiggering et al., 2006).

5.10. SUMMARIES AND PROPOSALS

In the current chapter there were pointed out the following topics concerning the following topics:

1. Which kind of Definition and Goals has been given to Indicators (*Section 5.2*);
2. What is the Design Process for the Sustainable Development Indicator (*Section 5.3*);
3. What are the Criteria for Sustainability (*Section 5.4*);
4. What is A Modeling Framework for Indicators (*Section 5.5*);
5. Which kind of Categorization and Principles of Indicators is described (*Section 5.6*);
6. Top-down and Bottom-up Approaches are provided in Sustainable Development (*Section 5.7*);
7. The composite indicator is defined (*Section 5.8*);
8. The Pressure State Response (PSR) indicator framework is discussed (*Section 5.9*).

Different authors represented the various views while are defining the indicators. Later on an attractive design process is provided for the sustainable development indicators. After defining the indicators, criteria for sustainability are discussed. Categorization and principles of indicators are a next step in sustainable development indicators. Interesting top-down and bottom-up approaches are highlighted in the current chapter. Finally, the pressure-state-response indicator framework is taken into consideration to show the purpose of each defined indicator.

The key point of this chapter is the definition of a composite indicator, which can be simply defined as an aggregation of different indicators under a well-developed and pre-determined methodology. This indicator is proposed to interlink the current chapter with **Chapter 4 – The Sustainability Indices**, where the Composite Sustainable Development Index (CSDI) was proposed for the evaluation of sustainable development. To meet the challenges of sustainability, an approach to integrated assessment is required to provide a good guidance for decision-making. Decision-makers had a very difficult task for assessment of sustainable development per region. Meanwhile, it is proposed that decision-makers combine indicators into one while referring to society. It is suggested that they merge into the other group of indicators while referring to the economy. In the same way, the environmental indicators are joined as another composite indicator. Therefore, three composite indicators, i.e. social, economic and environmental indicators, are proposed to highlight the concept of sustainable development. To review and define each composite indicator, refer to **Chapter 6 – Theoretical Framework**.

PART B

FRAMEWORKS

In Part B, frameworks are stated to be a preamble for the key model of the PhD thesis, namely theoretical framework, and to represent the role of the suggested model and further steps, namely, methodological framework. A model with dimensions (S, EC, EN), themes (S1-S6, EC1-EC6, EN1-EN6) and indicators for sustainable development is proposed. The further development of the model leads to the subsequent extent themes (S1, EC3-EC6, EN1-EN4), where the environmental themes are drafted from the biodiversity concept, namely vegetation are of EN1-Sparse; EN2 – Medium, EN3- Dense and EN4-Landscape. The three(3) sub-models as to each dimension, namely Social, Economic and Environmental ones, are presented separately. The final look at the proposed model of the current thesis shows all the connectances for core model with the evolved chapters.

CHAPTER 6

THEORETICAL FRAMEWORK

Chapter 6 – Theoretical Framework, reviewed approximately 350 indicators, which belong to three dimensions, i.e. Social Indicators (**Appendix 1** - **Social Indicators**); Economic Indicators (**Appendix 2** - **Economic Indicators**); Environmental Indicators (**Appendix 3** – **Environmental Indicators**). Each indicator is separately discussed taking into consideration the huge range of overviews of the authors on diverse topics of sustainable development. In general, the overviews of different authors were kept to show not only the precise opinions of the authors but also their diverse thoughts on the same indicator. Afterwards the Proposed Model with Dimensions, Themes and Indicators for Sustainable Development (see *Section 6.2*) is proffered in *Figure 6.1* of the current chapter.

Mainly two (2) themes, i.e. Population (S1) and Transportation (S6), out of six (6), namely, S1-S6, are discussed in *Sub-Section 6.2.1 – Social Indicators (S)* of *Section 6.2 – Proposed Themes and Indicators for Sustainable Development* in **Chapter 6 – Theoretical Framework**. These two (2) themes are chosen as they have an important role in Sustainable Development of Greece. By the words of Baldwin-Edwards (2006), migration at the borders of Turkey from S1 theme and Traffic especially in Athens from S6 theme are the main problems for social dimensions of sustainable development. In addition, the interlink of human security, well-being & sustainability to population is shown in *Figure 6.2* (Anand & Gasper, 2007) of **Chapter 6 – Theoretical Framework.** Furthermore, Population (S1) & Transportation (S6) somehow correlate to each other as shown by the conceptual model of land development in *Figure 6.3* (White et. Al, 2009) and represented in **Chapter 6 – Theoretical Framework**.

All six (6) themes of Economic (EC) dimension have a major impact on Sustainable Development of Greece (Hellenic Ministry for the Environment, 2002; Blue Plan – Regional Activity Centre, 2007; 2008). Primarily, two (2) main themes, Agriculture (EC4) & Tourism (EC6) interrelate with each other (*Figure 6.5 –The Derived System Graphs for "School" & "Agriculture" Groups* of **Chapter 6** – **Theoretical Framework**).

Environmental Indicators (See **Appendix 3** – **Environmental Indicators (EN)**) are categorized into six (6) themes, i.e. EC1-EC6, which have relation to the Environmental Footprint by Eaton et al. (2007) & Chambers et al. (2000B), whose approach is shown by the schematic representation of the environmental footprint & its land types in *Figure 6.6* of **Chapter 6** – **Theoretical Framework**. "Ecological" or "Environmental" Footprints represent the indicators for the sustainable development. As it was shown by the Level of Biodiversity in *Table 2.1* of **Chapter 2** – **Economic Valuation of Biodiversity Loss** of *Section 2.2 –Environmental Foundations for Biodiversity Analysis & Valuation*, the general model for biodiversity is shown in *Figure 6.7* of **Chapter 6** – **Theoretical Framework**, where not only Economic & Environmental Evaluations are presented but also Evaluation of Biodiversity using GIS as a tool. Recently, the new technology has been developed that even for Gene level, a few evaluation can be performed using the Remote Sensing & Geographic Information System. The general model for biodiversity (*Figure 6.7*) of **Chapter 6** – **Theoretical Framework** with the proposed themes and indicators for sustainable development (see *Figure 6.1*) has an interesting interlink, which has the following indication:

1. Ecosystem = Dimension (S; EC; EN);
2. Species = Themes (S1 – S6; EC1 – EC6; EN1 – EN6);
3. Genes = Indicators organized by themes;
4. Functions = Interaction between Direction, Themes & Indicators.

There is another interesting point to be mentioned in the current thesis. If Ecosystem is taken at the level of themes, let say Agriculture (EC4), then the following indication of the general model for biodiversity will be:

1. Ecosystem = Agriculture (EC4);
2. Species = Agronomists; Lands; Plants; Trees; Animals; Water; Heats; Pesticides etc.
3. Genes = Each Agronomist with His Own Land, Number of Plants; Trees and Animals; the Amount of Used Water; Heat & Pesticides
4. Functions = Interaction Between Ecosystem; Species & Genes to Reach Optimal Needs & Solutions

Finally, the concept of biodiversity presented as general model for biodiversity can be applied to different subjects and levels.

6.1. INTRODUCTION

By reviewing the literature it is possible to point out the main features that should characterize sustainability indicators:

1. ***Multidimensionality***:

   Indicators must describe the different dimensions of sustainability – economy, environment, society – with an integrated perspective (Distaso, 2007; Lindholm et al., 2007; Ness et al., 2007; Bohringer and Loschel, 2006; Egger, 2006; Nijkamp and Vreeker, 2000; Atkinson and Hamilton, 1996; Munasinghe and McNeely, 1995);

2. ***Guidance to Policy-Making***:

   Indicators must support the decision processes. They must assess the main problems, guide choices and solutions, and facilitate the verification of the targets achieved (Hezri and Dovers, 2006; Olewiler, 2006; Hezri, 2004; Herzi and Hasan, 2004; Capello and Nijkamp, 2002; Kates et al., 2001; Hardi and Zdan, 1997; ICLEI, 1995);

3. ***Sharing***:

   Indicators must support the sharing of local policy general strategies among local communities and the sharing of development goals towards sustainable development. This is possible only through a clear and comprehensible communication of complex information (Jollands and Harmsworth, 2007; Olewiler, 2006; Yuan et al., 2003; Lindholm and Nordeide, 2000; ICLEI, 1994);

4. ***Objectivity and Relevance:***

   Indicators must be significant and also be an exact portrayal of the considered context. In their definition, technical competences are needed (Bohringer and Jochem, 2007; Fraser et al., 2006; Olewiler, 2006; Hezri, 2004; Custance and Hillier, 1998; Harger and Meyer, 1996; ICLEI, 1995);

5. ***On the Basis of the Objectives and the Context:***

   Indicators must be coherent with the development goals set down by the LA21 process. This is important to guarantee the efficacy and the utility of the evaluations that follow in every single local context (Rosenstrom and Kyllonen, 2007; Wilson et al., 2007; Hezri and Dovers, 2006; Olewiler, 2006; Hezri, 2004; Hukkinen, 2003; Hardi and Zdan, 1997; ICLEI, 1995);

6. ***Participation:***

The choice of indicators must be the result of a bottom-up process. This process ensures sharing of the measurement tool and validity of the evaluations that follow to all the stakeholders (Jollands and Harmsworth, 2007; Rosenstromand Kyllonen, 2007; Mickwitz et al., 2006; Reed et al., 2006; Hezri, 2004; Corbiere-Nicollier et al., 2003; Yuan et al., 2003; Fraser, 2002; Morse et al., 2001; Valentin and Spangenberg, 2000; Bouni, 1998; Pinfield, 1996).

The European Union Strategy for Sustainable Development focuses on six themes, which are enhanced, by four other themes derived from further discussion on sustainability by the EU, UN, etc. (EUROSTAT, 2007). In this Chapter, approximately 350 indicators are classified into three dimensions, i.e. social, economic and environmental dimensions. Each dimension is sub- classified into 6 themes.

Table 6.1: Three dimensions of SD with Proposed Sub-Classified 6 Themes

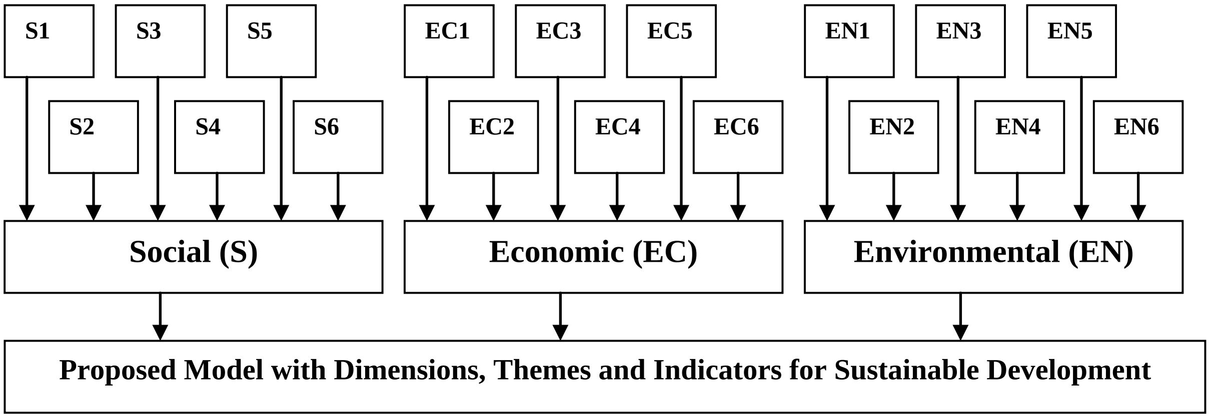
1. Social (S) :	**2. Economic (EC) :**	**3. Environmental (EN):**
S1 : Population;	EC1 : Investment;	EN1 : Land & Soil;
S2 : Social Conditions;	EC2 : Standard of Living;	EN2 : Water;
S3 : Knowledge & Wisdom;	EC3 : Production & Consumption;	EN3 : Air;
S4 : Health;	EC4 : Agriculture;	EN4 : Biodiversity;
S5 : Political Conditions;	EC5 : Industry;	EN5 : Climate Change & Energy;
S6 : Transport.	EC6 : Tourism.	EN6 : Nature.

The current Section reviews the authors' point of view per each indicator. It is necessary to associate a sustainability measure with every single indicator. This measure has the exact meaning of whether an indicator is expected to increase or decrease or to stay stable to keep the local sustainability over time. The trend of sustainability is shown to improve sustainable development for the region. The PSR system provides an overall framework for indicator selection. The whole presentation of all described indicators with just stated points are presented in **APPENDIX 1 – Social Indicators**; **APPENDIX 2 – Economic Indicators**; **APPENDIX 3 – Environmental Indicators**.

6.2. PROPOSED MODEL WITH DIMENSIONS, THEMES AND INDICATORS FOR SUSTAINABLE DEVELOPMENT

Approximately 350 indicators are classified into three dimensions, i.e. social, economic and environmental dimensions. Each dimension is sub-classified into 6 themes as presented in the proposed model with dimensions, themes and indicators for sustainable development (see *Figure 6.1*).

Figure 6.1: Proposed Model with Dimensions, Themes and Indicators for Sustainable Development



The current Sub-Section reviews the authors' point of view per each indicator. The PSR system provides an overall framework for indicator selection. The trend of sustainability is shown to improve sustainable development for the region.

6.2.1. Social Indicators (S)

All six (6) themes of Social (S) dimension have major impact to Sustainable Development.

Full descriptions of Social indicators are presented in **Appendix 1** – **Social Indicators (S)**. Only 2 themes, i.e. **Population (S1)** and **Transportation (S6)** are discussed here. These two (2) themes are chosen as they have an important role in Sustainable Development of Greece (Maldwin-Edwards, 2006). Migration in the borders of Turkey from S1 theme and Traffic especially in Athens from S6 theme are the main problems for the social dimension of sustainable development. In addition, **Population (S1)** and **Transportation (S6)** somehow correlate to each other presented in conceptual model of land development (*Figure 6.3*). Small research of Indicators of Sustainable Transportation was conferred in **Appendix 4** – **Indicators of Sustainable Transportation**.

6.2.1.1. Population (S1)

In his essay on the principle of population, Malthus (1798) discussed the potential for human population growth to exceed the capacity of the resources required to sustain it (Luck, 2007). Keiner (2006) has pointed to the following laws concerning population:

Law 1: Population growth and/or growth in the rates of consumption of resources cannot be sustained.

Law 2: In a society with a growing population and/or growing rates of consumption of resources, the larger the population, and/or the larger the rates of consumption of resources, the more difficult it will be transformed the society to the condition of sustainability.

Law 3: The response time of populations to changes in the human fertility rate is the average length of a human life, or approximately 70 years.

Law 4: The size of population that can be sustained (the carrying capacity) and the sustainable average standards of living of the population are inversely related to one another.

Law 5: One cannot sustain a world in which some regions have high standards of living while others have low standards of ling.

Law 6: All countries cannot simultaneously be importers of carrying capacity.

Law 7: A society that has to import people to do its daily work is not sustainable.

Law 8: Sustainability requires that the size of the population is less than or equal to the carrying capacity of the ecosystem for the desired standard of living.

Law 9: The benefits of population growth and of growth in the rates of consumption of resources accrue to a few; the costs of population growth and growth in the rates of consumption of resources are borne by all of society.

Law 10: Growth in the rate of consumption of a non-renewable resource, such as a fossil fuel, causes a dramatic decrease in the life expectancy of the resource.

Law 11: The time of expiration of non-renewable resources can be postponed, possibly for a very long time.

Law 12: When large efforts are made to improve the efficiency with which resources are used, the resulting savings are easily and completely wiped out by the added resources that are consumed as a consequence of modest increases in population.

Law 13: The benefits of large efforts to preserve the environment are easily canceled by the added demands on the environment that result from small increases in human population.

Law 14: When rates of pollution exceed the natural cleansing capacity of the environment, it is easier to pollute than it is to clean up the environment.

Law 15: The chief cause of the problem is solutions.

Law 16: Humans will always be dependent on agriculture.

Law 17: If, for whatever reason, humans fail to stop population growth and growth in the rates of consumption of resources, Nature will stop these growths.

Law 18: In a local situation within the US, creating jobs increases the number of people locally who are out of work.

Law 19: Starving people don’t care about sustainability.

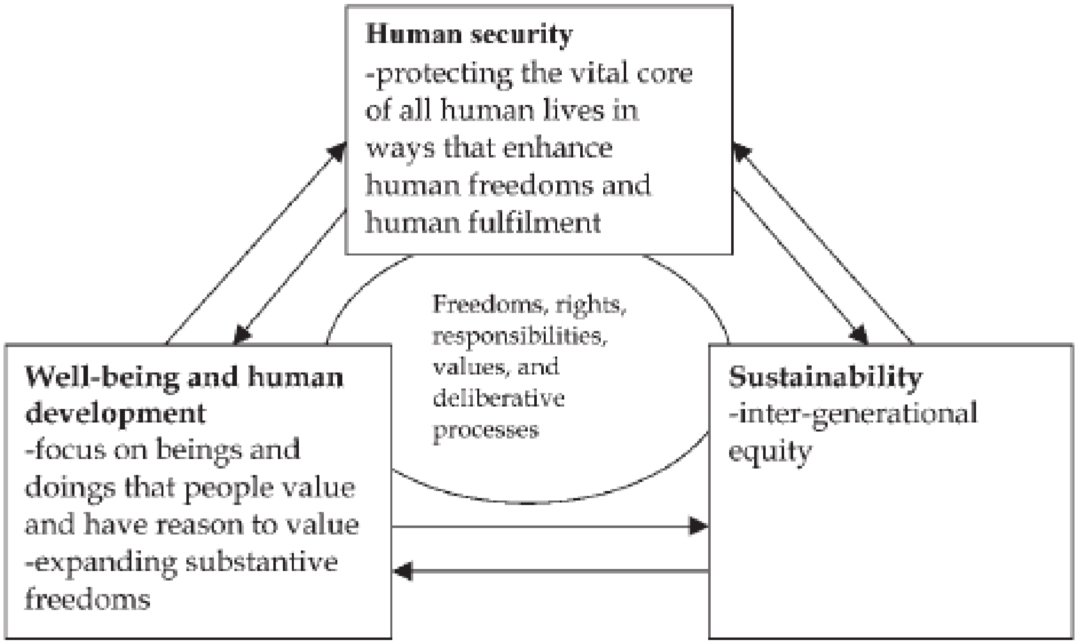
Law 20: The addition of the word “sustainable” to our vocabulary, to our reports, programs and papers, to the names of our academic institutes and research programs, and to our community initiatives, is not sufficient to ensure that our society becomes sustainable.

Law 21: Extinction is forever.

According to Stoms (2000), the magnitude and location of human population growth in many parts of the world and its associated impact on biodiversity are a major environmental conflict. There is a tendency of increasing population causing insufficient provision of public service and degrading quality of life; so a particular municipality may stabilize its population through growth management, and this may be reflected in positive values for urban sustainability indicators (Schetke and Haase, 2008; Huang et al., 1998). Recent evidence on the location of urban growth indicates that exurban areas, those located well outside established urban and suburban boundaries, have witnessed a disproportionate amount of population growth and new land settlement in recent decades (Clark et al., 2009; Berube et al., 2006; Fulton et al., 2001). High population densities offer opportunities for efficient use of resources, such as electricity and transport facilities, as well as providing an efficient structure for waste disposal and sewage infrastructure (Giradet, 1999; Moles et al., 2008). Currit and Easterling (2009) focus on rural household demographics, like household size, fertility, on-farm population density, age and mortality.

The connectance of not only human security, well-being and sustainability (see *Figure 6.2*, Anand and Gasper, 2007), but also land development (*Figure 6.3*, White et al., 2009) to population is considered.

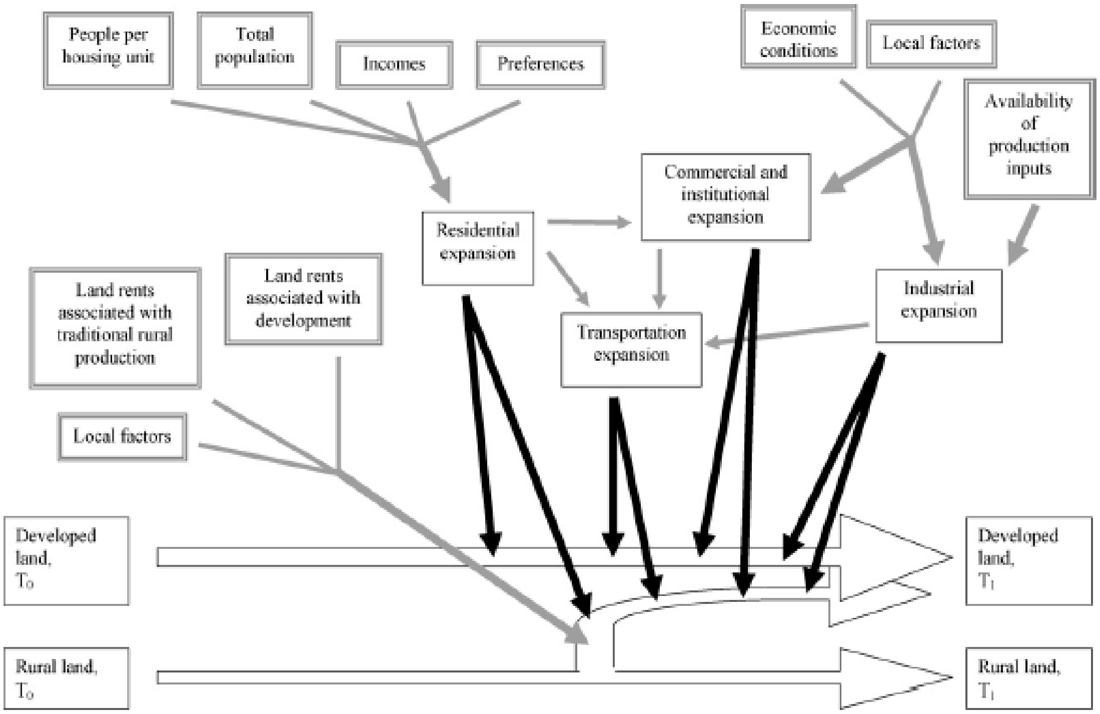
Figure 6.2: Human Security, Well-Being and Sustainability



Source: Anand and Gasper (2007)

According to McGranahan (2008), migration, i.e. population change, is a major life decision, correspondence between preferred landscapes and migration would provide strong evidence of a fundamental importance of landscape. Migration is also of interest given the evolutionary biologists' argument that contemporary landscape preferences.

Figure 6.3: Conceptual Model of Land Development. Arrows illustrate changes in the area of developed and rural land over time (white), factors affecting development (gray and black), and four categories of land-use expansion (residential (*D*R), commercial and institutional (*D*C), industrial (*D*I), and transportation (*D*T); black).



Source: White et al. (2009)

6.2.1.2. Transportation (S6)

As it is visible from the conceptual model of land development (see *Figure 6.3)*, that Population (S1) and Transportation (S6) somehow correlate to each other. As it has been mentioned above transportation in Athens is a problematic topic. A small review of research has been done related to Indicators of Sustainable Transportation. The whole paper is located in **Appendix 4 – Indicators of Sustainable Transportation**. Generally, the current paper is a literature review of the following topics:

1. History of Environmental economics is highlighting the views of classical and neoclassical Economists;
2. History and definitions for Sustainable Development by referring to the equity issues and transportation impacts on sustainability;
3. Introduction to Urban Transportation reviewing the factors influencing urban behavior, the comparison of traditional transportation planning with sustainable development orientations, urban activity and transportation

Interaction, various models, first described the procedural steps by a decision maker, the linkage between transportation planning and stages of decision making, economic valuation methods etc.

4. Sustainability Indicators analyzing the objectives-led structure for strategy formulation, suggested indicators for different transport policy objectives, simple and comprehensive sustainable transportation indicators, defined 26 variables and the matrix of interrelations between each other, the society indicator (I_9) with respect to relatively global weight W_9 out of 10 general indicators.

5. Some suggestions are provided for the future work considering the case study (Greece).

Future Work

One of the problematic issues is Transportation Traffic, especially, in the city of Athens, Greece. The necessity of sustainable indicators for transportation is required. The section of sustainability indicators outlines some already classified indicators. The first core task will be to identify indicators for the transportation sustainability with the case of Greece. Secondly, suitable variables for the current study will be chosen out of 26 variables taken from the paper of Ulengin et al (2008). Thirdly, the weights will be given to each indicator considering the interlinks or interactions between each indicator (Liu and Lai, 2009). Later on, the intersection of variables and indicators with their own weights will be analyzed. The new interlinked matrix for the variables will be constructed. Finally, the relationships between variables based on proper proposed hypothesis will be settled down.

This approach was suggested but not performed due to lack of existing statistical data like indicators for the transportation sustainability with the case of Greece.

6.2.2. Economic Indicators (EC)

All six themes of Economic (EC) dimension have major impact to Sustainable Development. Full descriptions of Economic indicators are presented in **Appendix 2 – Economic Indicators (EC)**. It is apparent from the contemporaneous economic data; four (4) themes (EC3-EC6) stand for the input data of economic indicators. Presenting differently the defined themes of economic indicators coincides with the real statistical ones as follows:

1. EC3 (Production & Consumption) – Agricultural Goods;
2. EC4 (Agriculture) – Agriculture;
3. EC5 (Industry) – Industry;
4. EC6 (Tourism) – Tourism.

Only 2 themes, i.e. **Agriculture (EC4)** and **Tourism (EC6)** are discussed here. These 2 themes are chosen as they have an important role in Sustainable Development of Greece (Hellenic Ministry for the Environment, 2002; Blue Plan - Regional Activity Centre, 2007; 2008). **Agriculture (EC4)** and **Tourism (EC6)** have an essential part of the Economy of Greece (OECD, 2002a). Additionally, **Agriculture (EC4)** and **Tourism (EC6)** somehow interrelate with each other through the derived system graphs for "School" and "Agriculture" groups (see *Figure 6.5*).

6.2.2.1. Agriculture (EC4)

Agricultural systems around the globe continuously change as a result of enlarging trade blocks, globalization and liberalization, introduction of novel agro-technologies, changing societal demands and climate change (van Ittersum et al., 2008). Parallel to liberalization of markets, the European Union (EU) has engaged in a political ambition to devise policies that aim to improve the sustainability of agricultural systems, i.e., their economic viability, environmental soundness and social acceptability, and to enhance the contribution of agricultural systems to sustainable development of society and ecosystems at large (EC, 2001). According to Schneeberger et al. (2007), the rates of change of the agricultural elements were mostly driven by national political forces (e.g. laws and regulations) and economic instruments (e.g. subsidies); the technical innovations coming from the international level; the farmers adopting these innovations (i.e., cultural factors on the farmer's level); and natural/structural factors within the municipalities.

Saifi and Drake (2008b) mention five central issues which stand out in brief discussion of agro-environmental history that is relevant both to the notion of coevolution and to sustainable agriculture.

(1) Although human beings initially evolved through genetic mutation and selection, the changes we have undergone during the agricultural era have been almost entirely cultural. Consciousness and learning have become the main forces in our ongoing development.

(2) The agricultural development is a coevolutionary process that initially involved the agricultural and ecological systems. It came to involve also larger socioeconomic system associated with the emergence of towns and cities.

(3) This development has been enhanced by conscious actions that resulted in increased long-term food production. These actions were based on a complex system of inter-generational learning and knowledge that have generally relied on the trial and error method.

(4) A slow growth in the demand for food enabled traditional agriculture to increase production while protecting the resource base.

(5) The interactive forces, which influence agricultural development, have gradually come to include the regional, national, and global levels of the ecological and socioeconomic systems.

Three (3) interesting questions follow from these broad vision statements about sustainability.

1. How does a general, economy-wide, vision apply to a single sector, such as agriculture?

2. Which impediments to a freely functioning market economy can explain failure of the agricultural sector to move on a sustainable path of economic development (Stimson et al., 2006)?

3. Which policies will steer the agricultural sector in a more sustainable direction?

These three questions provide a natural foundation for analyzing the sustainability of agriculture (Aldy et al., 1998).

Sustainability, sustainable development and so sustainable agriculture are terms that tend to be diluted and in consequence easily "abused" as it is also the case of the term "integrated" (integrated crop production, integrated pest management, etc.), due to the lack of clearly defined criteria, principles and limitations (Buchs, 2003). Appropriate principles and indicators of sustainable agriculture in a country or region can thus be found in the following dimensions:

1. Value system and ethics
2. Traditional agriculture
3. Food demand
4. Technological development
5. Energy and biomass
6. On-farm natural resources
7. Off-farm natural resources
8. Ecological system and environmental degradation
9. Food safety and other health aspects
10. Food security and regional distribution
11. Farm economy

In the opposition to the opinion of Tzilivakis and Lewis (2004), there are no breakdowns of the indicator values by farm type or geographical demarcation, some are not measured directly on the farm and fewer have direct links with on-farm management decisions. Zahm et al. (2008) points to the indicators, which aim to characterize the key concepts taken from the definition of sustainable agriculture:

1. ***Viability*** involves, in economic terms, the efficiency of the production system and is securing the sources of income of the farming production system in the face of market swings and uncertainties surrounding direct payments.

2. ***Livability*** focuses on analyzing whether the farming activity provides a decent professional and personal life for the farmers and their families.

3. ***The environmental reproducibility*** of the ecosystems linked with the farms can be analyzed using agro-environmental indicators in particular, which characterize the impacts of farming practices on the environment.

Vlahos and Beopoulos (2003) described groups of indicators in Greece which is estimated based on organic agriculture and integrated crop management documentation:

- Response (Public policy; Market signals; Technology – qualifications);

- Driving forces (Management; Trends; Input use; Land use);

- Pressure (Resource exhaustion; Pollution; Benefits);

- State (Natural landscape; Biodiversity; Natural resources);

- Impacts (Habitats and biodiversity; Natural resources).

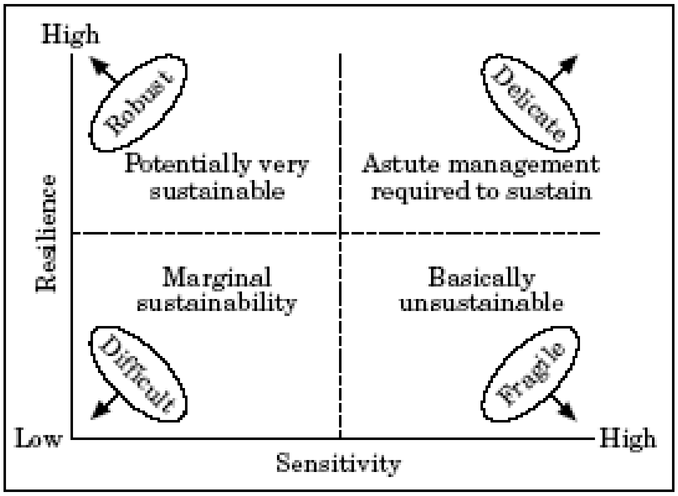
By studying important sustainability issues in each of the above dimensions for a particular country or region and by discussing the relations pertaining between these issues, Saifi and Drake (2008b) may be able to depict a limited number of reasonable principles of sustainable agriculture. Although the above eleven dimensions are relevant to sustainability with respect to most agricultural systems, they vary in content between societies, between periods of development within a given society, and between communities in relation to nutrients circulation and local ecological systems.

Tellarini and Caporali (2000) and Lynam and Herdt (1989) emphasized that agricultural researchers should:

a. Recognize the importance of the sustainability of agricultural systems,
b. Devise appropriate ways of measuring sustainability,
c. Empirically examine the sustainability of some well-defined cropping or farming systems,
d. Define the externally present in such systems,
e. Develop methods to measure those externally.

The paper argues that this is due to the neglect of market opportunity as a driving force for lowland use and the agro-ecological gradient as an important modifier. The paper of Erenstein et al. (2006) argues that lowland development efforts are due to the neglect of market opportunity as a driving force for lowland use and the agro-ecological gradient as an important modifier. Furthermore, agro-ecosystem analysis also analyses resilience and sensitivity and therefore falls into this category of sustainability assessment (Smith and McDonald, 1998). Blaikie and Brookfield (1987) show that by treating both as vectors, resilience and sensitivity can be used to classify the sustainability of agro-ecosystems (see *Figure 6.4*). Sustainability, productivity, stability, equitability and practicability are also measures commonly used in agro-ecosystem analysis (Conway, 1985). Altieri (1989) goes further, incorporating political issues and socioeconomic aspects.

Figure 6.4: Categories of Potential Sustainability of Agro-ecosystems



Source: Blaikie and Brookfield (1987)

Moreover, according to Smith et al. (2000) and Smith and McDonald (1998), the conceptual approaches to agricultural sustainability assessment are therefore:

1. Sustainability as an approach to agriculture:
   - Sustainability as an alternative ideology;
   - Sustainability as a set of strategies.
2. Sustainability as a property of agriculture:
   - Sustainability as an ability to satisfy goals;
   - Sustainability as an ability to continue

Agricultural landscapes are mosaics of physical and human-managed patches that vary in size, shape and arrangement (Forman and Gordron, 1986; Fu et al., 2006). In common agricultural policy domain (including fisheries policies and forest policy) of EU policies, reducing overuse would be beneficial for biodiversity (Polski, 2005; Cenni, 2006), but also cost saving and a contribution to global sustainable development (Spangenberg, 2007). The interrelations between poverty, biodiversity of agro-ecosystems and agricultural development are complex and poorly understood. Hengsdijk et al. (2007) use the model to examine the consequences of a set of regional poverty and biodiversity indicators, of four so-called poverty reduction strategies, i.e.

(1) Intensification of production;

(2) Diversification towards livestock production;

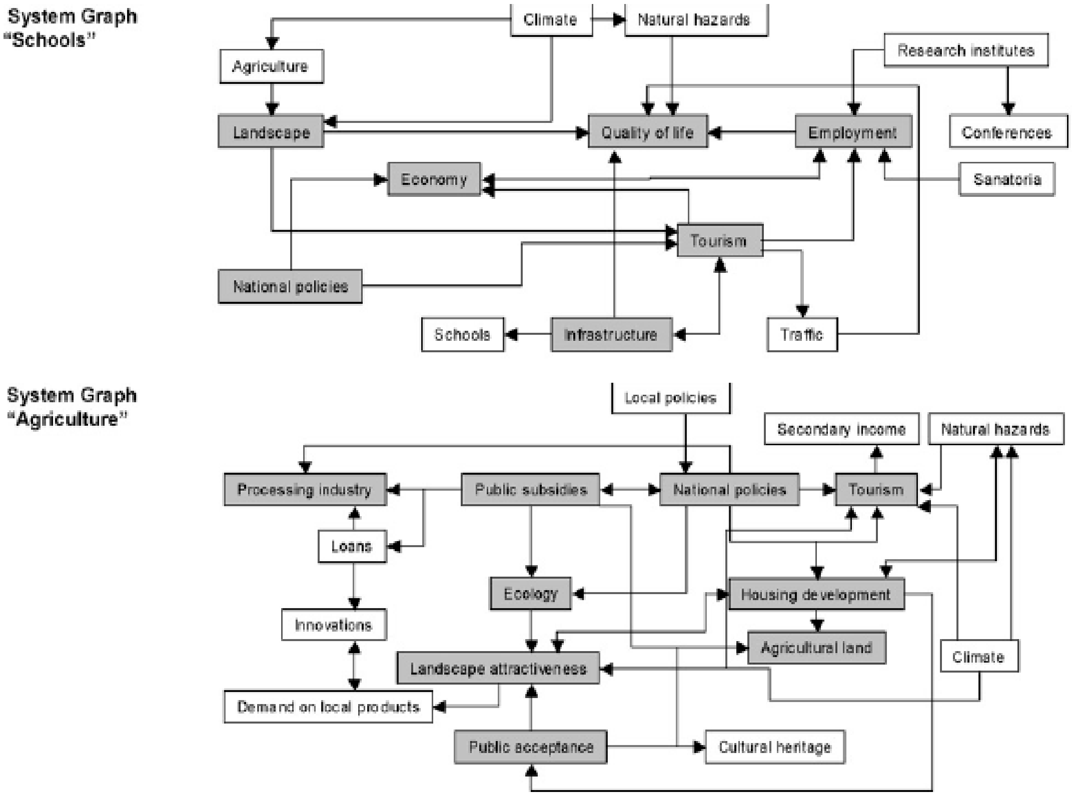
(3) Land expansion;

(4) An exit from agriculture.

Furthermore, it has been shown by Buchs et al. (2003) that an exclusive or prior-ranking assessment of biodiversity as richness of species, cultivars, genotypes, etc. by surrogates according to popular assessment criteria (e.g. “ecological priority areas”; Roth and Schwabe, 2003) does not include the major problem that we face in assessing the agricultural landscape today. Particularly for the biotic assessment of the *cultivated* areas criteria are demanded which are not based only on a pure maximizing of “biodiversity”, but include more structural and functional qualities of the biocoenosis according to the hierarchic components (structure, function and composition) defined by Noss (1990). Furthermore, “Sustainable agriculture is the management and utilization of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality and ability to function, so that it can fulfill—today and in the future—significant ecological, economic, and social functions at the local, national, and global levels, and does not harm other ecosystems” (Lewandowski et al., 1999; Rodrigues et al., 2003).

Walz et al. (2007) has derived the system graphs for “School” and “Agriculture” groups (see *Figure 6.5*).

Figure 6.5: The Derived System Graphs for "School" and "Agriculture" Groups



Source: Walz et al. (2007)

6.2.2.2. Tourism (EC6)

As it can be seen *from* the derived system graphs for "School" and "Agriculture" groups (see *Figure 6.5*), Agriculture (EC4) and Tourism (EC6) somehow interrelate with each other. Tourism is one of the few potential growth sectors of mature economies (Neves, 2006). In the 20th century, the globalization of capitalism, the movement of populations, and advances in transportation and communication technology have helped to develop tourism into one of the world's largest industries. According to the World Travel & Tourism Council (2004), world tourism receipts will reach approximately $727.9 billion by the end of 2004, with tourism generating more than 214 million jobs and is contributing about $5.5 trillion of gross domestic product (GDP), 10.4% of the world's total. Because of its ability to create income, taxes, hard currency and jobs, tourism has made a significant contribution to the economics of many communities around the world (Sirakaya et al., 2001; Choi and Sirakaya, 2006).

Ecotourism is often identified as a strategy that embodies a middle ground (e.g., Place, 2001). By having people pay to visit nature, it holds the potential to maintain ecosystem services, raise standards of living for locals, and foster economic growth (Honey, 1999). The International Ecotourism Society defines ecotourism as "responsible travel to natural areas that conserves the environment and improves the well-being of local people" (Neves, 2006). Two concerns surround ecotourism initiatives, however. First, ecotourism that is part of an integrated reserve matrix system that meets sustainable development goals differs from that which seeks to serve as the primary economic base for a regional economy, of which there are few success stories (Buckley, 2003; Duffy, 2002). In addition, vulnerability analysis suggests that diversification may contribute to more resilient use systems that enhance society's capacity to respond, adjust and adapt to perturbations (Cross, 2001; Turner et al., 2003). If ecotourism schemes are not part of integrated land-use systems they violate this indicator of sustainability. Second, ecotourism's conceptual basis perpetuates the schism between nature and society; even if a worthy stop-gap measure; slowing rapid environmental degradation in the short term for a specific locality, it does not represent a model for sustainable development in society writ large (Klepeis and Laris, 2006).

For tourism development to be sustainable, Butler (1991) suggested that such prerequisites as coordination of policies, pro-active planning, acceptance of limitations on growth, and commitment to a long-term vision, should be fulfilled during the early stage of planning (Ahn et al., 2002).

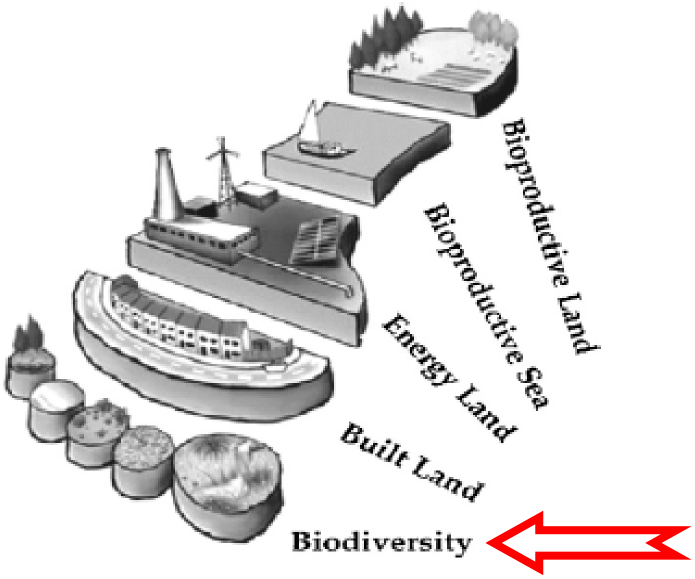
It should come as no surprise, then, that sustainable community tourism (SCT) has had limited practical application in the areas of management, planning and monitoring systems in the local level (Butler, 1999). Berry and Ladkin (1997) have argued that the relatively small size of tourism businesses and the dramatic rise of the sustainability issue have raised serious questions about implementing and monitoring sustainable tourism at local levels. Consequently, individual countries have no clearly defined national policies and strategic reports on sustainable development and its implementation. Neither a common management framework nor indicators exist to systematically track and monitor socioeconomic and political changes in communities. According to Weaver and Lawton (1999), indicator studies in tourism are still in their infancy, although the WTO and other organizations are making sporadic efforts to develop them (Sirakaya et al., 2001; Choi and Sirakaya, 2006). Miller (2001) presents the filtering device for indicators of sustainable tourism, which answers to the following question:

1. Is the indicator applicable to tourism?
2. Is the indicator a complete indicator?
3. Is the indicator applicable to all types of tourism?
4. Is the data for the indicator easily obtained?
5. Is the calculation required for the indicator simple?
6. Is the indicator understandable?
7. Is the data objective, quantifiable and reliable?
8. Does the indicator point towards sustainable development?
9. Can the indicator be measured on an ongoing basis?

6.2.3. Environmental Indicators (EN)

Environmental Indicators (See Appendix 3 **- Environmental Indicators (EN)**) are categorized into 6 themes, which have a relationship to the environmental footprint presented by Eaton et al. (2007) and Chambers et al. (2000b). For the schematic representation of the environmental footprint and its land types refer to *Figure 6.6*. "Ecological" or "Environmental" Footprints (and related parameters) represent partially the sustainability indicators (Hammond, 2006).

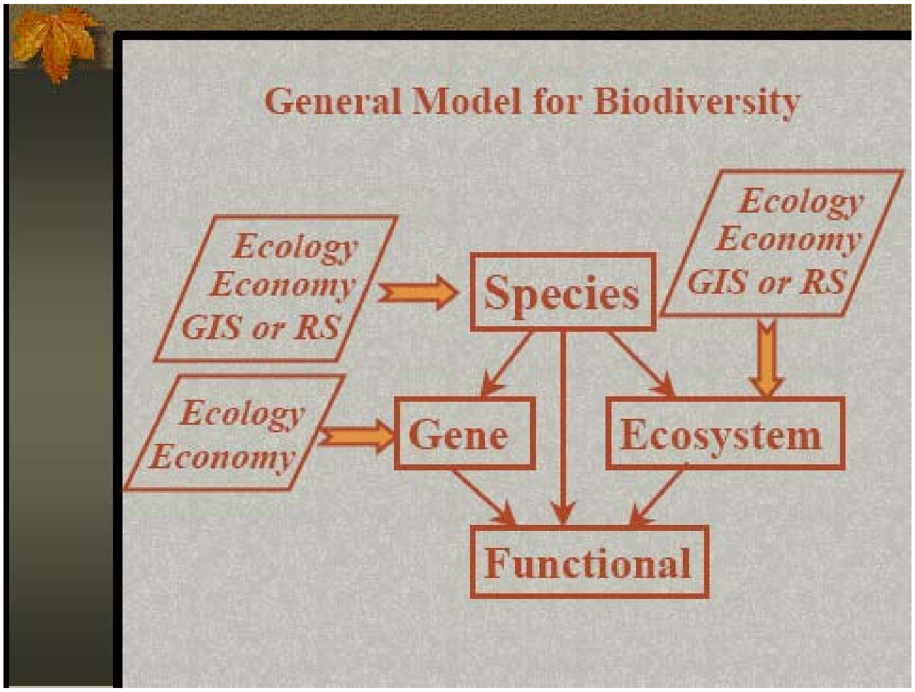
Figure 6.6: Schematic Representation of the Environmental Footprint and its Land Types



Source: Eaton et al. (2007) and Chambers et al. (2000b)

The current thesis outlines the evaluation of Biodiversity in Sustainable Development. As it was shown in levels of biodiversity (see *Table 2.1)* of Chapter 2 – Economic Valuation of Biodiversity Loss; *Section 2.2 - Environmental Foundations for Biodiversity Analysis and Valuation*, another approach for the levels of biodiversity are shown by the general model for biodiversity (see *Figure 6.7*), where not only economic and environmental evaluations are given but also evaluation of biodiversity using GIS as a tool. Recently, the technology has been developed that even for Gene level some evaluations can be performed using Remote Sensing and Geographic Information System. However, this case was preferably excluded from the current thesis.

Figure 6.7: General Model for Biodiversity



The general model for Biodiversity (*Figure 6.7*) and the proposed themes and indicators for sustainable development per the environmental dimension of the suggested model (see *Figure 6.1*) has an curious connectance, which is the following indication:

Ecosystem = Dimensions (S; EC; EN)
Species = Themes (S1-S6; EC1-EC6; EN1-EN6)
Genes = Indicators organized by themes
Functions = Interactions between Dimensions; Themes and Indicators

There is another interesting point to be mentioned in the current thesis. If Ecosystem is taken at the level of Themes, let say Agriculture (EC 4), then the following indication of the general model for biodiversity will be:
Ecosystem = Agriculture (EC4)
Species = Agronomists; Lands; Plants; Trees; Animals; Water; Heats Pesticides etc.
Genes = Each agronomist with his own land, number of plants, trees and
animals, the amount of used water, heat and pesticides
Functions = Interactions between Ecosystem, Species and Genes to reach
optimal needs and solutions

Finally, the concept of biodiversity presented as general model for biodiversity can be applied to different subjects and levels.

6.3. SUMMARIES AND PROPOSALS

This Section reviewed approximately 350 indicators, which belong to three dimensions, i.e. social (S), economic (EC) and environmental (EN). Each dimension is classified into six themes. Social indicators (Appendix 1 **- Social Indicators**) have the following themes: (S1) – population, (S2) – social conditions, (S3) – knowledge & wisdom, (S4) – health, (S5) – political conditions, (S6) – transport. Economic indicators (Appendix 2 **- Economic Indicators**) consist of the following themes: (EC1) – investment, (EC2) – standard of living, (EC3) – production & consumption, (EC4) – agriculture, (EC5) – industry, (EC6) – tourism. Environmental indicators (Appendix 3 **– Economic Indicator**s) sub-classified into the following themes: (EN1) – land & soil, (EN2) – water, (EN3) – air, (EN4) – biodiversity, (EN5) – climate change & energy, (EN6) – nature. Each indicator was separately discussed taking into consideration the huge range of overviews of the authors on diverse topics of sustainability. In general, overviews of different authors were kept to show not only the precise opinions of the authors but also their diverse thoughts on the same indicator. Afterwards the Proposed Model with Dimensions, Themes and Indicators for Sustainable Development (Section 6.2) presented in *Figure 6.1*.

The current thesis outlines the evaluation of Biodiversity in Sustainable Development. As it was shown by the levels of biodiversity (see *Table 2.1)* of Chapter 2 **– Economic Valuation of Biodiversity Loss**; *Section 2.2 - Environmental Foundations for Biodiversity Analysis and Valuation,* the levels of biodiversity are shown in the general model for biodiversity (see *Figure 6.7*), where not only economic and environmental evaluations but also evaluation of biodiversity using GIS as a tool, are given. Later on, the concept of biodiversity presented as a general model for biodiversity is being applied to different subjects and levels. That is why the third dimension, i.e. Environmental Indicators (Section 6.2.3), are more applied according to the concept of Biodiversity.

To have a better idea of the current thesis and all links between Chapters, refer to the next chapter, i.e. Chapter 7 **– Methodological Framework**.

CHAPTER 7

METHODOLOGICAL FRAMEWORK

The methodological framework shows all the interrelationships between the chapters and represents the core model drafted from the theoretical framework. The proposed model has taken the roots from the concept of SD, i.e. Society, Economy and Environment (see *Figure 4.8* and *Figure 4.9* of the *Section 4.12 – Sustainable Development Index* of Chapter 4 – **The Sustainability Indices**) and the Composite Sustainable Development Index (see *Section 4.13 – Composite Sustainable Development Index* of Chapter 4 – **The Sustainability Indices**). The Core Proposed Model (see *Figure 7.1*) is driven from the proposed model with dimensions, themes and indicators for the sustainable development (see *Figure 6.1* of Chapter 6 – **Theoretical Frameworks**) and has three (3) sub-models:

1. The first sub-model represents the first dimension, i.e. Society (S). The social indicators per social themes (S1-S6) are shown in Appendix 1 – **Social Indicators (S)**. The theoretical approach to the Social dimension is overviewed in *Subsection 6.2.1 – Social Indicators* of Chapter 6 – **Theoretical Framework**. The direct input of Social data is equal to the Population (S1) data (see *Figure 7.2*) is presented in *Section 7.2 – Social Indicators (S).*

2. The second sub-model represents the second dimension, i.e. Economy (EC). The economic indicators of economic themes (EC1-EC6) are shown in Appendix 2 – **Economic Indicators (EC)**. The theoretical approach to the Economic dimension is overviewed in *Subsection 6.2.2 – Economic Indicators* of Chapter 6 – **Theoretical Framework**. The inputs of Economic data have the subsequent branches:
    - EC3 (Production & Consumption) – Agricultural Goods;
    - EC4 (Agriculture) – Agriculture;
    - EC5 (Industry) – Industry;
    - EC6 (Tourism) – Tourism.

   These four (4) branches of Economic Data are depicted in *Section 7.3 – Economic Indicators (EC)* (see *Figure 7.3*).

3. The third sub-model represents the third dimension, i.e. Environment (EN). The environmental indicators of environmental themes (EN1-EN6) are shown in Appendix 3 – **Environmental Indicators (EN)**. Due to the lack of Greek statistical environmental data per municipality, an interesting approach has been applied to the proposed model. The only two (2) levels are retrieved from an idea of Biodiversity (see Chapter 2 – **Economic Valuation of Biodiversity Loss**) which is used by McGarigal and Marks (1995) in the Fragstat program, as follows:

   - Ecosystem = Landscape Level
   - Species = Class Level
     - Class 1 – Sparse Vegetation;
     - Class 2 – Medium Vegetation;
     - Class 3 – Dense Vegetation.

   The detailed approach is provided in the branches of Environmental Data (see *Figure 7.4)* of *Section 7.4 – Environmental Indicators (EN).*

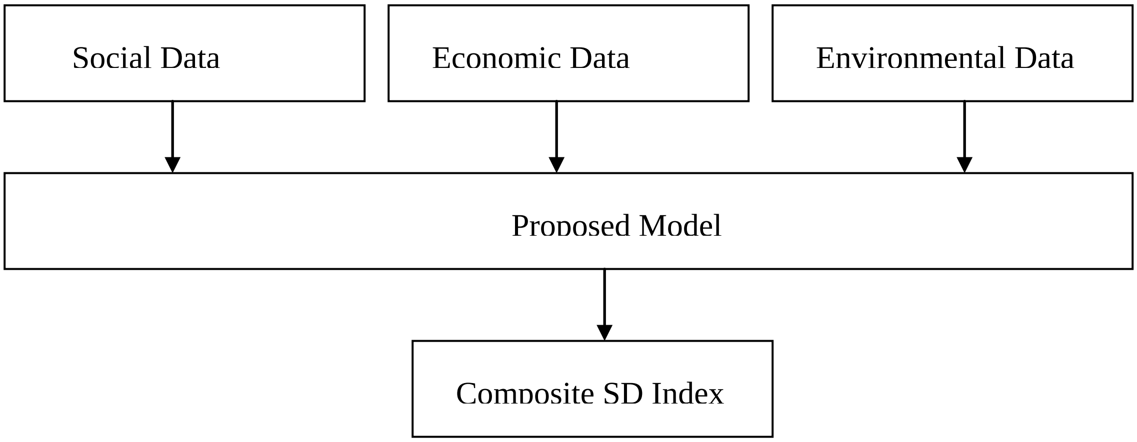
The three (3) aforementioned sub-models are enlarged and are inputs to the Proposed Model (see *Figure 7.5*) presented at the final look of the current chapter.

7.1. INTRODUCTION

Sustainable development is centered on developing a reciprocally advantageous relationship between society, economic development and the environment. Lyytimaki and Rosenstrom (2008) showed a holistic illustration of the sustainable development framework (see *Figure 4.8* in **Chapter 4 – The Sustainability Indices**). Levett (1998) confers the (proposed) Russian dolls model of sustainability (see *Figure 4.9* in **Chapter 4 – The Sustainability Indices**). Underlying Concept of Sustainable Development (see *Figure 4.10* of **Chapter 4 – The Sustainability Indices)** also presents the diverse states of sustainability that could exist for every development.

Approximately 350 indicators, which are classified into three dimensions, i.e. social, economic and environmental dimensions. Each dimension out of three (3) is sub-classified into 6 themes and presented by Proposed Model with Dimensions, Themes and Indicators for Sustainable Development (see *Figure 6.1* and *Table 6.1* of **Chapter 6 - Theoretical Framework**). The idea is based on the *Generic Hierarchy Scheme for Calculation of the Composite Sustainable Development Index* (see *Figure 4.14* of **Chapter 4 – The Sustainable Indices)**. All determined indicators with just described approach are presented in **Appendix 1 – Social Indicators**; **Appendix 2 – Economic Indicators; Appendix 3 – Environmental Indicators**. The reason of presenting by the *Core of Proposed Model* (see *Figure 7.1* of the current chapter).

Figure 7.1: Core of Proposed Model



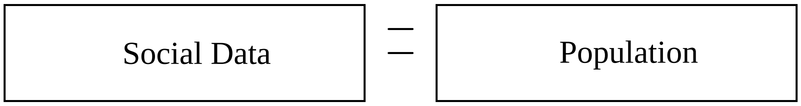
The background, implementation and results of the proposed model are offered by the *Section 11.4 – An Integrated Assessment of Sustainable Development* in the **Chapter 11 – A Model for Integrated Assessment of Sustainable Development**.

7.2. SOCIAL INDICATORS (S)

As is discussed in *Section 6.2.1 – Social Indicators* of **Chapter 6 – Theoretical Framework** the full descriptions of social indicators are presented in **Appendix 1 – Social Indicators (S).** Representation of the social indicators, according to the following six themes: (S1) – population, (S2) – social conditions, (S3) – knowledge & wisdom, (S4) – health, (S5) – political conditions, (S6) – transport, are offered in **Appendix 1 – Social Indicators**.

Mainly two themes, which are (S1) – population and (S6) – transport, play a major role in the sustainable development of Greece. Due to a lack of existing data for social indicators, only one theme, i.e. (S1) – population, is considered as an input to the model of sustainable development (*Section 11.1 – Calculations and Results of Social Indicators* of **Chapter 11 – A Model for Integrated Assessment of Sustainable Development)**. In other words, the input of Social Data represents only Population Data, i.e. *Social Data is Equal to Population Data* (see *Figure 7.2*).

Figure 7.2: Social Data is Equal to Population Data



Population presents a significant key to sustain the world. Human population growth influences to the capacity of the resources. The well-being of humanity is also considered an important factor in the sustainable development of the country. Despite the fact that many of the themes of social indicators are missing, the main theme, i.e. (S1) – population, which is presented by the available or suggested statistical data and final proposed datasets (see *Table 8.2, Table 8.3 and Table 8.7* of **Chapter 8 – Study Area and Datasets)**, serves to go on with the calculation of social data (*Section 11.1 – Calculations and Results of Social Indicators* of **Chapter 11 – A Model for Integrated Assessment of Sustainable Development)**.

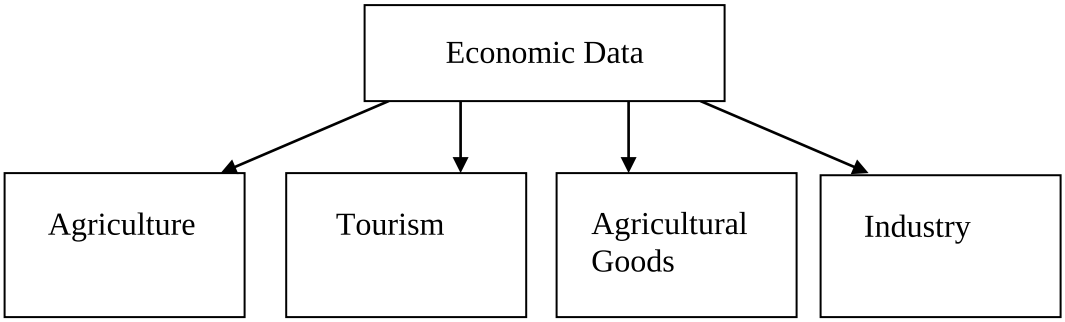
The procedure of calculating the Social Indicators is divided into several parts, which are presented by the procedure of calculating CSDI (see *Figure 4.15* - Krajnc and Glavic, 2005a) and by the scheme for calculation of CSDI (see *Figure 4.16* –Krajnc and Glavic, 2005b) in **Chapter 4 – The Sustainable Indices.** In order to use each indicator, it is necessary to normalize the values. The steps of normalization are examined in *Section 9.3 – Normalization* in **Chapter 9 – Data Preprocessing and Normalization**. Further on, it is required to award weights to each indicator. Due to the hugeness of the numbers of indicators, i.e. 605 indicators, the calculation of the weightings of the indicators are provided in *Section 11.1 – Calculations and Results of Social Indicators, particularly, in Division of Weightings in a matrix in Table 11.2* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development**. Finally, Social Sustainability Sub-index is presented in *Section 11.4.3 – Results* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development**.

7.3. ECONOMIC INDICATORS (EC)

As is discussed in *Section 6.2.2 – Economic Indicators* in **Chapter 6 – Theoretical Framework** there are full descriptions of economic indicators are presented in **Appendix 2 – Economic Indicators (EC)**. There is a demonstration of the economic indicators, according to the following six themes: (EC1) – investment, (EC2) – standard of living, (EC3) – production & consumption, (EC4) – agriculture, (EC5) – industry, (EC6) – tourism, is suggested in **Appendix 2 – Economic Indicators**.

Each country has various economic parameters that influence of the sustainable development of each country. Principally two themes, which are Agriculture (EC4) and Tourism (EC6), have a significant pressure on the sustainable development of Greece. However, the inputs for the Economic Data present the following existing economic Greek statistical data: Agriculture, Tourism, Agricultural Goods and Industry are presented by the branches of economic data (see *Figure 7.3*). The available or suggested data and final proposed datasets are shown by *Table 8.2, Table 8.3* and *Table 8.7* in **Chapter 8 – Study Area and Datasets**, stand for the economic data, i.e. Agriculture, Tourism, Agricultural Goods and Industry, which are considered inputs to the model of sustainable development (*Section 11.2 – Calculations and Results of Economic Indicators* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development)**. In other words, the inputs of Economic Data represent Agriculture, Tourism, Agricultural Goods and Industry Data, where they are presented as the branches of the economic data (*Figure 7.3*).

Figure 7.3: The Branches of Economic Data



The method of counting the Economic Indicators is divided into several parts, which are available by the procedure of calculating the CSDI (see *Figure 4.15* – Krajnc and Glavic, 2005a) and by the scheme for calculation of the CSDI (see *Figure 4.16* – Krajnc and Glavic, 2005b in **Chapter 4 – The Sustainable Indices)**. With the purpose of each indicator's use, it is compulsory to normalize the values. The steps of normalization are examined in *Section 9.3 – Normalization* in **Chapter 9 – Data Preprocessing and Normalization**. Additionally, it is necessary to reward weights to each indicator. The calculation of the weight of the indicators is provided in *Section 11.2 – Calculations and Results of Economic Indicators* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development**. Finally, Economic Sustainability Sub-index is presented in *Section 11.4.3 – Results* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development**.

7.4. ENVIRONMENTAL INDICATORS (EN)

As discussed in *Section 6.2.3 – Environmental Indicators* in **Chapter 6 – Theoretical Framework**, a full description of environmental indicators is presented in **Appendix 3 – Environmental Indicators (EN)**. Expressions of the environmental indicators, according to the following six themes: (EN1) – land & soil, (EN2) – water, (EN3) – air, (EN4) – biodiversity, (EN5) – climate change & energy, (EN6) – nature, are recommended in **Appendix 3 – Environmental Indicators.**

Raw Remote Sensing Data are shown by the available remote sensing data (see *Table 8.1* in **Chapter 8 – Study Area and Datasets**). In order to make use of remote sensing images, data preprocessing and processing are performed. Particularly, Coregistration (*Section 9.1 – Co-registration* in **Chapter 9 – Data Preprocessing and Normalization**) and Noise Reduction (*Section 9.2 – Noise Reduction* in **Chapter 9 – Data Preprocessing and Normalization**) are illustrated in the main flowchart of data pre-processing (see *Figure 9.1* in **Chapter 9 – Data Preprocessing and Normalization)**. Afterward processing of Landsat TM and ETM images is shown in the flowchart of methodology (see *Figure 10.1* in **Chapter 10 – Processing and Results of Remote Sensing Data**. Specifically, the processing of remote sensing data is discussed in *Section 10.2 – Processing of Remote Sensing Data* in Chapter 10 **– Processing and Results of Remote Sensing Data**. Moreover, results of remote sensing data, which represent processed data using Fragstat as software, are highlighted in *Section 10.3 – Results of Remote Sensing Data* in Chapter 10 **– Processing and Results of Remote Sensing Data.**

Retrieved Remote Sensing data, which are shown by the final proposed datasets (see *Table 8.7* in Chapter 8 **– Study Area and Datasets**, become an input of Environmental Data. The theory of derived metrics is discussed in Chapter 3 **– Landscape Metrics based on Remote Sensing Data.** The metrics are related to the Biodiversity concept. The concept of biodiversity in terms of economics is presented by the levels of biodiversity (see *Table 2.1 of Section 2.2 – Environmental Foundations for Biodiversity Analysis and Valuation* in Chapter 2 **– Economic Valuation of Biodiversity Loss)**. Furthermore, the Proposed "Provisions" of Mediterranean Forest are shown in *Figure 2.13 of Section 2.4 – Summaries and Proposals* in Chapter 2 **– Economic Valuation of Biodiversity Loss**. In addition, it is apparent that biodiversity is interrelated with the schematic representation of an environmental footprint; refer to the schematic representation of the Environmental Footprint and it's Land Types (see *Figure 6.6* in Chapter 6 **– Theoretical Framework)**. In addition, a general model of biodiversity is presented by the *Figure 6.7* in Chapter 6 **– Theoretical Framework**. The general model of biodiversity was derived from the levels of biodiversity (see *Table 2.1* in Chapter 2 **– Economic Valuation of Biodiversity Loss**).

In the same way, the output of the Fragstat program has three levels, i.e. Patch, Class and Landscape. The equivalence can be obtainable on the following ways:

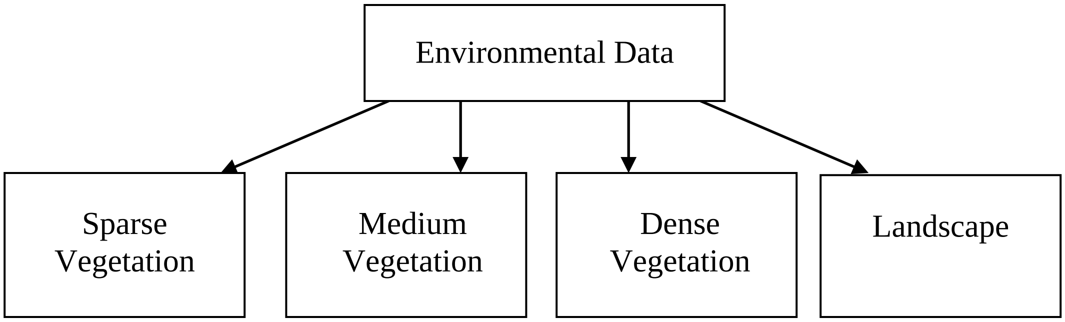
1. Patch = Gene;
2. Class = Species;
3. Landscape = Ecosystem

Patch, i.e. Gene level, is not taken into consideration. Class, i.e. Species level, is considered as three subclasses: Sparse, Medium and Dense vegetation (*Section 10.4.1 – Landscape Indicators at Class Level* in Chapter 10 **– Processing and Results of Remote Sensing Data**), which are considered as inputs to environmental data. Landscape (*Section 10.4.2 – Landscape Indicators at Landscape Level* of Chapter 10 **– Processing and Results of Remote Sensing Data**), i.e. ecosystem level, is considered as an input of the environmental data. The Banches of the environmental data (see *Figure 7.4*), i.e. Vegetation occurred as:

1. Sparse (C1) or (*EN1*);
2. Medium (C2) or (EN2);.

3. Dense (C3) or (EN3);
4. Landscape (L4) or (EN4).

Figure 7.4: The Branches of Environmental Data



The technique of estimating the Environmental Indicators is divided into numerous elements, which are available by the procedure of calculating the CSDI (see *Figure 4.15*–Krajnc and Glavic, 2005a) and the scheme for calculation of the CSDI (see *Figure 4.16*–Krajnc and Glavic, 2005b) of **Chapter 4 – The Sustainable Indices.** With the reason of each indicator's application, it is necessary to normalize the values. The steps of normalization are observed in *Section 9.3 – Normalization* in **Chapter 9 – Data Preprocessing and Normalization.** Later on, it is compulsory to offer weight to each indicator. The estimations of the weights of the indicators are provided in *Section 11.3 – Calculations and Results of Environmental Indicators* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development.** Lastly, Environmental Sustainability Sub-index is presented in *Section 11.4.3 – Results* of **Chapter 11 – A Model for Integrated Assessment of Sustainable Development.**

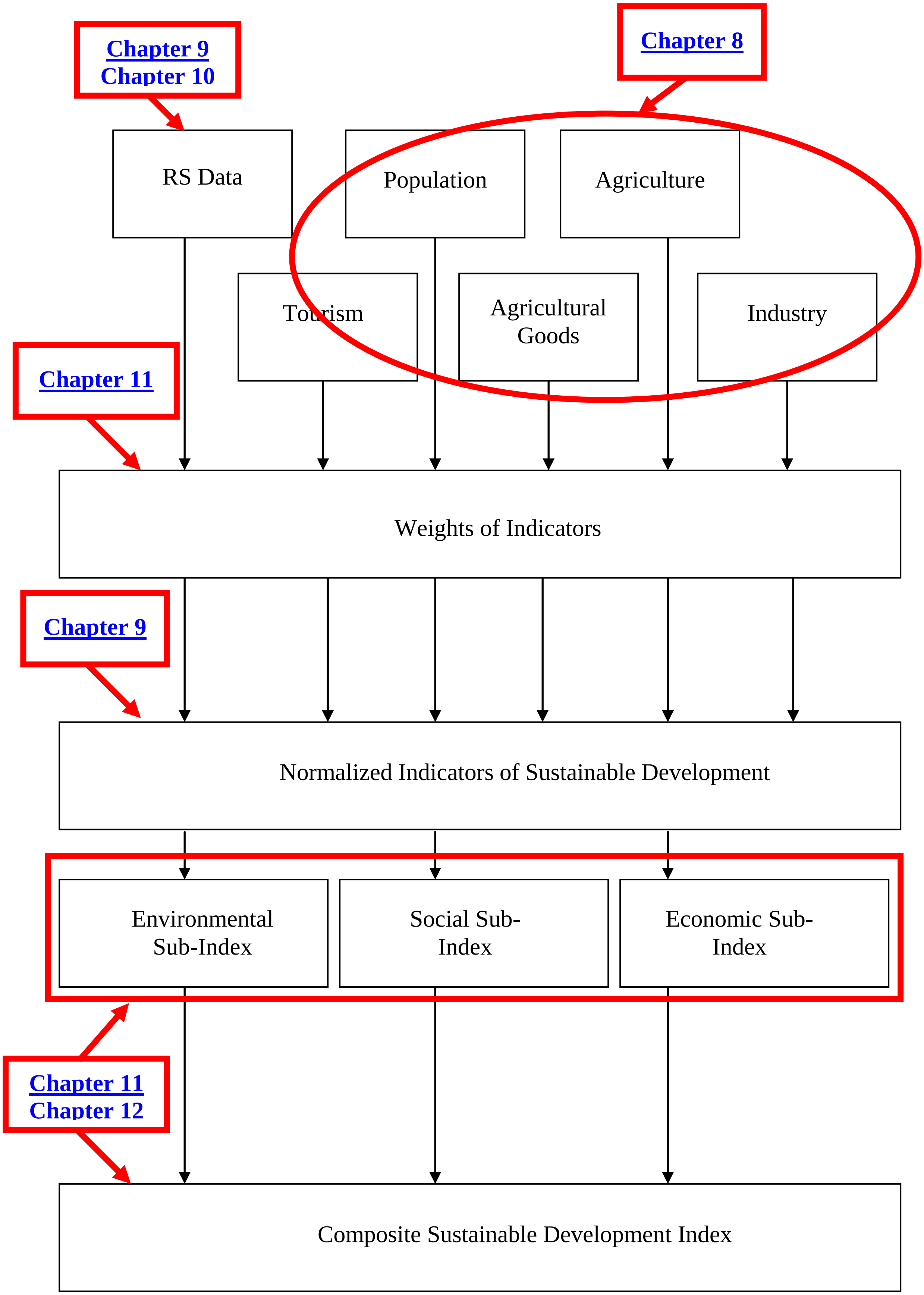
7.5. SUMMARIES AND PROPOSALS

The final look of the proposed model (see Figure 7.5) of the current thesis is enlarged as the core of the proposed model (see *Figure 7.1* of the current chapter). The proposed model is discussed in *Section 6.2 – Proposed Model with Dimensions, Themes and Indicators for Sustainable Development*, particularly, in *Figure 6.1* in **Chapter 6 – Theoretical Framework.** The concept of the proposed model is represented by the procedure of calculating the CSDI (see *Figure 4.15* – Krajnc and Glavic, 2005a) and by the scheme for Calculation of CSDI (see *Figure 4.16* – Krajnc and Glavic, 2005b) in **Chapter 4 – The Sustainable Indices.** The procedure of calculating the CSDI is divided into several parts: selecting, grouping, weighting, judging, normalizing indicators, calculating sub-indices and combining them into the CSDI (*Section 11.4 – An Integrated Assessment of Sustainable Development* in **Chapter 11 – A Model for Integrated Assessment of Sustainable Development**).

It is observable that the direct inputs of Social, i.e. Population data, where social data is equal to population data (see *Figure 7.2*) is presented in *Section 7.2 – Social Indicators* and of Economic, i.e. Agriculture, Tourism, Agricultural Goods and Industry data, which are driven from the branches of economic data (see *Figure 7.3)* are available in *Section 7.3 – Economic Indicators.* Due to lack of Greek statistical environmental data per municipality, an interesting approach has been applied to the proposed model. The detailed approach is provided by the branches of environmental data (see *Figure 7.4*) in *Section 7.4 – Environmental Indicators.*

The practical part of the current thesis according to the appropriate chapter is shown by the final look at the proposed model (see *Figure 7.5*) of the current chapter.

Figure 7.5: Final Look at the Proposed Model



PART C

THE CSDI MODEL’S PERFORMANCES

In Part C, the study area of Nea Makri, Athens, Greece is considered, where the inputs of the CSDI model represent three (3) types of datasets as: Society (GR stat. data), Economy (GR stat. data) and Environment (RS data). Each dataset is constructed from its own existent indicators which are grouped per branches. Later on, all the indicators are weighted and normalized. To compute the three (3) afore-marked datasets, the three (3) subsequent Sub-indices are required as:

(1) Society Sub-Index, i.e. Population(S1) Sub-index or Branch;
(2) Economy Sub-Index, i.e. Agriculture(EC4); Tourism(EC6); Agricultural Goods(EC3) and Industry (EC5) Sub-indices or Branches;
(3) Environment Sub-Index, i.e. Vegetation of Sparse (EN1), Medium (EN2), Dense (EN3) and Landscape (EN4) Sub-indices or Branches.

Further on, the three (3) afore-marked Sub-Indices are combined to the CSDI and some recommendations for the future work are suggested. These are the CSDI model’s enforcements or

CHAPTER 8

STUDY AREA AND DATASETS

The current chapter describes the Environmental Conditions on the municipality of Nea Makri, Athens, Greece. There are two (2) types of data are used in the current dissertation and are as:

(1) GR stat data:

- Population Dataset (Society Branch) for the time series of ten (10) years;
- Agriculture Dataset (Economy Branch) for the time series of ten (10) years;
- Tourism Dataset (Economy Branch) for the time series of each year;
- Agricultural Dataset (Economy Branch) for the time series of each year;
- Industry Dataset (Economy Branch) for the time series of each year.

(2) RS data, i.e. Landsat TM and ETM images for the time series of three (3) years.

The first type of dataset, i.e. GR stat dataset, represents two (2) branches, i.e. Society and Economy. The existent GR stat dataset is shown in Available Statistical data (see *Table 8.2*). However, the used GR stat dataset is shown in Suggested Statistical data (see *Table 8.3*) is derived from the existent GR stat dataset because of the differences of the time series. The second type of dataset, i.e. RS dataset, where seven (7) Landsat TM and ETM RS images are used, is shown in Available Remote Sensing Data (see *Table 8.1*) of the current chapter. Due to the afore-marked differences of time series, the final suggested statistical data is given in the *Table 8.7* of the current chapter. The role of the current chapter in the PhD thesis is to introduce the existent and suggested data for the further usage.

8.1. ENVIRONMENTAL CONDITIONS ON THE MUNICIPALITY OF NEA MAKRI, ATHENS GREECE

The Municipality of Nea Makri, Athens, Greece (see *Figure 8.1*) is a town located in the northeastern part of Athens. The area was once known as Plesti, but following the 1922 Greek military disasters in Asia Minor and the subsequent repatriation of Greeks from the town of Makri, it was renamed Nea Makri (New Makri). Until the 1970s, most of the population was rural. As housing developments came to the area, the population boomed and filled into the settlements. Housing developments continue to this day. According to statistics taken from the National Statistical Service of Greece (2001) and from Wikipedia (free encyclopedia), Nea Makri has the population of 14,809, the density of 404 /km² and the area of 36.662km².

The Penteli Mountains that are covered with forests lie to the west and southwest while farmlands are within the Petalies Gulff and to the north except for the downtown part of Nea Makri. Beaches cover the eastern part and areas within the short lines are covered by restaurants, hotels and taverns.

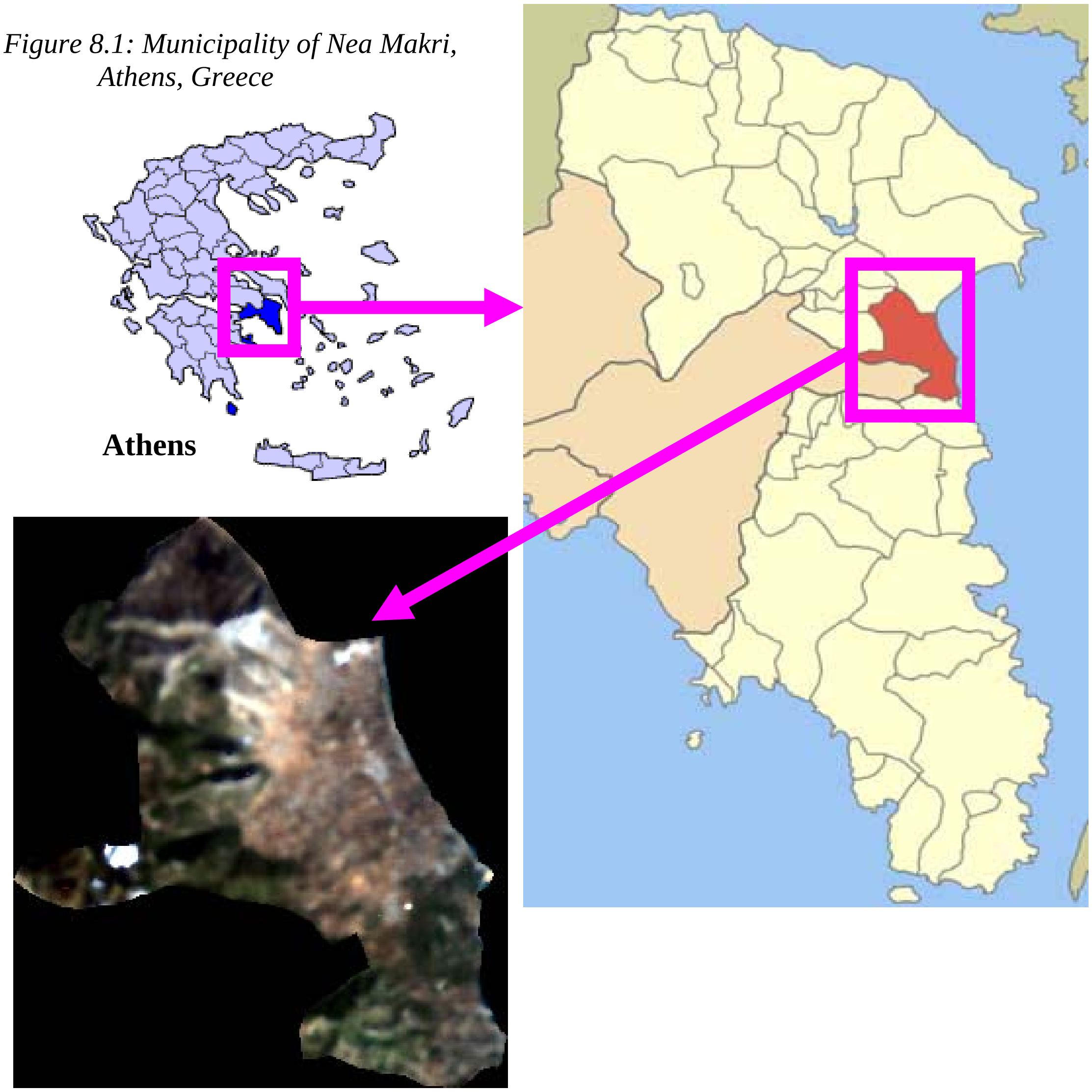


Figure 8.1: Municipality of Nea Makri, Athens, Greece

General and special data and leadings that affect to the Municipality of Nea Makri, Athens, Greece, are the followings (Kosioni-Koen and Papastergiou-Mitsopoulou, 2004):

- Selection and protection of historical data for the landscape of Athens, mountains represented by the mountains of the municipality of Nea Makri, Athens (see *Figures 8.2)* and by the landscapes of the Municipality of Nea-Makri, Athens (see *Figure 8.3*);
- Pollution reduction of the environment;
- Implementation of political residence and incorporation of shaped areas in the urban planning;
- Flood and earthquake prevention;
- Reconstruction of neighborhoods, interception of flooring, improvement of the town, control of treatments and densities;
- Redistribution of treatments and operation and organization of development for the urban planning;
- Qualitative interferences of big scaling;
- Aid to the secondarily urban centers for developments;
- Creation of recreated systems for big towns and nets for connecting green and archeological areas, coastlines, sidewalks and cyclist paths;
- A survey of Olympic Hospitality in all camps of Nea Makri and Agio Andrea;
- A survey of Olympic Works in the Marathon and North of Nea Makri;
- Improvements and upgrades of the roads to Marathon;
- Operation of new airport “ El Benizelos” in Spata;
- Hierarchical subsystems of seaports;
- New lines of railways and trains with the length of Athens Roads and Stavro-Rafinas highways;
- New wide roads (Stavro-Rafinas highways and Athens Roads).

Bearing in mind the fact that Nea Makri, because of the benefits of good weather and location, considering that there are ample services and traditional interfaces with the northern part of the Athens Basin (Lekanopedio), makes the area desirable for people of middle and high means, it is an area for settlement, while it will be attractive for the same reasons to vacationers.

Figure 8.2: The Mountains of the Municipality of Nea Makri, Athens, Greece

Figure 8.3: The Landscapes of the Municipality of Nea Makri, Athens, Greece

In summary, the development model of the municipality for the year 2011 will be suggested as:

1. The Municipality of Nea Makri, Athens, Greece, is planning to have a population of 47000 with 21000 (44%) private and 26000 (56%) vacationers;

2. The following areas are classified and protected and development are limited:
    - Penteliko with the limits of protection which was established in the year of 1988;
    - Forested areas;
    - Coastlines;
    - Remote zones;
    - Archeological area for protection Briksezas and small archeological area in the center. Recently, an ongoing Archeological Museum of Municipality of Nea Makri, Athens, Greece, has been organized (see *Figure 8.4*);
    - Metavizantina Monuments of Monon Agia Paraskevi and Agios Ioannis Theologou and the chapel of Agiou Petrou.

3. Given for the zone development;

Figure 8.4: Ongoing Archeological Museum of the Municipality of Nea Makri, Athens, Greece

4. Conservation and support of highlighted characters of the center of Nea Makri and developing areas of recreation and cultural accoutrements according to the subsequent items:
    - Creation of the Multifunctional Park with the cultural-athletic-educational use of the full space of the old American Base, Outdoors Theaters of old Tamari and a Cultural Center;
    - Development of zones for tourists and pleasures along the seaside;
    - Functionality of camps in Agio Andrea;
    - Creation of marinas for tourists;
    - Extension and accoutrements of the center of town;
    - New wide roads (Stavros-Rafinas highways Athens Roads).
5. Organization of the municipality;
6. The forecasting of the needs of all types of social services;
7. Works on the drainage systems;
8. Topics of Traffic;
9. Creation of networks in general organization of roads;
10. Creation of sidewalks and bicycling networks.

Other networks described are suggested to be enlarged as:

1. ***Water Supply:***

   Municipality of Nea Makri doesn't belong to the district serviced by EYDAP, but the water supply is coming from the highway of Marathon and is applied according to the rules of EYDAP.

2. ***Drainage System:***

   The Municipality of Nea Makri does not have an issue of uncleanness. Drainage is done with absorbents cesspools, which are not in need of regular draining because of beneficially absorbent soils. There is a biological cleaning with irrigation in the hotels of the regions of Marathon, Nireas, Zouberi, Mati and the units of "Posedonia", where there is danger of land pollution. There was neither a plan nor ability for construction of a new infrastructure for the service of renovation of the units of camps, until the recent works for 2004 for the camps with the creation of the Hospitality Representatives Settlement's for Mass Communication. The Municipality of Athens Camp has biological cleaning with irrigation. Furthermore, there is a biological cleaning only in the camps of KEDA and KAA in the area of Agio Andrea.

3. ***Energy:***

   The main use of energy is electrical energy provided by DEH. Petroleum is also another means of energy, which is used in heating systems. There is no central heating; there is not even the beginning of central heating. The carriage substation for the Municipality of Nea Makri is 150/20KV, with the settlements of 2X25MVA, which is considered sufficient nowadays. Because of the increase in the use of energy and reliability of the supply, an increase in the output of the substation was demanded. It has been listed in the transit program (1999-2003), and the replacement should be done with 50MVA for the current substation. It has been set the automatic switches with the arrival of transmission lines of 150000Volt and thus the probability of interruption has been substantially decreased.

4. ***Telephones:***

   The telephone service for the Municipality of Nea Makri is provided by OTE, which provides for the whole country. The OTE building in the municipality of Nea Makri is located on Marathon Road and opposite the Town Hall (Dimarxeio) and contains the phone center for the code of 22940 and the offices for customer services. The capacity of the center is 16000 contacts from which 14000 contacts are in use. There is a need for an increase in the capacity for the predictable population in the year of 2011. Mobile phones are functioning as they function throughout the whole country of Greece.

5. ***Wastes:***

The final destination of wastes is located in the area of Ano Losia. There is also a need for reduction of mass of waste disposal, which should be accomplished recycling of glass, aluminum, plastics and papers in the best ways.

8.2. DATASETS DESCRIPTIONS

8.2.1. Existing Remote Sensing Data

There are five (5) Landsat Thematic Mapper and two (2) Landsat Enhanced Thematic Mapper Plus (ETM+) Satellite or Remote Sensing images. All the information for satellite images is shown in the *Table 8.1*, where Available Remote Sensing Datasets are offered.

Table 8.1: Available Remote Sensing Dataset

No.	Type of data used	Resolution	Acquisition Date
1.	***Landsat TM image***	***30m***	***23 / 10 / 1984***
2.	Landsat TM image	30m	13 / 08 / 1987
3.	***Landsat TM image***	***30m***	***04 / 07 / 1990***
4.	Landsat TM image	30m	14 / 09 / 1993
5.	Landsat TM image	30m	14 / 08 / 1996
6.	Landsat ETM+ image	30m	05 / 07 / 1999
7.	***Landsat ETM+ image***	***30m***	***14 / 08 / 2002***

The detailed work has been performed initially for all images. However, only highlighted images, i.e. Landsat TM (23/10/1984); Landsat TM (04/07/1990) and Landsat ETM+ (14/08/2002) will be used to analyze the existent RS data.

8.2.2. Existent GR Stat Dataset

Existent GR Stat Dataset are presented by the Available Statistical Data (see *Table 8.2).*

Table 8.2: Available Statistical Dataset

No.	Description	Dates
1.	Population	1981, 1991, 2001
2.	Agriculture	1981, 1991, 2001
3.	Tourism	1993-2007
4.	Agricultural Goods	1993-2006
5.	Industry	1993-2008

Due to the magnitude of the current dissertation, only the selected datasets will be employed as the suggested statistical Dataset (See *Table 8.3*).

Table 8.3: Suggested Statistical Dataset

No.	Description	Dataset 1	Dataset 2	Dataset 3
1.	Population	1981	1991	2001
2.	Agriculture	1981	1991	2001
3.	Tourism	-	1993	2001
4.	Agricultural Goods	-	1993	2001
5.	Industry	-	1993	2001

1. Population

The statistical data of the population is presented by the Suggested Statistical Dataset (see *Table 8.3*) are located in **Appendix 5**. For details of Original Statistical Data for Population (1981) use *Table 8.4* and *Appendix 5.1 – Original Statistical Data Population 1981* as references. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

Table 8.4: Original Statistical Data for Population (1981)

No.	Description	Reference
1.	A population with Sex and Age Groups (1981)	Table A.5.1.1
2.	A population with Sex, Age Groups and Family Situation (1981)	Table A.5.1.2
3.	A population with Sex, Age Groups and Level of Education (1981)	Table A.5.1.3
4.	Economic Actors and Non-Actors Population with Sex and Age Groups (1981)	Table A.5.1.4
5.	Economic Actors with Sex, Age Groups and Groups of Personal Professions (1981)	Table A.5.1.5
6.	An economic Actors' Population by Sex, Age Groups of Economic Activities Branches and Positions to the Professions (1981)	Table A.5.1.6
7.	An economic Actors' Population by Sex, Age Groups of Personal Professions and Positions to the Professions (1981)	Table A.5.1.7
8.	Housekeepers with Size and Members who are Regular Residents accordingly with Agreeing Residence and with Non-Regular Residence (1981)	Table A.5.1.8
9.	Housekeepers with Size and Members who stay in Regular Residence accordingly with the Number of Rooms which are Arrangements of the Housekeepers (1981)	Table A.5.1.9
10.	Housekeepers and Members who stay in Regular Residence accordingly with the Density of Residence and with Arranged Comforts (1981)	Table A.5.1.10
11.	Regular Residence with Vehicle Owners and Non-Regular Residence (1981)	Table A.5.1.11
12.	Regular Residence is according to the Number of Available Rooms (1981)	Table A.5.1.12
13.	Regular Residence is according to the Available Comforts (1981)	Table A.5.1.13

For details of Original Statistical Data for Population (1991) use *Table 8.5* and *Appendix 5.2 – Original Statistical Data Population 1991* as references. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

Table 8.5: Original Statistical Data for Population (1991)

No.	Description	Reference
1.	A population with Sex and Age Groups (1991)	Table A.5.2.1
2.	A population with Sex, Age Groups and Family Situation (1991)	Table A.5.2.2
3.	A population with Sex, Age Groups and Level of Education (1991)	Table A.5.2.3
4.	Economic Actors and Non-Actors Population with Sex and Age Groups (1991)	Table A.5.2.4
5.	Economic Actors with Sex, Age Groups and Groups of Personal Professions (1991)	Table A.5.2.5
6.	An economic Actors' Population by Sex, Age Groups of Economic Activities Branches and Positions to the Professions (1991)	Table A.5.2.6
7.	An economic Actors' Population by Sex, Age Groups of Personal Professions and Positions to the Professions (1991)	Table A.5.2.7
8.	Housekeepers with Size and Members who are Regular Residents accordingly with Agreeing Residence and with Non-Regular Residence (1991)	Table A.5.2.8
9.	Housekeepers with Size and Members who stay in Regular Residence accordingly with the Number of Rooms which are Arrangements of the Housekeepers (1991)	Table A.5.2.9
10.	Housekeepers and Members who stay in Regular Residence accordingly with the Density of Residence and with Arranged Comforts (1991)	Table A.5.2.10
11.	Regular Residence with Vehicle Owners and Non-Regular Residence (1991)	Table A.5.2.11
12.	Regular Residence is according to the Number of Available Rooms (1991)	Table A.5.2.12
13.	Regular Residence is according to the Available Comforts (1991)	Table A.5.2.13

For details of Original Statistical Data for Population (2001) use *Table 8.6* and *Appendix 5.3* – *Original Statistical Data Population 2001* as references. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

Table 8.6: Original Statistical Data for Population (2001)

No.	Description	Reference
1.	A population with Sex and Age Groups (2001)	Table A.5.3.1
2.	A population with Sex, Age Groups and Family Situation (2001)	Table A.5.3.2
3.	A population with Sex, Age Groups and Level of Education (2001)	Table A.5.3.3
4.	Economic Actors and Non-Actors Population with Sex and Age Groups (2001)	Table A.5.3.4
5.	Economic Actors with Sex, Age Groups and Groups of Personal Professions (2001)	Table A.5.3.5
6.	An economic Actors' Population by Sex, Age Groups of Economic Activities Branches and Positions to the Professions (2001)	Table A.5.3.6
7.	An economic Actors' Population by Sex, Age Groups of Personal Professions and Positions to the Professions (2001)	Table A.5.3.7
8.	Housekeepers with Size and Members who are Regular Residents accordingly with Agreeing Residence and with Non-Regular Residence (2001)	Table A.5.3.8
9.	Housekeepers with Size and Members where stay in the Regular Residence accordingly with the Number of Rooms which are Arrangements of the Housekeepers (2001)	Table A.5.3.9
10.	Housekeepers and Members who stay in Regular Residence accordingly with the Density of Residence and with Arranged Comforts (2001)	Table A.5.3.10
11.	Regular Residence with Vehicle Owners and Non-Regular Residence (2001)	Table A.5.3.11
12.	Regular Residence is according to the Number of Available Rooms (2001)	Table A.5.3.12
13.	Regular Residence is according to the Available Comforts (2001)	Table A.5.3.13

2. Agriculture

The Suggested Statistical Data of Agriculture (see *Table 8.3*) are located in Appendix 6. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

- Refer to Tab Original Data of *Appendix 6.1* – *Original & Normalized & Final Values Agriculture 1981* for Original Statistical Data of Agriculture 1981.

- Refer to Tab Original Data of *Appendix 6.2 – Original & Normalized & Final Values Agriculture 1991* for Original Statistical Data of Agriculture 1991.
- Refer to Tab Original Data of *Appendix 6.3 – Original & Normalized & Final Values Agriculture 2001* for Original Statistical Data of Agriculture 2001.

3. Tourism

The Suggested Statistical Data of Tourism (see *Table 8.3*) are located in Appendix 7. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

- Refer to Tab Original Data of ***Appendix 7.1*** *– Original & Normalized & Final Values Tourism 1993* for Original Statistical Data of Tourism 1993.
- Refer to Tab Original Data of ***Appendix 7.2*** *– Original & Normalized & Final Values Tourism 2001* for Original Statistical Data of Tourism 2001.

4. Agricultural Goods

The Suggested Statistical Data of Agricultural Goods (see *Table 8.3*) are located in Appendix 8. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

- Refer to Tab Original Data of ***Appendix 8.1*** *– Original & Normalized & Final Values Agricultural Goods 1993* for Original Statistical Data of Agricultural Goods 1993.
- Refer to Tab Original Data of ***Appendix 8.2*** *– Original & Normalized & Final Values Agricultural Goods 2001* for Original Statistical Data of Agricultural Goods 2001.

5. Industry

The Suggested Statistical Data of Industry (see *Table 8.3*), which are generally related to the constructions of buildings, are located in Appendix 9. To have a clear idea of the types of the datasets the subsequent tables are provided for the references.

- Refer to Tab Original Data of Appendix 9.1 – *Original & Normalized & Final Values Industry 1993* for Original Statistical Data of Industry 1993.
- Refer to Tab Original Data of Appendix 9.2 – *Original & Normalized & Final Values Industry 2001* for Original Statistical Data of Industry 2001.

8.3. SUMMARIES AND PROPOSALS

There are two kinds of data used in the current thesis. The first Datasets is Remote Sensing Datasets, which are presented by the *Available Remote Sensing Data* (see *Table 8.1*). The second Datasets is GR statistical Datasets, which are shown by the *Available Statistical Data* (see *Table 8.2*). As the datasets have different years, the chosen statistical data are presented as *Suggested Statistical Datasets* (see *Table 8.3*). Therefore, only three datasets are derived for Remote Sensing and Statistical Datasets. The *Final Proposed Datasets* (see *Table 8.7*), proposes three datasets.

Table 8.7: Final Proposed Datasets

No.	Description	Dataset 1	Dataset 2	Dataset 3
1.	Remote Sensing Dataset	23/10/1984	04/07/1990	14/08/2002
2.	Population Data	1981	1991	2001
3.	Agriculture Data	1981	1991	2001
4.	Tourism Data	-	1993	2001
5.	Agricultural Goods	-	1993	2001
6.	Industry Data	-	1993	2001

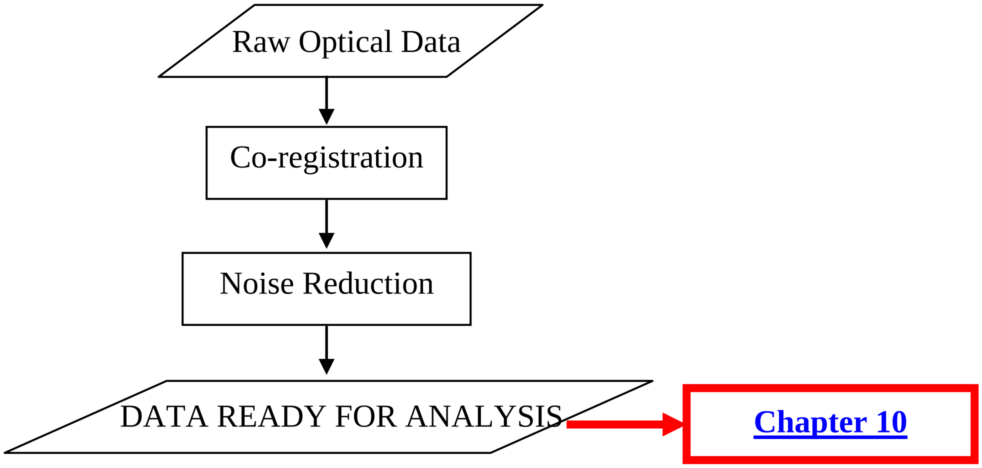
Remote Sensing Datasets are considered in Data Preprocessing (*Section 9.1 – Co-registration and Section 9.2 – Noise Reduction* in **Chapter 9 – Data Preprocessing and Normalization**). Statistical Datasets, i.e. Population, Agriculture, Tourism, Agricultural Goods and Industry Datasets, are utilized for normalizing data (*Section 9.3 – Normalization* in **Chapter 9 – Data Preprocessing and Normalization**) for further use.

CHAPTER 9

DATA PREPROCESSING AND NORMALIZATION

The Landsat TM and +ETM data used for the analysis included several preprocessing steps, which are illustrated in the main flowchart (see *Figure 9.1*) of Data Pre-Processing. Each part of the flowchart is discussed later in the current chapter.

Figure 9.1: The Main Flowchart of Data Pre-Processing



9.1. CO-REGISTRATION

In many cases, images of one area that are collected from different sources must be used together. To be able to compare the separate images pixel by pixel, the pixel grids of each image must conform to the other images in the database. The tools for rectifying image data are used to transform disparate images to the same coordinate system. Registration is the process of making an image conforms to another image. A map coordinate system is not necessarily involved. For example, if an image A is not rectified and it is being used with image B, then image B must be registered to image A so that they conform to each other. In this example, image A is not rectified to a particular map projection, so there is no need to rectify image B to a map projection (Karydas, 2005).

9.1.1. Background

Four basic processes must be performed to co-register an image into an image (Jensen, 1996):

1. Identify ground control Points (GCPs) which should be in evidence on both images;
2. Define geometrical relationships involving the (GCPs) for geometric transformation with a polynomial technique using least-square criteria;
3. Relocate or rearrange every pixel in the original input image (x´, y´) to its proper position in the rectified output image (x, y);
4. Intensity interpolation to extract the brightness values for every pixel from a (x´, y´) location in the original input image and its relocation to the appropriate (x, y) coordinate location in the rectified output image (*image resampling*).

Before applying the co-registration to the entire image, it is important to determine how well the parametrical model fits for the geometric distortions in the input image. The method used most often involves the computation of the root-mean-square error (RMS_{error})

RMS_{error} is the distance between the input (source) location of a GCP and the retransformed location for the same GCP. In other words, it is the difference between the desired output coordinate for a GCP and the actual output coordinate for the same point, when the point is transformed with the geometric transformation.
The RMS error is calculated with a Distance (see *Equation 9.1*):

Equation 9.1: The RMS Error Calculation with a Distance

$$RMSerror = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

Where:

x_i and y_i are the input source coordinates

x_γ and y_γ are the retransformed coordinates

RMS_{error} is expressed as a distance in the source coordinate system. It is important to remember that the RMS error is reported in pixels. Therefore, in order rectify the Landsat TM to be accurate within 30 meters; the RMS_{error} should not exceed 1.00. Acceptable the RMS_{error} is less than 0.6, according to Luque (2000).

Three common methods for resampling are used to determine and relocate the brightness from their original location in the rectified image. The *Nearest neighbor* is a method that assigns to each pixel the brightness value of its nearest neighbor in the new coordinate system; *Bilinear interpolation* takes a weighted average of four pixels in the original image nearest to the new pixel location and *Cubic convolution* goes even further to calculate a distance weighted average of a block of sixteen pixels from the original image which surround the new output pixel location. As the Nearest neighbor does not alter the original brightness values during the resampling (Duggin and Robinve, 1990), it was used in this study as the resampling method, whereas the other two methods use averages to compute the output brightness values, often removing valuable spectral information.

9.1.2. Implementation

Image-to-image co-registration was used to co-register the Landsat TM images. As the transformation accuracy depends on the even distribution of the geographic control points (GCPs) over the image, approximately 30 GCPs clearly points have been identified with well-distributed in the one image and matched them to the other image. Once the GCPs have been identified, the image transformation was performed using the nearest neighbor algorithm to determine the digital values to place in the new pixel locations of the corrected output image and to avoid altering the original pixel values of the image data (ERDAS 1997).

The Landsat TM (+ETM) image was then re-projected using a continuous polynomial approximation into the UTM projection system, as this is the only flexible projection, which can be used for different images with applied ERDAS Imagine Software.

9.1.3. Resulting Images

All seven (7) images (see *Section 8.2.1 – Existing Remote Sensing Data* of **Chapter 8 – Study Area and Datasets**) were co-registered while associated with 30 GCP points, which were distributed through the whole area of the Municipality of Nea Makri. The RMS_{error} for all images are between 0 and 1 and was accepted as a pass level. In order to have accurate results for the classification of vegetation, like vegetated and not vegetated, for a Landsat TM image, the pixel error should be less than 1 pixel.

To be sure about the accuracy of co-registration, the one image was overlaid with the second one. Both images were viewed simultaneously, using the swipe function of ERDAS Imagine. Another way to check the accuracy was to geo-link two (2) images together and to use the Inquire Cursor function of ERDAS Imagine. Identifying marks, such as crossroads or coastlines, were located to enable the comparison through the whole image. By checking in these 2 ways, it could be concluded that not only the RMS_{error} was at an acceptable level, but also the one image had a good fit to the second one.

9.2. NOISE REDUCTION

9.2.1. Background

Noise Reduction removes noise using an adaptive filter.

Fourier transformations are typically used for the removal of noise such as striping, spots, or vibration in imagery by identifying periodicities (areas of high spatial frequency). Fourier editing can be used to remove regular errors in data such as those caused by sensor anomalies (e.g., striping). This analysis technique can also be used across bands as another form of pattern/feature recognition.

The FFT calculation is presented by Equation 9.2:

Equation 9.2: FFT Calculation

$$F(u,v) \leftarrow \sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[f(x,y)e^{-j2\pi ux/M - j2\pi vy/N}\right]$$

Where:

M = the number of pixels horizontally
N = the number of pixels vertically
u, v = spatial frequency variables
e = 2.71828, the natural logarithm base
j = the imaginary component of a complex number

The number of pixels horizontally and vertically must each be a power of two. If the dimensions of the input image are not a power of two, they are padded up to the next highest power of two (Oppenheim and Schafer, 1975; Press et al, 1988).

Occasionally, images are corrupted by noise that is periodic in nature. An example of this is the scan lines that are present in some TM images. When these images are transformed into Fourier space, the periodic line pattern becomes a radial line. The Fourier analysis functions provide two main tools for reducing noise in images:

1. ***Editing***

   In practice, it has been found that the radial lines centered at the Fourier origin (u,v=0,0) are the best removed using back-to-back wedges centered at (0, 0). It is possible to remove these lines using very narrow wedges with the Ideal window. However, the sudden transitions resulting from zeroing-out sections of a Fourier image cause a ringing of the image when it is transformed back into the spatial domain. This effect can be lessened by using a less abrupt window, such as Butterworth.

   Other types of noise can produce artifacts, such as lines not centered on u,v = 0,0 or circular spots in the Fourier image. These can be removed using the tools provided in the FFT Editor. As these artifacts have always symmetrical in the Fourier magnitude image, editing tools operated on both components simultaneously. The FFT Editor contains tools that enable you to attenuate a circular or rectangular region anywhere on the image.

2. ***Automatic Periodic Noise Removal***

   The use of the FFT Editor, as described above, enables you to selectively and accurately remove periodic noise from any image. However, operator interaction and a bit of trial and error are required. The automatic periodic noise removal algorithm has been devised to address images degraded uniformly by striping or other periodic anomalies. Use of this algorithm requires a minimum of input from you.

   The image is first divided into 128 × 128 pixel blocks. The Fourier Transform of each block is calculated and the log-magnitudes of each FFT block are averaged. The averaging removes all frequency domain quantities except those that are present in each block (i.e., some sort of periodic interference). The average power spectrum is then used as a filter to adjust the FFT of the entire image. When the IFFT is performed, the result is an image that should have any periodic noise eliminated or significantly reduced. This method is partially based on the algorithms outlined in Cannon (1983) and Srinivasan et al. (1988).

9.2.2. Implementation

To remove noise from the images, noise reduction is implemented. Automatic periodic noise removal was implemented in each image of seven (7) images presented in *Section 8.2.1 – Existing Remote Sensing Data* in **Chapter 8 – Study Area and Datasets**.

9.2.3. Resulting Images

To be sure of the accuracy of noise reduction, the image without automatic periodic noise removal overlaid with the image with automatic periodic noise removal. Both images were viewed simultaneously, using the swipe function of ERDAS Imagine. Another way to check the accuracy was to geo-link two (2) images together and to use the Inquire Cursor function of ERDAS Imagine. Identifying marks, such as crossroads or coastlines, were located to enable the comparison through the whole image. By checking in these 2 ways, it could be concluded that the blurriness of the image has been removed.

9.3. NORMALIZATION

9.3.1. Background

The main problem of aggregating indicators or data into the CSDI is the fact that indicators or data may be expressed in different units. One way to solve this problem could be *normalizing* each indicator *i* by dividing its value in time (year) *t* with its average value of all the time in years measured (*Equations 9.3 and 9.4*).

Equation 9.3: Normalization of the Data or Indicators (1)

$$I^{+}_{N,ijt} = \frac{I^{+}_{A,ijt}}{I^{+}_{ij}}$$

Equation 9.4: Normalization of the Data or Indicators (2)

$$I^{-}_{N,ijt} = \frac{I^{-}_{A,ijt}}{I^{-}_{ij}}$$

Where $I^{+}_{\mathrm{N},ijt}$ is the normalized indicator *i* (with positive impact) for group of indicators *j* for time (year) *t* and $I^{-}_{\mathrm{N},ijt}$ is the normalized indicator *i* (with negative impact) for group of indicators *j* for the same time (year) *t*.

The second way could be normalizing each indicator *i* using *Equations 9.5 and 9.6:*

Equation 9.5: Normalization of the Data or Indicators (3)

$$I_{N,ijt}^{+} = \frac{I_{A,ijt}^{+} - I_{\min,jt}^{+}}{I_{\max,jt}^{+} - I_{\min,jt}^{+}}$$

Equation 9.6: Normalization of the Data or Indicators (4)

$$I_{N,ijt}^{-} = \frac{I_{A,ijt}^{-} - I_{\min,jt}^{-}}{I_{\max,jt}^{-} - I_{\min,jt}^{-}}$$

In both ways, the possibility of incorporating different kinds of quantities, with different units of measurement (i.e. physical, economic, etc.), is offered. Among the advantages of the proposed normalization of indicators is the clear compatibility of different indicators, since all indicators are normalized.

9.3.2. Implementation

Despite the fact that both ways of normalizations are offered in the above mentioned section, the second way of normalizing each indicator or data is implemented in the current PhD thesis using Equations 9.5 and 9.6 of the current chapter.

For the MAX and MIN values of all indicators according to each theme, refer to the Available Statistical Dataset (see *Table 8.2*) of Section 8.2.2 – Existing Statistical Data of Section 8.2 – Datasets described in **Chapter 8** **- Study Area and Datasets** are as.

1. **Population**

   - ➢ MAX and MIN values of theme Population 1981 are as:

     MAX = 28570 MIN = 0

   - ➢ MAX and MIN values of theme Population 1991 are as:

     MAX = 37449 MIN = 0

   - ➢ MAX and MIN values of theme Population 2001 are as:

     MAX = 45067 MIN = 0

2. **Agriculture**

   - ➢ MAX and MIN values of theme Agriculture 1981 are as:

     MAX = 2684 MIN = 4

- MAX and MIN values of theme Agriculture 1991 are as:

  MAX = 2455 MIN = 0

- MAX and MIN values of theme Agriculture 2001 are as:

  MAX = 3415 MIN = 0

3. Tourism

- MAX and MIN values of theme Tourism 1993 are as:

  MAX = 20985 MIN = 0

- MAX and MIN values of theme Tourism 2001 are as:

  MAX = 7230 MIN = 0

4. Agricultural Goods

- MAX and MIN values of theme Agricultural Goods 1993 are as:

  MAX = 175000 MIN = 0

- MAX and MIN values of theme Agricultural Goods 2001 are the following:

  MAX = 174000 MIN = 0

5. Industry

- MAX and MIN values of theme Industry 1993 are the following:

  MAX = 63044 MIN = 0

- MAX and MIN values of theme Industry 2001 are the following:

  MAX = 120543 MIN = 0

9.3.3. Normalized Data

To observe details of Normalized Data according to each theme, look below:

1. Population

The Normalized Data of Population are located in **Appendix 10.**

- Refer to Tab Normalized Data of *Appendix 10.1 – Original & Normalized & Final Values Population 1981* for Normalized Data by Population 1981.
- Refer to Tab Normalized Data of *Appendix 10.2 – Original & Normalized & Final Values Population 1991* for Normalized Data by Population 1991.
- Refer to Tab Normalized Data of *Appendix 10.3 – Original & Normalized & Final Values Population 2001* for Normalized Data by Population 2001.

2. Agriculture

The Normalized Data of Agriculture are located in **Appendix 6.**

- Refer to Tab Normalized Data of *Appendix 6.1 – Original & Normalized & Final Values Agriculture 1981* for Normalized Data of Agriculture 1981.
- Refer to Tab Normalized Data of *Appendix 6.2 – Original & Normalized & Final Values Agriculture 1991* for Normalized Data of Agriculture 1991.
- Refer to Tab Normalized Data of *Appendix 6.3 – Original & Normalized & Final Values Agriculture 2001* for Normalized Data of Agriculture 2001.

3. Tourism

The Normalized Data of Tourism are located in **Appendix 7.**

- Refer to Tab Normalized Data of *Appendix 7.1 – Original & Normalized & Final Values Tourism 1993* for Normalized Data of Tourism 1993.
- Refer to Tab Normalized Data of *Appendix 7.2 – Original & Normalized & Final Values Tourism 2001* for Normalized Data of Tourism 2001.

4. Agricultural Goods

The Normalized Data of Agricultural Goods are located in **Appendix 8.**

- Refer to Tab Normalized Data of *Appendix 8.1 – Original & Normalized & Final Values Agricultural Goods 1993* for Normalized Data of Agricultural Goods 1993.

- Refer to Tab Normalized Data of *Appendix 8.2 – Original & Normalized & Final Values Agricultural Goods 2001* for Normalized Data of Agricultural Goods 2001.

5. Industry

The Normalized Data of Industry, which are generally related to the constructions of buildings, are located in **Appendix 9.**

- Refer to Tab Normalized Data of *Appendix 9.1 – Original & Normalized & Final Values Industry 1993* for Normalized Data of Industry 1993.

- Refer to Tab Normalized Data of *Appendix 9.2 – Original & Normalized & Final Values Industry 2001* for Normalized Data of Industry 2001.

9.4. SUMMARIES AND PROPOSALS

The Remote Sensing Datasets are presented by the Available Remote Sensing Data (see *Table of* **Chapter 8 – Study Area and Datasets**) are used for the analysis included several preprocessing steps, which are demonstrated in the aforementioned main flowchart of the Data Preprocessing (see *Figure 9.1*). Image-to-image co-registration was used to co-register the Landsat TM images. Later on Noise Reduction removes noise using an adaptive filter. Further on, the preprocessed Landsat TM and ETM images are presented as an input to the processing remote sensing data, which are discussed in detail in **Chapter 10 – Processing and Results of Remote Sensing Data.**

The Suggested Statistical Datasets (see *Table 8.3*of **Chapter 8 – Study Area and Datasets**) are normalized. Later on these normalized data are used as inputs to the model for integrated assessment of sustainable development; for details refer to **Chapter 11 – A Model for Integrated Assessment of Sustainable Development.**

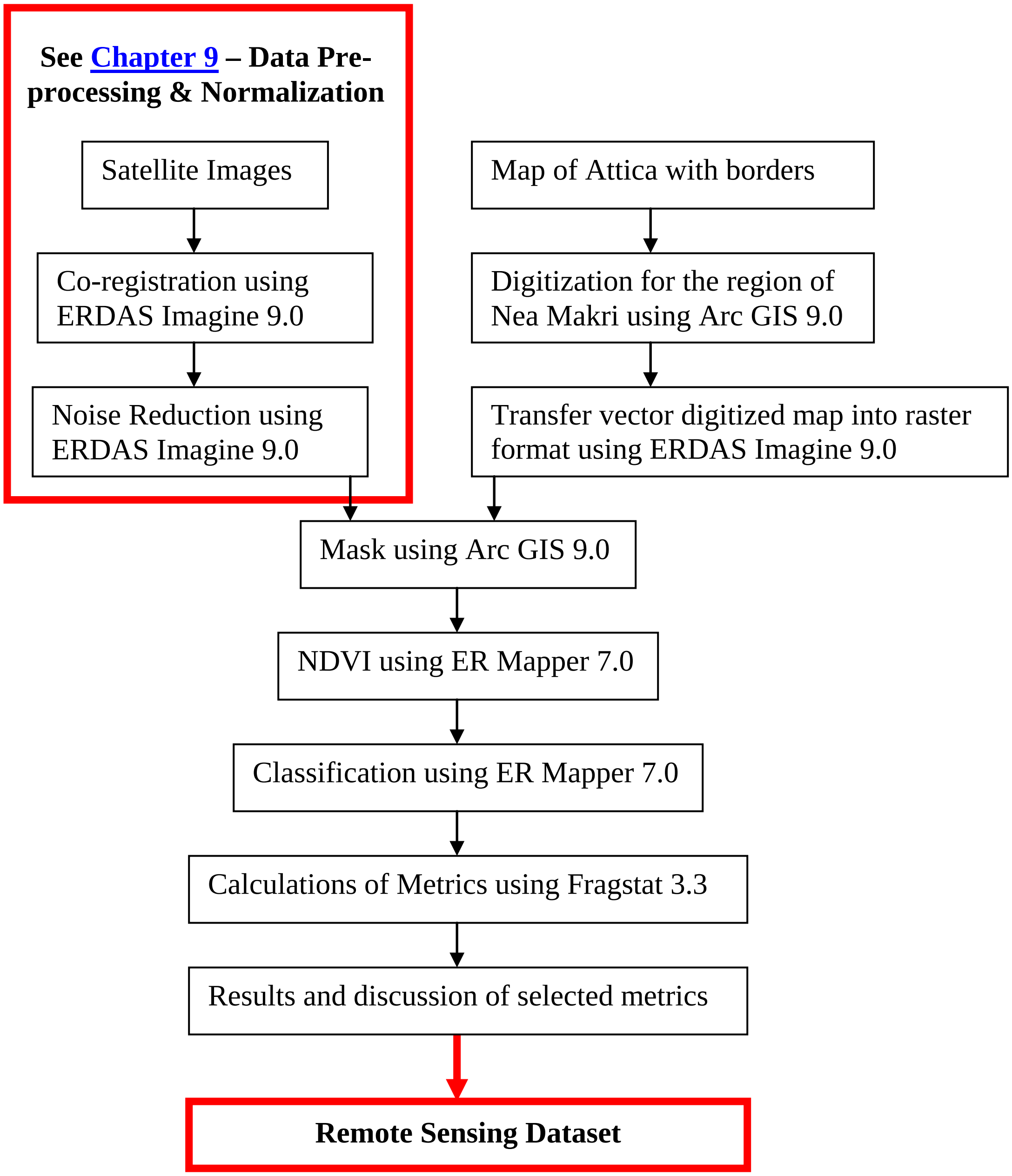
It is proposed to normalize not only all existing statistical datasets but also remote sensing data. However, the normalization of remote sensing data is performed only after preprocessing and processing data which are conferred in **Chapter 10 – Processing and Results of Remote Sensing Data** for the further work.

CHAPTER 10

PROCESSING AND RESULTS OF REMOTE SENSING DATA

To understand the activity occurrence requires land use change analysis and the related biodiversity variations identification and computation of landscape metrics. Erdas (Leica) (ERDAS, 2005), ArcGIS software ESRI (Koutsopoulos and Androulakis, 2005), ER Mapper (ER MAPPER, 2005) and Fragstat (McGarigal and Marks, 1995) software are used. The complete review of the current chapter is presented in the Flowchart of Methodology (see *Figure 10.1*). Each part of the flowchart is discussed later in the current chapter, except the portion of Data Pre-processing (Co-Registration and Noise Reduction), which is highlighted with Red Quadrate, and is discussed in **Chapter 9 – Data Pre-processing and Normalization.** Furthermore, the results of landscape metrics will be represented as Remote Sensing Data and become an input to the final look on the proposed model which is located by the Final Look at the Proposed Model (see *Figure 7.5*) of the **Chapter 7 – Methodological Framework.**

Figure 10.1: Flowchart of Methodology



10.1. INTRODUCTION

During the last two centuries, the impact of human activities on the land has grown enormously, altering entire landscapes with important ecological consequences like biodiversity loss, deforestation, soil erosion, and desertification. Before the presence of the man, natural processes shaped the landscape, but after the man came to Earth, Earth's face has changed. In the past two centuries, the impact of human agricultural, industrial, and extractive activities, combined with natural and human actions, induced climatic variations, which led to land degradation on an unprecedented scale (Giordano & Marini, 2008).

Many protected ecosystems are difficult to monitor because they are in remote or poorly accessible areas of the world. Remote sensing data significantly contributed to the estimation of the landscape metrics, i.e. **Chapter 3** **-** Landscape Metrics based on Remote Sensing Data (Nagler et al., 2009; McDermid et al., 2005; Melesse et al., 2007). Remote Sensing and Geographic Information Systems provide successful tools for land degradation detecting and monitoring (King and Delpont, 1993; De Jong, 1994). Particularly, to monitor vegetation productivity over a long temporal scale and on a large spatial scale, the use of satellite imagery is the only viable option (Symeonakis and Drake, 2004). Satellite based Normalized Difference Vegetation Index (NDVI) is the most commonly used method to monitoring vegetation change and it's mapping (Peter et al., 2008; Tagil, 2007; Yemefack et al., 2006; Mahiny and Turner, 2005; Seaquist et al., 2003; Parodi, 2002; Argialas, 2000, Tian and Min, 1998; San Miguel-Ayanz, 1996).

Humans have had major deleterious effects on the environment that impact significantly sustainable resource use. To study and mitigate against further environmental degradation, as well as to monitor progress of sustainable development, indicators of environmental status are required (Hall, 2001). Indicators of the environment that increase our scientific understanding and help direct the application of knowledge are required so that resources may be used sustainably, now and in the future. There are many potential indicators of environmental conditions that may be of value in developing a system to monitor sustainable resource use. For example, ANZECC (2000) provides a list of 75 indicators and many of these have the potential to be remotely sensed, directly by the Significant Environmental Indicators (See *Table 10.1)* (Foody, 2003).

Table 10.1: Significant Environmental Indicators

Theme/Issue	***Indicator***	***An example of the potential remote sensing input***
Biodiversity		
Threatening process	Native vegetation clearing Aquatic habitat destruction Fire regimes	Monitor land cover change Monitor land cover change Estimate canopy moisture content, map drought
Loss of biodiversity	Extent of native vegetation Extent of aquatic habitats Populations of selected species	Map land cover Map land cover Map land cover and link to bio-geo-graphical models
Conservation and management	Terrestrial protected areas Map and monitor land cover Area revegetated	Recovery plans Monitor land cover, estimate biophysical variables Monitor land cover
Land (Jat et al., 2008)		
Use and management	Changes in land use	Monitor land cover
Erosion	Potential for erosion	Map land cover, link to disturbance and environmental data

Source: Foody (2003)

There are several ways of calculating the aforementioned indicators. According to Sala et al., (2000); Foley et al., (2005); Fischer & Lindenmayer (2007), landscape modification and habitat fragmentation are considered severe threats to global biodiversity. Some terms and definitions are covered by the Selected Key Terms to Conceptualize the Ecology of Modified Landscapes (see *Table 10.2*) (Fischer & Lindenmayer, 2007).

Table 10.2: Selected Key Terms to Conceptualize the Ecology of Modified Landscapes

Term	***Definition***
Fragmented landscape	A landscape characterized by a strong contrast between vegetation patches and their surrounding matrix (native vegetation cover typically *c.* 10–60%); often seen in formerly forested areas
Habitat	The range of environments suitable for a particular species
Habitat loss	Loss of habitat for a particular species
Habitat sub-division	A subdivision of habitat for a particular species
Landscape	A human-defined area ranging
Landscape heterogeneity	A human perspective of environmental gradients and land-cover types in a landscape

Source: Fischer & Lindenmayer (2007)

In this chapter, an attempt is made to investigate the usefulness of spatial techniques like Remote Sensing and GIS and to assess land use change and the related biodiversity variations. The NDVI is calculated. Classification into 3 classes is performed. Landscape metrics are computed.

10.2. PROCESSING OF REMOTE SENSING DATA

As the area of the original images is much larger than the required study area, then subsets of five (5) Landsat TM and two (2) Landsat ETM+ are performed using ERDAS Imagine 9.0 software. To observe the necessary operation on images, at least co-registration (see *Section 8.1 – Co-Registration* of **Chapter 8 - Data Preprocessing and Normalization**) is desirable. RMS Errors for all images are between 0 and 1 pixels. To remove noises from the images, noise reduction (*See Section 9.2 – Noise Reduction* of **Chapter 9 – Data Preprocessing and Normalization**) is performed.

Geo-referenced images to the map are carried out. Digitization for the Municipality of Nea Makri using Arc GIS 9.0 is executed manually. The format of the digitized region of Nea Makri is a vector format. In order to acquire the region of Nea Makri only in satellite images, the vector format of the digitized map is transformed into the raster format and a mask of each satellite image with the raster format of digitized map of Nea Makri is accomplished. The resulting images are five (5) Landsat TM and two (2) Landsat ETM+ satellite images only for the Municipality of Nea Makri, Athens, Greece.

The NDVI is a quasi-continuous field that is calculated as a normalized difference between the reflectance of two biologically meaningful bands of the electromagnetic spectrum. Actively, as a source of energy for photosynthesis, leaves absorb the red wavelengths (Landsat TM Band 3) and reflect the short wave infrared (Landsat Tm Band 4), the difference between the two is proportional to the amount of photosynthesis. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum (Parodi, 2002 and Schreiber, 2006). The following *NDVI* index is used in *Equation 10.1:*

Equation 10.1: The Formula of NDVI

$$NDVI = \frac{BAND4(NIR) - BAND3(RED)}{BAND4(NIR) + BAND3(RED)}$$

The raw NDVI values are fractional real numbers that range between –1.0 to +1.0. An NDVI value of zero, i.e. –0.32 to 0 means no green vegetation and close to +1 indicates the highest possible density of green leaves. Essentially, vegetation values have a range between 0.1 to 0.35. Higher values are associated with healthier vegetation and greater density and greenness of the plant canopy (Tagil, 2007).

NDVI for all satellite images for the region of Nea Makri is calculated using ER Mapper 7.0. The minimum and maximum values of each image are taken from the histogram and represented by the *MIN and MAX Values of NDVI* (see *Table 10.3*).

Table 10.3: MIN and MAX Values of NDVI

Type of data used	***Date of Acquisition***	***MIN NDVI VALUE***	***MAX NDVI VALUE***
Landsat TM image	23 / 10 / 1984	-0.08	0.34
Landsat TM image	13 / 08 / 1987	0	0.30
Landsat TM image	04 / 07 / 1990	-0.02	0.27
Landsat TM image	14 / 09 / 1993	-0.01	0.35
Landsat TM image	14 / 08 / 1996	-0.03	0.33
Landsat ETM+ image	05 / 07 / 1999	-0.14	0.29
Landsat ETM+ image	14 / 08 / 2002	-0.32	0.08

The interval between -0.32 to 0.35 is divided into three parts and two thresholds (-0.10; +0.12) were produced using ER Mapper 7.0 software. Classification of remotely sensed data requires the assignment of each of the pixels in an image to a class. The spectral information contained in the original and transformed bands is used to characterize each class pattern and to discriminate between classes (San Miguel-Ayanz and Biging, 1997). All classified Landsat TM and ETM+ images are saved as 8-bit binary images. In order to examine indicators for fragmentation, Fragstat 3.3 program is used. The inputs are seven classified into three classes 8-bit binary images with cell size 30m, the number of rows 316 and the number of columns 282. For the detailed discussion about each metrics refer to the following section.

10.3. RESULTS OF REMOTE SENSING DATA

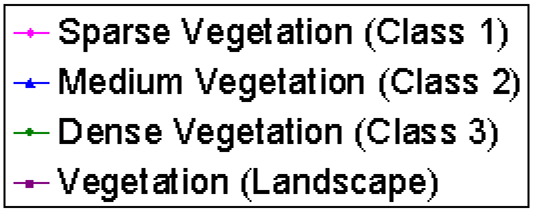
The results from the Fragstat Program (see *Table 10.4*) and discussions of all metrics, which are located in *Section 3.2 -Landscape Metrics* of **Chapter 3 – Landscape Metrics based on Remote Sensing Data**, used in the current subsection. The results running Fragstat 3.3 program are given in **Appendix 11 – Result from the Fragstat Program**.

Table 10.4: Result from the Fragstat Program

Names	*All Tables are located in* **Appendix 11** *-* **Result from the Fragstat Program**	*All Sections are located in Section 3.2 - Landscape Metrics of* **Chapter 3** **– Landscape Metrics based on Remote Sensing Data**
Area / Edge / Density	Table A.11.1	Sub-section 3.2.1 - Area / Edge / Density
Shape	Table A.11.2	Sub-section 3.2.2 – Shape and Core Area
Core Area	Table A.11.3	Sub-section 3.2.2 – Shape and Core Area
Isolation Proximity	Table A.11.4	Sub-section 3.2.3 - Isolation Proximity
Connectivity	Table A.11.5	Sub-section 3.2.4 - Connectivity
Contagion Interspersion	Table A.11.6	Sub-section 3.2.5 - Contagion Interspersion
Diversity	Table A.11.7	Sub-section 3.2.6 - Diversity

In order to observe the state of the land, metrics are calculated. NDVI is computed to monitor the condition of the vegetation. That is why the interval between -0.32 to 0.35 is divided into three parts and two thresholds (-0.10; +0.12) were produced. The classes are presented by the Colors According the Distribution of Classes (see *Figure 10.2*):

Figure 10.2: Colors According the Distribution of Classes



(1) Class metrics are computed for every patch type or class in the landscape; the resulting class output file contains a row (observation vector) for every class, where the columns (fields) represent the individual metrics. There are two basic types of metrics at the class level:

- Indices of the amount and spatial configuration of the class;

- Distribution statistics that provide first- and second-order statistical summaries of the patch metrics of the focal class.

The latter is used to summarize the mean, area-weighted mean, median, range, standard deviation, and coefficient of variation in the patch attributes across all patches in the focal class.

(2) Landscape metrics are computed for entire patch mosaic; the resulting landscape output file contains a single row (observation vector) for the landscape, where the columns (fields) represent the individual metrics. Like class metrics, there are two basic types of metrics at the landscape level:

- Indices of the composition and spatial configuration of the landscape;

- Distribution statistics that provide first- and second-order statistical summaries of the patch metrics for the entire landscape.

The latter is used to summarize the mean, area-weighted mean, median, range, standard deviation, and coefficient of variation in the patch attributes across all patches in the landscape.

Here six (6) major groups of metrics are taken into consideration by the Result from the Fragstat Program (See *Table 10.4*). The groups are as:

1. Area / Edge / Density:

This group of metrics represents a loose collection of metrics that deal with the number and the size of patches and the amount of edge created by these patches. Although these metrics could easily be subdivided into separate groups or assigned to other already recognized groups, there is enough similarity in the basic patterns assessed by these metrics to include them under one umbrella as performed.

2. Shape and Core Area:

The interaction of patch shape and size can influence a number of important ecological processes. Patch shape has been shown to influence inter-patch processes such as small mammal migration (Buechner, 1989) and woody plant colonization (Hardt and Forman, 1989), and may influence animal foraging strategies (Forman and Godron, 1986). However, the primary significance of shape in determining the nature of patches in a landscape seems to be related to the “edge effect”.

Core area is defined as the area within a patch beyond some specified depth-of-edge influence (i.e., edge distance) or buffer width. Like patch shape, the primary significance of the core area in determining the character and function of patches in a landscape appears to be related to the "edge effect". Edge effects result from a combination of biotic and abiotic factors that alter environmental conditions along patch edges compared to patch interiors. The nature of the edge effect differs among organisms and ecological processes (Hansen and di Castri, 1992). For example, some bird species are adversely affected by predation, competition, brood parasitism, and perhaps other factors along forest edges. The Core area has been found to be a much better predictor of habitat quality than a patch area for these forest interior specialists (Temple, 1986). Unlike the patch area, the core area is affected by the patch shape. Thus, while a patch may be large enough to support a given species, it still may not contain enough suitable core area to support the species. In some cases, it seems likely that edge effects would vary in relation to the type and nature of the edge (e.g., the degree of floristic and structural contrast and orientation). Thus, FRAGSTATS allows the user to specify an edge depth file that contains edge influence the distances for every pairwise combination of patch types. In the absence of such information, a single edge depth for all edge types can be specified by the user.

3. Isolation Proximity:

Isolation deals explicitly with the spatial and temporal *context* of habitat patches, rather than the spatial character of the patches themselves. Isolation of habitat patches is a critical factor in the dynamics of spatially structured populations. For example, there has been a proliferation of mathematical models on population dynamics and species interactions in spatially subdivided populations (Kareiva, 1990), and results suggest that the dynamics of local plant and animal populations in a patch are influenced by their proximity to other subpopulations of the same or competing species. Patch isolation plays a critical role in island biogeographic theory (MacArthur and Wilson, 1967) and meta-population theory (Levins, 1970; Gilpin and Hanski, 1991). The role of patch isolation (e.g., as measured by inter-patch distance) in meta-population has had a preeminent role in conservation efforts for endangered species (e.g., McKelvey et al., 1992; Lamberson et al., 1992).

4. Connectivity:

Connectivity refers to the degree to which a landscape facilitates or impedes ecological flows (e.g., the movement of organisms among habitat patches and therefore the rate of movement among local populations in a meta-population). An abrupt change in the connectivity of the landscape, for example, as might be caused by habitat loss and fragmentation, may interfere with dispersal success, such that formerly widespread populations may suddenly become fragmented into small, isolated populations. This may in turn lead to an abrupt decline in patch occupancy (meta-population dynamics) and ultimately the extinction of the population across the landscape (extinction thresholds).

5. Contagion Interspersion:

Contagion refers to the tendency to patch types to be spatially aggregated; that is, to occur in large, aggregated or "contagious" distributions. Interspersion, on the other hand, refers to the intermixing of patches of different types and is based solely on patch (as opposed to cell) adjacencies. Contagion and interspersion are both aspects of landscape texture; they both reflect the adjacency on patch types, but do so in a different manner. Contagion reflects both the dispersion (i.e., the spatial distribution) and intermixing of patch types, whereas interspersion reflects only the latter. Thus, contagion subsumes interspersion as a measure of landscape texture.

6. Diversity:

Diversity measures have been used extensively in a variety of ecological applications. They originally gained popularity as measures of plant and animal species diversity. There has been a proliferation of diversity indices and we will make no attempt to review them here. FRAGSTATS computes 3 diversity indices. These diversity measures are influenced by 2 components--richness and evenness. Richness refers to the number of patch types present; evenness refers to the distribution of area among different types. Richness and evenness are generally referred to as the compositional and structural components of diversity, respectively. Some indices (e.g., Shannon's diversity index) are more sensitive to richness than evenness. Thus, rare patch types have a disproportionately large influence on the magnitude of the index. Other indices (e.g., Simpson's diversity index) are relatively less sensitive to richness and thus place more weight on the common patch types. These diversity indices have been applied by landscape ecologists to measure one aspect of landscape structure – landscape composition (e.g., Romme, 1982; O'Neill et al., 1988; Turner, 1990).

The detailed definition of each index of the main groups is presented in **Chapter 3 – Landscape Metrics based on Remote Sensing Data**, the results of each index from each group are illustrated in **Appendix 11 – Result from the Fragstat Program.** Several indices of each group are depicted below as graphs. Refer to the *Figures 10.3-10.6 for group 1: Area / Edge / Density*. Specifically, *Number of Patches (NP) – Figure 10.3; Patch Density (PD) – Figure 10.4; Largest Patch Index (LPI) – Figure 10.5 and Mean Value of Patch Area (AREA_MN) – Figure 10.6.*

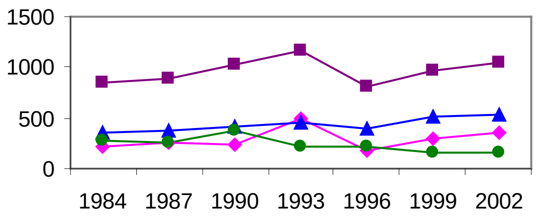


Figure 10.3: NP

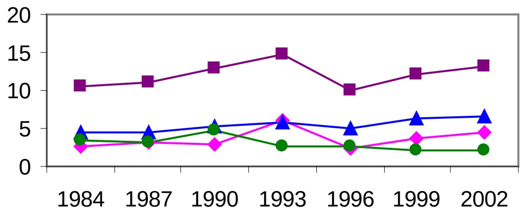


Figure 10.4: PD

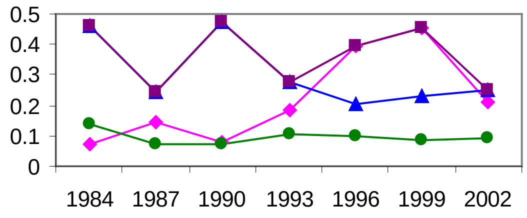


Figure 10.5: LPI

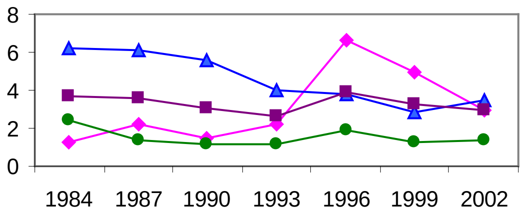


Figure 10.6: AREA_MN

Refer to the *Figures 10.7 and 10.8 for group 2: Shape and Core Area. Particularly, Mean Value of Shape Index (SHAPE_MN) – Figure 10.7; Mean Value of Contiguity Index (CONTIG_MN) – Figure 10.8.*

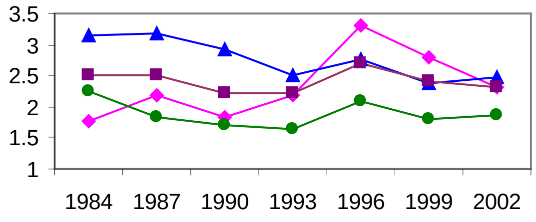


Figure 10.7: SHAPE_MN

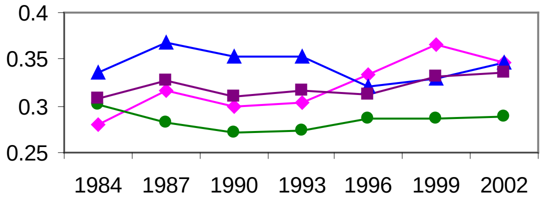


Figure 10.8: CONTIG_MN

Refer to the *Figure 10.9 for group 2: Shape and Core Area. Particularly, Mean Value of Core Area (CORE_MN) – Figure 10.9. Refer to the Figure 10.10 for group 3: Isolation Proximity*. Mainly, *Mean Value of Proximity Index (PROX_MN) – Figure 10.10.*

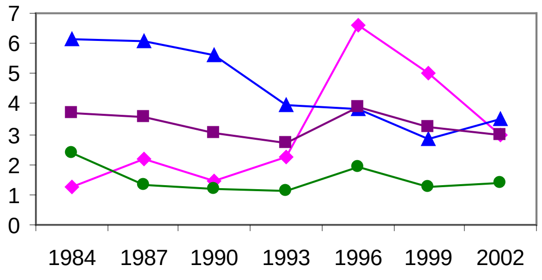


Figure 10.9: CORE_MN

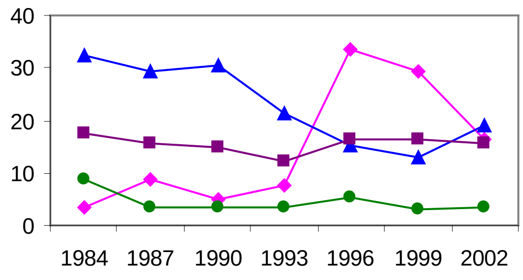


Figure 10.10: PROX_MN

Refer to the *Figure 10.11 for group 4: Connectivity. Principally, Connectance Index (CONNECT) – Figure 10.11.* Refer to the *Figure 10.12 for group 5: Contagion Interspersion. Generally, Interspersion Juxtaposition Index (IJI) – Figure 10.12.*

Figure 10.11: CONNECT

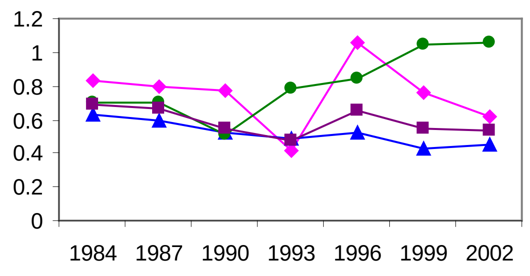
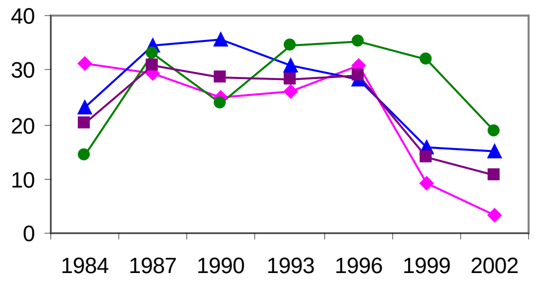


Figure 10.12: IJI



Refer to the *Figures 10.13 and 10.14 for group 6: Diversity*, which is only applicable for landscape level. Principally, *Shannon's Diversity Index (SHDI) – Figure 10.13 and Shannon's Evenness Index (SHEI) – Figure 10.14.*

Figure 10.13 SHDI

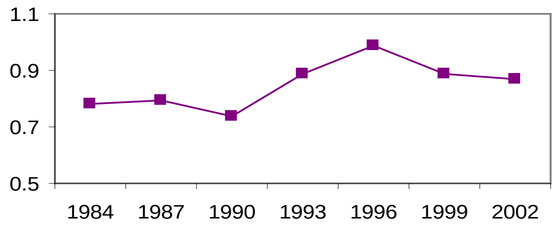
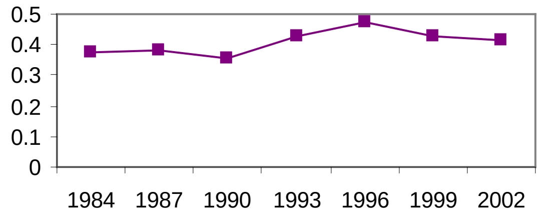


Figure 10.14: SHEI



10.4. DISCUSSION OF REMOTE SENSING DATA

The series of classified satellite images was the source for the landscape metrics computation at Class Level (*Section 10.4.1*) and at Landscape Level (*Section 10.4.2*) using Fragstat software as a tool.

10.4.1. Landscape Indicators at Class Level

Graphs depicted in *Figures 10.3 through 10.12 by applied Pink (Class 1), Blue (Class 2) and Green (Class 3) colors.* For the analysis and the comprehension of landscape metrics at class level, it is advisable not to analyze just the landscape metrics but rather a set of metrics to better understand and describe the dynamics of ecosystems and landscape structure, as Giordano & Marini (2008) wrote in their paper.

1. Sparse Vegetation (Class 1) in this chapter represents the minor class of landscape (*Table A.11.1 through A.11.6* of **Appendix 11 – Result from the Fragstat Program**). The study shows an increase with some variations in terms of the Number of Patches *(NP) (Figure 10.3)*, the Patch Density *(PD) (Figure 10.4)*, the Largest Patch Index *(LPI) (Figure 10.5)* and Mean Value of Patch Area *(AREA_MN) (Figure 10.6)* during the period from 1984 to 2002. In addition, the highest values of the Mean Shape Index *(SHAPE_MN) (Figure 10.7)*, Mean Contiguity Index *(CONTIG_MN) (Figure 10.8)*, *M*ean Core Area *(CORE_MN) (Figure 10.9)*, *M*ean Proximity Index *(PROX_MN) (Figure 10.10)* and *Connectance Index (CONNECT) (Figure 10.11)* are in the year of 1996. There is also a decrease in the Interspersion Juxtaposition Index *(IJI) (Figure 10.12)* mainly between 1996 and 2002 years.

2. Medium Vegetation (Class 2) in the current study is characterized as the major class of landscape (*Table A.11.1 through A.11.6* of **Appendix 11 – Result from the Fragstat Program**). The study shows a small increase in terms of the Number of Patches *(NP) (Figure 10.3)*, the Patch Density *(PD) (Figure 10.4)* and decrease in terms of the Largest Patch Index *(LPI) (Figure 10.5)*, Mean Value of Patch Area *(AREA_MN) (Figure 10.6)* during the period from 1984 to 2002. Furthermore, there is a decrease in the values of Mean Shape Index *(SHAPE_MN) (Figure 10.7)*, *M*ean Core Area *(CORE_MN) (Figure 10.9)*, Mean Proximity Index *(PROX_MN) (Figure 10.10)*, *Connectance Index (CONNECT) (Figure 10.11)* and the Interspersion Juxtaposition Index *(IJI) (Figure 10.12)* from the time period from 1984 to 1999. Moreover, there is a somehow stability in the Mean Contiguity Index *(CONTIG_MN) (Figure 10.8).*

3. Dense Vegetation (Class 3) in the present study is illustrated as the medium to minor class of landscape (*Table A.11.1 through A.11.6* of **Appendix 11 – Result from the Fragstat Program**). The study shows stabilization with small variation in terms of the Number of Patches *(NP) (Figure 10.3)*, the Patch Density *(PD) (Figure 10.4)*, the Largest Patch Index *(LPI) (Figure 10.5)* and Mean Value of Patch Area *(AREA_MN) (Figure 10.6)* during the period from 1984 to 2002. Besides, a small decrease for the time period of 1984 – 1993 and a small increase in the time period of 1993 – 2002 exist in the values of Mean Shape index *(SHAPE_MN) (Figure 10.7)*, Mean Contiguity Index *(CONTIG_MN) (Figure 10.8)*, Mean Core Area *(CORE_MN) (Figure 10.9)* and Mean Proximity Index *(PROX_MN) (Figure 10.10)*. Furthermore, there is an augment to the value of *the Connectance Index (CONNECT) (Figure 10.11)* and the Interspersion Juxtaposition Index *(IJI) (Figure 10.12)* with the sharp decline within the years of 1987 – 1990 and 1999 – 2002.

10.4.2. Landscape Indicators at the Landscape Level

Figures 10.3 through 10.14 show the most relevant metrics performed at landscape level for the study.

As observable from *Figure 10.3 and Figure 10.4*, during the years of 1984 – 1993 and 1996 – 2002 the values for the Patch Number *(NP)* and Patch Density *(PD)* are increased in the current study. The values of the Largest Patch Index (LPI) (Figure 10.5) are strongly deviated. There is a decrease in terms of the Mean Value of Patch Area *(AREA_MN) (Figure 10.6)*, Mean Value of Shape Index *(SHAPE_MN) (Figure 10.7)*, Mean Value of Contiguity Index *(CONTIG_MN) (Figure 10.8)*, Mean Value of Core Area *(CORE_MN) (Figure 10.9)*, Mean Value of Proximity Index *(PROX_MN) (Figure 10.10)* and *Connectance Index (CONNECT) (Figure 10.11)* for the time periods from 1984 to 2002 and increased for the time period from 1993 to 1996. The values of the Interspersion Juxtaposition Index (IJI) (Figure 10.12) increased in the years from 1984 to 1987, stabilized in the years from 1987 to 1996 and decreased in the years from 1996 to 2002.

There is a kind of stabilization for the time period of 1984 – 1990 and 1996 – 2002 and augment for the years of 1990 – 1996 for the Shannon Diversity *(SHDI) (Figure 10.13)* and Evenness *(SHEI) (Figure 10.14)* indices. The Shannon's diversity index is, in fact, a popular measure of diversity in community ecology, applied to landscapes in the Municipality of Nea Makri as a measure of the equitability of the number of patch types and of the proportional distribution of area among patch types. Shannon evenness index, as written by McGarigal et al. (2002) is another popular diversity measure borrowed from community ecology, indicating the evenness of the distribution of area among the different patch types.

10.5. SUMMARIES AND PROPOSALS

The investigation carried out illustrated that the landscape of the study area is dominated by medium vegetation, followed by dense vegetation and sparse vegetation. During the study period (1984 – 2002), medium and dense vegetation are decreased while sparse vegetation is increased. The last shows that there are an increase of urban area and a change from vegetated area to the non-vegetated area.

The current work explains the analysis achieved in terms of land cover and landscape change by means of remote sensing and GIS techniques in an area prone to land change from vegetated in the less vegetated area in Nea Makri, Athens, (Greece) during the years of 1984–2002. For this reason, a set of indicators was setup, and a quantitative characterization of changes was performed. The combination of Landsat data, ERDAS Imagine, GIS, ER Mapper and Fragstat software were generally supportive in providing techniques to monitor land cover and landscape evolution during the study period. Further research is required in order to better understand the development of land cover and landscape in areas where process is occurring from vegetated areas to the non-vegetated ones.

Despite the Remote Sensing Data, which were processed for all seven Landsat TM and ETM images in the current chapter, exemplified in *Table 8.1 – Available Remote Sensing Data* of **Chapter 8 – Study Area and Datasets.** Only three (3) Remote Sensing Datasets, which are acquainted in *Table 8.7 – Final Proposed Datasets* of **Chapter 8 – Study Area and Datasets,** are insinuated as inputs for Calculations of Environmental Indicators of the Model for Integrated Assessment of Sustainable Development (**Chapter 11 – A Model for Integrated Assessment of Sustainable Development** *Section 11.3 - Calculations and Results of Environmental Indicators of the next chapter*).

CHAPTER 11

A MODEL FOR INTEGRATED ASSESSMENT OF SUSTAINABLE DEVELOPMENT

Approximately 350 indicators which were classified into three dimensions: social (**Appendix 1 - Social Indicators (S)**), economic (**Appendix 2 - Economic Indicators (EC)**) and environmental (**Appendix 3 - Environmental Indicators (EN)**) dimensions. The existent dimensions are retrieved as:

1. Society Sub-Index, i.e. Population Sub-Index;
2. Economy Sub-Index, i.e. Agriculture, Tourism, Agricultural Googs and Industry Sub-Index;
3. Environment Sub-Index, i.e. Sparse, Medium, Dense and Landscape Sub-Index.

The concepts of the three (3) afore-marked dimensions, i.e. sub-indices, are performed by the Core of the Proposed Model (see *Figure 7.1*) in **Chapter 7 – Methodological Framework**. The just referred framework was driven from the idea, where each dimension is sub-classified into 6 themes by the Proposed Model with Dimensions, Themes and Indicators for Sustainable Development (see *Figure 6.1)* of *Section 6.2 - Proposed Themes and Indicators for Sustainable Development* of **Chapter 6 – Theoretical Framework**).

11.1. CALCULATIONS AND RESULTS OF SOCIAL INDICATORS

11.1.1. Background

All six themes of Social (S) dimension have a major impact to Sustainable Development. Full descriptions of Social indicators are presented in **Appendix 1 – Social Indicators (S).** Only 2 themes, i.e. *Population (S1)* and *Transportation (S6)* are suggested to be used as inputs to Social (S) dimension. These 2 themes are chosen as they have an important role in Sustainable Development of Greece. Migration at the borders of Turkey from S1 theme and Traffic especially in Athens from S6 theme is major problems for the social dimension of sustainable development. In addition, *Population (S1)* (See *Section 6.2.1.1 – Population* of **Chapter 6 – Theoretical Framework**) and *Transportation (S6)* (See *Section 6.2.1.2 – Transportation* of **Chapter 6 – Theoretical Framework**) somehow correlate to each other (*Figure 6.3 – Conceptual Model of Land Development* in **Chapter 6 – Theoretical Framework**). Even though small research of Indicators of Sustainable Transportation was conferred in **Appendix 4 - Indicators of Sustainable Transportation** and due to the enormity of the work and the lack of statistical data, the current dissertation will be directed mainly to the Population theme as a main input to the Social (S) dimension.

11.1.2. Implementation

Decision-makers have different views and are interested in different indicators. As indicators guide management control and strategic planning, Social indicators (See **Appendix 1 – Social Indicators (S)**) have been defined with care. There are different strategies of SD; therefore different indicators are focused, attributing different weights to individual indicators. Consequently, the next procedural part of calculating the CSDI (See *Section 4.13 - Combined / Composite Sustainable Development Index* in **Chapter 4 – The Sustainability Indices**) involves *determining weights*, which should be combined with each indicator. Even more difficulties are expected in obtaining the weights for social indicators. Therefore, to derive the weights practically, the analytic hierarchy process (AHP) was used in the model.

The AHP (Saaty, 1980) has been accepted as a leading multi-attribute decision model, both by practitioners and academics. In this thesis it is attempted to derive weights of indicators by the prioritization of their impact to overall sustainability assessment. Let us assume that N indicators of SD are being considered with the goal of providing and quantifying judgments on the relative weight (expressed as a fraction of importance) of each indicator with respect to all the other indicators of group j. The first step is setting the problem as a *hierarchy*, where the topmost node is the overall objective of the decision, while subsequent nodes at lower levels consist of the criteria used in arriving at this decision.

The second step requires *pairwise comparisons* to make between each pair of indicators (of the given level of the hierarchy). This is done by pairwise comparisons between each pair of indicators, by giving to each indicator the values of 1 to 5, which shows the importance towards Sustainable Development. The comparisons are made by already posed determined value towards Sustainable Development how much the indicator i is more important than indicator k with respect to the SD, respectively as shown by the Importance towards Sustainable Development (see *Table 11.1*). The value of 1 indicates equality between the two indicators while a preference of 5 indicates that one indicator is five times the importance of the one to which it is being compared. This scale was chosen, because in this way comparisons are being made within a limited range where perception is sensitive enough to make a distinction.

Table 11.1: Importance towards Sustainable Development

The Factor of Preference	***The importance of the definition***
1	*Less Importance*
2	*Moderate Importance*
3	Strong or essential importance
4	Very strong or demonstrated the importance
5	*The extreme importance*

To have a better picture of the weights for Society Sub-Index see the subsequent references:

1. Refer to Tab Weighting towards SD of Appendix 10.1 – *Original & Normalized & Final Values Population 1981* for Weighting towards SD of Population 1981.

2. Refer to Tab Weighting towards SD of Appendix 10.2 – *Original & Normalized & Final Values Population 1991* for Weighting towards SD of Population 1991.

3. Refer to Tab Weighting towards SD of Appendix 10.3 – *Original & Normalized & Final Values Population 2001* for Weighting towards SD of Population 2001.

11.1.3. Results

These pairwise comparisons result in a ($N \times N$) positive reciprocal matrix A, where the diagonal $a_{ii} = 1$ and reciprocal property $a_{ji} = (1/a_{ij})$, $i, j = 1, \ldots, n$.

1. Only the first column of the matrix A is provided, i.e., the relative importance of indicators 2, 3, . . ., n, with respect to indicator 1.

2. The process of comparison is repeated for each column of the matrix, making independent judgments over each pair of indicators.

3. At the end of the comparisons, the matrix A is filled with the relative weights.

A quick way to find the normalized weight of each indicator is normalizing each column in the matrix A (dividing an indicator relative weight by the sum of relative weights in column), and then averaging the values across the rows; this average column is the normalized weight vector $\boldsymbol{W}$ containing weights (W_{ji}) of sustainability indicators selected.

As there are approximately 604 indicators for Population and there is the limitation in Excel for the calculation of aforementioned matrix A, each Weighting is shown in a Matrix (see *Table 11.2*) and referred as:

Table 11.2: Division of Weightings in a Matrix

	Indicators 2-202	*Indicators 203-404*	*Indicators 405-605*
Indicators 2-202	Weighting_1	Weighting_2	Weighting_3
Indicators 203-404	Weighting_4	Weighting_5	Weighting_6
Indicators 405-605	Weighting_7	Weighting_8	Weighting_9

For each weighting of the afore-marked weighting system (see *Table 11.2*) for the 1981 year refer to:

1. Refer to Sheet Weighting_1 towards SD of Appendix 10.1 – *Original & Normalized & Final Values Population 1981* for Weighting_1 of Population 1981.

2. Refer to Sheet Weighting_2 towards SD of Appendix 10.1 – *Original & Normalized & Final Values Population 1981* for Weighting_2 of Population 1981.

3. Refer to Sheet Weighting_3 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_3 of Population 1981.

4. Refer to Sheet Weighting_4 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_4 of Population 1981.

5. Refer to Sheet Weighting_5 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_5 of Population 1981.

6. Refer to Sheet Weighting_6 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_6 of Population 1981.

7. Refer to Sheet Weighting_7 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_7 of Population 1981.

8. Refer to Sheet Weighting_8 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_8 of Population 1981.

9. Refer to Sheet Weighting_9 towards SD of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for Weighting_9 of Population 1981.

For each weighting of the afore-marked weighting system (see *Table 11.2*) for the 1991 year refer to:

1. Refer to Sheet Weighting_1 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_1 of Population 1991.

2. Refer to Sheet Weighting_2 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_2 of Population 1991.

3. Refer to Sheet Weighting_3 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_3 of Population 1991.

4. Refer to Sheet Weighting_4 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_4 of Population 1991.

5. Refer to Sheet Weighting_5 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_5 of Population 1991.

6. Refer to Sheet Weighting_6 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_6 of Population 1991.

7. Refer to Sheet Weighting_7 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_7 of Population 1991.

8. Refer to Sheet Weighting_8 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_8 of Population 1991.

9. Refer to Sheet Weighting_9 towards SD of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for Weighting_9 of Population 1991.

For each weighting of the afore-marked weighting system (see *Table 11.2*) for the 2001 year refer to:

1. Refer to Sheet Weighting_1 towards SD of *Appendix 10.3* – *Original & Normalized & Final Values Population 2001* for Weighting_1 of Population 2001.

2. Refer to Sheet Weighting_2 towards SD of *Appendix 10.3* – *Original & Normalized & Final Values Population 2001* for Weighting_2 of Population 2001.

3. Refer to Sheet Weighting_3 towards SD of *Appendix 10.3* – *Original & Normalized & Final Values Population 2001* for Weighting_3 of Population 2001.

4. Refer to Sheet Weighting_4 towards SD of *Appendix 10.3* – *Original & Normalized & Final Values Population 2001* for Weighting_4 of Population 2001.

5. Refer to Sheet Weighting_5 towards SD of *Appendix 10.3* – *Original & Normalized & Final Values Population 2001* for Weighting_5 of Population 2001.

6. Refer to Sheet Weighting_6 towards SD of Appendix 10.3 – *Original & Normalized & Final Values Population 2001* for Weighting_6 of Population 2001.

7. Refer to Sheet Weighting_7 towards SD of Appendix 10.3 – *Original & Normalized & Final Values Population 2001* for Weighting_7 of Population 2001.

8. Refer to Sheet Weighting_8 towards SD of Appendix 10.3 – *Original & Normalized & Final Values Population 2001* for Weighting_8 of Population 2001.

9. Refer to Sheet Weighting_9 towards SD of Appendix 10.3 – *Original & Normalized & Final Values Population 2001* for Weighting_9 of Population 2001.

After representation of Matrix A into sub-matrices as represented by the *Division of Weightings in a Matrix* (see *Table 11.2*), the Normalization (See *Section 9.3 – Normalization* of **Chapter 9 - Data Preprocessing and Normalization**) to each weighting is provided on a down part of each sheet, separately.

To present the normalized values of weightings in the vertical way for the 1981 year as:

1. The Normalized Values for Weighting_1, Weighting_4 and Weighting_7 for the Population 1981 are collected under Tab Normalized Weighting _1_4_7 of *Appendix 10.1 – Original & Normalized & Final Values Population 1981*.

2. The Normalized Values for Weighting_2, Weighting_5 and Weighting_8 for the Population 1981 are collected under Tab Normalized Weighting _2_5_8 of *Appendix 10.1 – Original & Normalized & Final Values Population 1981*.

3. The Normalized Values for Weighting_3, Weighting_6 and Weighting_9 for the Population 1981 are collected under Tab Normalized Weighting _3_6_9 of *Appendix 10.1 – Original & Normalized & Final Values Population 1981*.

To present the normalized values of weightings in the vertical way for the 1991 year as:

1. The Normalized Values for Weighting_1, Weighting_4 and Weighting_7 for the Population 1991 are collected under Tab Normalized Weighting _1_4_7 of *Appendix 10.2 – Original & Normalized & Final Values Population 1991*.

2. The Normalized Values for Weighting_2, Weighting_5 and Weighting_8 for the Population 1991 are collected under Tab Normalized Weighting _2_5_8 of Appendix 10.2 – *Original & Normalized & Final Values Population 1991*.

3. The Normalized Values for Weighting_3, Weighting_6 and Weighting_9 for the Population 1991 are collected under Tab Normalized Weighting _3_6_9 of Appendix 10.2 – *Original & Normalized & Final Values Population 1991*.

To present the normalized values of weightings in the vertical way for the 1981 year as:

1. The Normalized Values for Weighting_1, Weighting_4 and Weighting_7 for the Population 2001 are collected under Tab Normalized Weighting _1_4_7 of Appendix 10.3 – *Original & Normalized & Final Values Population 2001*.

2. The Normalized Values for Weighting_2, Weighting_5 and Weighting_8 for the Population 2001 are collected under Tab Normalized Weighting _2_5_8 of Appendix 10.3 – *Original & Normalized & Final Values Population 2001*.

3. The Normalized Values for Weighting_3, Weighting_6 and Weighting_9 for the Population 2001 are collected under Tab Normalized Weighting _3_6_9 of Appendix 10.3 – *Original & Normalized & Final Values Population 2001*.

Later on the Final Normalized Weights which is equal to the sum of Normalized Weighting _1_4_7, Weighting _2_5_8 and Weighting _3_6_9 and the references for the three (3) time series are presented as:

1. Refer to Tab Final Normalized Weights of Appendix 10.1 – *Original & Normalized & Final Values Population 1981* for Final Normalized Weights of Population 1981.

2. Refer to Tab Final Normalized Weights of Appendix 10.2 – *Original & Normalized & Final Values Population 1991* for Final Normalized Weights of Population 1991.

3. Refer to Tab Final Normalized Weights of Appendix 10.3 – *Original & Normalized & Final Values Population 2001* for Final Normalized Weights of Population 2001.

Finally, the Final Normalized value is equal to the Normalized Data (See Section 9.3 – Normalization of **Chapter 9** **- Data Preprocessing and Normalization**) times just described Final Normalized Weights and is represented for the three (3) time series as.

1. Refer to the Tab Final Normalized value of *Appendix 10.1* – *Original & Normalized & Final Values Population 1981* for the Final Normalized Value of Population 1981.

2. Refer to the Tab Final Normalized Value of *Appendix 10.2* – *Original & Normalized & Final Values Population 1991* for the Final Normalized Value of Population 1991.

3. Refer to the Tab Final Normalized Value of *Appendix 10.3* – *Original & Normalized & Final Values Population 2001* for the Final Normalized Value of Population 2001.

11.2. CALCULATIONS AND RESULTS OF ECONOMIC INDICATORS

11.2.1. Background

All six (6) themes of Economic (EC) dimension have major impact to Sustainable Development. Full descriptions of Economic Indicators are presented in ***Appendix 2*** **– Economic Indicators (EC)**. Only two (2) themes, i.e. Agriculture (EC4) and Tourism (EC6) were discussed in Section 6.2.2 – Economic Indicators (EC) of ***Chapter 6*** **– Theoretical Framework.** These two (2) themes are chosen as they have an important role in Sustainable Development of Greece (Hellenic Ministry for the Environment, 2002; Blue Plan - Regional Activity Centre, 2007; 2008). Agriculture (EC4) (See Section 6.2.2.1 – Agriculture of Chapter 6 – Theoretical Framework) and Tourism (EC6) (See Section 6.2.2.2 – Tourism of Chapter 6 – Theoretical Framework) has an essential part in the Greek Economy (OECD, 2002a). Essential part in the Economy of Greece (OECD, 2002a). Additionally, Agriculture (EC4) and Tourism (EC6) somehow interrelate with each other by the Derived System Graphs for "School" and "Agriculture" Groups (see *Figure 6.5*) of ***Chapter 6*** **– Theoretical Framework**).

11.2.2. Implementation

For the assessment of sustainability, a number of described Economic Indicators (See **Appendix 2** **– Economic Indicators (EC)**), particularly, *Agriculture (EC4), Industry (EC5) and Tourism (EC6)* themes, are considered, which are used to evaluate progress of the organization towards sustainability. The individual importance of these indicators is very difficult to determine with sufficient accuracy (Fagan and Carvalho, 2004). To determine the weights of indicators, the evaluators are often confronted with a lack of data. Therefore, the pairwise comparison technique is used in the next procedural part of calculating the CSDI (see *Section 4.13 - Combined / Composite Sustainable Development Index* of **Chapter 4 – The Sustainability Indices**) in order to derive relative weights of each indicator practically.

The pairwise comparison technique is based on the method developed by Saaty (1995) called the Analytic Hierarchy Process (AHP). Krajnc and Glavic (2005a) described the procedural details of AHP along with an application on the case study of sustainability assessment. In the following, the method is briefly introduced only to highlight its applicability and suitability in the context of sustainability assessment.

Let us assume that N indicators of SD are being considered with the goal of quantifying relative weights of each indicator with respect to all the other indicators of group j towards Sustainable Development. The pairwise comparisons between each pair of indicators, by giving to each indicator the values of 1 to 5, which shows the importance towards Sustainable Development, are implemented. The comparisons are made by already posed determined value towards Sustainable Development how much the indicator i is more important than indicator k with respect to the SD, respectively, by the Importance towards Sustainable Development (See *Table 11.1*) of the current chapter. The intensity of preference is expressed on a factor scale from 1/5 to 5. The value of 1 indicates equality between the two indicators while a preference of 5 indicates that one indicator is 5 times the importance of the one to which it is being compared. This scale is chosen because in this way comparisons are being made within a limited range where perception is sensitive enough to make a distinction.

The sequence of the discussions of results is kept according to the sequence of shown in the existing statistical data by the Final Proposed Datasets (See *Table 8.7* of **Chapter 8 - Study Area and Datasets**).

1. Agriculture (EC4)

The Weightings towards SD of Agriculture are located in Appendix 6 and are referred as.

- Refer to Tab Weighting towards SD of *Appendix 6.1 – Original & Normalized & Final Values Agriculture 1981* for Weighting towards SD of Agriculture 1981.
- Refer to Tab Weighting towards SD of *Appendix 6.2 – Original & Normalized & Final Values Agriculture 1991* for Weighting towards SD of Agriculture 1991.

- Refer to Tab Weighting towards SD of *Appendix 6.3 – Original & Normalized & Final Values Agriculture 2001* for Weighting towards SD of Agriculture 2001.

2. Tourism (EC6)

The Weightings towards SD of Tourism are located in Appendix 7 and are referred as.

1. Refer to Tab Weighting towards SD of *Appendix 7.1 – Original & Normalized & Final Values Tourism 1993* for Weighting towards SD of Tourism 1993.

2. Refer to Tab Weighting towards SD of *Appendix 7.2 – Original & Normalized & Final Values Tourism 2001* for Weighting towards SD of Tourism 2001.

3. Agricultural Goods (EC2)

The Weightings towards SD of Agricultural Goods are located in Appendix 8 and are referred as.

- Refer to Tab Weighting towards SD of *Appendix 8.1 – Original & Normalized & Final Values Agricultural Goods 1993* for Weighting towards SD of Agricultural Goods 1993.

- Refer to Tab Weighting towards SD of *Appendix 8.2 – Original & Normalized & Final Values Agricultural Goods 2001* for Weighting towards SD of Agricultural Goods 2001.

4. Industry (EC5)

The Weightings towards SD of Industry, which are generally related to the constructions of buildings, are located in Appendix 9 and are referred as.

- Refer to Tab Weighting towards SD of *Appendix 9.1 – Original & Normalized & Final Values Industry 1993* for Weighting towards SD of Industry 1993.

- Refer to Tab Weighting towards SD of *Appendix 9.2 – Original & Normalized & Final Values Industry 2001* for Weighting towards SD of Industry 2001.

11.2.3. Results

These pairwise comparisons result in a (N_N) positive reciprocal matrix A, where the diagonal a_{ik} = 1 and reciprocal property a_{ki}=(1/a_{ik}), i, k = 1,. . ., n. A quick way to find the normalized weight of each indicator is normalizing each column in the matrix A (dividing an indicator relative weight by the sum of relative weights in column), and then averaging the values across the rows; this average column is the normalized weight vector W containing weights (W_{ji}) of sustainability indicators selected.

a) Agriculture (EC4)

The Matrix with Weightings towards SD of Agriculture is located in Appendix 6 and is referred as.

- Refer to the Sheet Weighting of *Appendix 6.1* – *Original & Normalized & Final Values Agriculture 1981* for Matrix with Weightings of Agriculture 1981.
- Refer to the Sheet Weighting of *Appendix 6.2* – *Original & Normalized & Final Values Agriculture 1991* for Matrix with Weightings Agriculture 1991.
- Refer to the Sheet Weighting of *Appendix 6.3* – *Original & Normalized & Final Values Agriculture 2001* for Matrix with Weightings of Agriculture 2001.

After representation of Matrix A, the normalization to each weighting is provided on a down part of the sheet. Then Final Normalized Weighting is calculated and is referred as.

- Refer to the Tab Final Normalized Weighting of *Appendix 6.1* – *Original & Normalized & Final Values Agriculture 1981* for Final Normalized Weighting of Agriculture 1981.
- Refer to the Tab Final Normalized Weighting of *Appendix 6.2* – *Original & Normalized & Final Values Agriculture 1991* for Final Normalized Weighting of Agriculture 1991.
- Refer to the Tab Final Normalized Weighting of *Appendix 6.3* – *Original & Normalized & Final Values Agriculture 2001* for Final Normalized Weighting of Agriculture 2001.

b) Tourism (EC6)

The Matrix for the Weightings is not performed due to the hugeness of indicators, which are approximately 1134 and the limitation of the Excel program. Instead the normalization (See *Section 9.3 – Normalization* of **Chapter 9 - Data Preprocessing and Normalization**) is done for the Weightings towards SD of Tourism, which are located in Appendix 7. Then Final Normalized Weighting is calculated and is referred as.

- ➢ Refer to the Tab Final Normalized Weighting of *Appendix 7.1 – Original & Normalized & Final Values Tourism 1993* for Final Normalized Weighting of Tourism 1993.

- ➢ Refer to the Tab Final Normalized Weighting of *Appendix 7.2 – Original & Normalized & Final Values Tourism 2001* for Final Normalized Weighting of Tourism 2001.

c) Agricultural Goods (EC2)

The Matrix for the Weightings is not performed because the weightings are all almost equal to 4 where there is a normal distribution of values. Instead the normalization (See *Section 9.3 – Normalization* of **Chapter 9 - Data Preprocessing and Normalization**) is done for the Weightings towards SD of Agricultural Goods are located in Appendix 8. Then Final Normalized Weighting is calculated and is referred as.

- ➢ Refer to the Tab Final Normalized Weighting of *Appendix 8.1 – Original & Normalized & Final Values Agricultural Goods 1993* for Final Normalized Weighting of Agricultural Goods 1993.

- ➢ Refer to the Tab Final Normalized Weighting of *Appendix 8.2 – Original & Normalized & Final Values Agricultural Goods 2001* for Final Normalized Weighting of Agricultural Goods 2001.

d) Industry (EC5)

The Matrix with Weightings towards SD of Industry, which are generally related to the constructions of buildings, is located in Appendix 9 and is referred as.

- ➢ Refer to the Sheet Weighting of *Appendix 9.1 – Original & Normalized & Final Values Industry 1993* for Matrix with Weightings of Industry 1993.

- Refer to the Sheet Weighting of Appendix 9.2 – *Original & Normalized & Final Values Industry 2001* for Matrix with Weightings of Industry 2001.

After representation of Matrix A, the normalization to each weighting is provided on a down part of the sheet. Then Final Normalized Weighting is calculated and is referred as.

- Refer to the Tab Final Normalized Weighting of Appendix 9.1 – *Original & Normalized & Final Values Industry 1993* for Final Normalized Weighting of Industry 1993.

- Refer to the Tab Final Normalized Weighting of Appendix 9.2 – *Original & Normalized & Final Values Industry 2001* for Final Normalized Weighting of Industry 2001.

11.3. CALCULATIONS AND RESULTS OF ENVIRONMENTAL INDICATORS

11.3.1. Background

Environmental Indicators (See **Appendix 3 - Environmental Indicators (EN)**) are categorized into 6 themes, which has a relationship to the environmental footprint and its land types, schematically presented by Chambers et al. (2000b) and Eaton et al., (2007) (See *Figure 6.6* of **Chapter 6 – Theoretical Framework**). "*Ecological*" or "*Environmental*" footprints (and related parameters) represent, albeit partial, sustainability indicators (Hammond, 2006).

The current thesis outlines the evaluation of Biodiversity in Sustainable Development. As it was shown by the Levels of Biodiversity (See *Table 2.1* of **Chapter 2 – Economic valuation of Biodiversity Loss** by *Section 2.2 - Environmental foundations for Biodiversity Analysis and Valuation*).The same levels of biodiversity are shown by the General Model for Biodiversity (See *Figure 6.7* of **Chapter 6 – Theoretical Framework**), where not only economic and environmental evaluations are given but also evaluation of biodiversity using GIS as a tool. Recently the technology has been developed that even for Gene level some evaluations can be performed using Remote Sensing and Geographic Information System. However, this case was excluded from the current thesis as is already huge.

11.3.2. Implementation

For the assessment of sustainability, a number of described Environmental Indicators (See **Appendix 3 – Environmental Indicators (EN)**) are considered, which are used to evaluate progress of the organization towards sustainability. The individual importance of these indicators is very difficult to determine with sufficient accuracy (Afgan and Carvalho, 2004). The weights of environmental indicators can be obtained from environmental expert surveys or from public surveys about environmental themes. However, to determine the weights of environmental indicators the evaluator is often confronted with a lack of data. Therefore, the pairwise comparison technique is used in the next procedural part of calculating the CSDI (See *Section 4.13 – Combined / Composite Sustainable Development Index* of **Chapter 4 – The Sustainability Indices**) in order to derive relative weights of each indicator practically.

Due to the lack of real environmental data for the municipality of Nea Makri, Athens, Greece, the environmental indicators were derived from Remote Sensing Data. A great variety of different landscape metrics based on remote sensing data (RS), for monitoring ecosystems and also different programs for their calculation (Fragstat, metrics, GIS) are discussed in details *Sub-Section 3.2 – Landscape metrics* of **Chapter 3 – Landscape Metrics based on Remote Sensing Data**. The investigation identified subsets of metrics, enabled scientists to recognize main aspects of landscape pattern, facilitated the compilation of groups of landscapes with similar characteristics and indicated which metrics are frequently useful in landscape studies. The frequency of used papers per each metric has been taken into account. In the current thesis, there are six (6) main categories of metrics. The most used to the least used metrics have the following order:

1. Area / Density / Edge (All types of RS data, 10 subcategories, 22 papers);
2. Isolation Proximity (All types of RS data, 2 subcategories, 15 papers);
3. Diversity (All types of RS data, 9 subcategories, 20 papers);
4. Contagion Interspersion (VHR and HR RS data, 8 subcategories, 12 papers);
5. Shape (VHR RS data, 13 subcategories, 17 papers);
6. Connectivity (VHR and HR RS data, 2 subcategories, 5 papers).

It is observed from the aforementioned list that the three (3) last categories of metrics use only VHR and/or HR remote sensing data. Particularly, only very high resolution (VHR) remote sensing data is used in the Shape Metric. This constraint can explain their limited use.

Furthermore, the frequency of used papers is divided into five groups. The frequency of used papers equals to the number of used papers per subcategory over the number of used papers per main category. It has been found that min=1/17=0.059 and max=12/15=0.8. The range from MIN to MAX has been divided into five equal pieces accordingly representing five groups, i.e. from Group A till Group E. To have a better idea of each group appearance per subcategory and main categories according to the frequency of used papers per each index, the first three before-mentioned groups has the following order:

1. Group A:
    - Euclidean Nearest Neighborhood (12/15=0.8) from Isolation Proximity main category;
    - Shannon Diversity Index (13/20=0.65) from Diversity main category;
    - Shape Index (11/17=0.647) from Shape main category;
    - Patch Density (13/22=0.591) from Area / Density / Edge main category (Exception);
2. Group B:
    - Patch Cohesion Index (3/5=0.6) from Connectivity main category;
    - Connectance Index (3/5=0.6) from Connectivity main category;
    - Contagion Index (7/12=0.583) from Contagion Interspersion main category;
    - Proximity Index Distribution (8/15=0.533) from Isolation Proximity main category;
    - Number of Patches (11/22=0.5) from Area / Density / Edge main category;
    - Interspersion Juxtaposition Index (6/12=0.5) from Contagion Interspersion main category;
3. Group C:
    - Largest Patch Index (9/22=0.409) from Area / Density / Edge main category;
    - Edge Density (9/22=0.409) from Area / Density / Edge main category;
    - Class Area (8/22=0.364) from Area / Density / Edge main category;
    - Patch Richness (7/20=0.35) from Diversity main category.

Finally, the Weightings towards SD according to being used by the authors are located in Appendix 12. The Sheet Weighting of the Class and Landscape Vegetation for the 1984 year is referred as:

1. Refer to the Sheet Weighting of ***Appendix 12.1*** – *RS ENV Sparse Vegetation 1984 for Matrix* with Weightings of Sparse Vegetation for 1984.
2. Refer to the Sheet Weighting of ***Appendix 12.2*** – *RS ENV Medium Vegetation 1984 for Matrix* with Weightings of Medium Vegetation for 1984.
3. Refer to the Sheet Weighting of ***Appendix 12.3*** – *RS ENV Dense Vegetation 1984 for Matrix* with Weightings of Dense Vegetation for 1984.
4. Refer to the Sheet Weighting of ***Appendix 12.4*** – *RS ENV Landscape 1984 for Matrix* with Weightings of Landscape for 1984.

The Sheet Weighting of the Class and Landscape Vegetation for the 1990 year is referred as:

1. Refer to the Sheet Weighting of ***Appendix 13.1*** – *RS ENV Sparse Vegetation 1990 for Matrix* with Weightings of Sparse Vegetation for 1990.
2. Refer to the Sheet Weighting of ***Appendix 13.2*** – *RS ENV Medium Vegetation 1990 for Matrix* with Weightings of Medium Vegetation for 1990.
3. Refer to the Sheet Weighting of ***Appendix 13.3*** – *RS ENV Dense Vegetation 1990 for Matrix* with Weightings of Dense Vegetation for 1990.
4. Refer to the Sheet Weighting of ***Appendix 13.4*** – *RS ENV Landscape 1990 for Matrix* with Weightings of Landscape for 1990.

The Sheet Weighting of the Class and Landscape Vegetation for the 1984 year is referred as:

1. Refer to the Sheet Weighting of ***Appendix 14.1*** – *RS ENV Sparse Vegetation 2002 for Matrix* with Weightings of Sparse Vegetation for 2002.
2. Refer to the Sheet Weighting of ***Appendix 14.2*** – *RS ENV Medium Vegetation 2002 for Matrix* with Weightings of Medium Vegetation for 2002.
3. Refer to the Sheet Weighting of ***Appendix 14.3*** – *RS ENV Dense Vegetation 2002 for Matrix* with Weightings of Dense Vegetation for 2002.

4. Refer to the Sheet Weighting of ***Appendix 14.4*** – *RS ENV Landscape 2002 for Matrix* with Weightings of Landscape for 2002.

11.3.3. Results

These pairwise comparisons result in a (N_N) positive reciprocal matrix A, where the diagonal a_{ik} = 1 and reciprocal property a_{ki}= (1/a_{ik}), i, k = 1, n. A quick way to find the normalized weight of each indicator is normalizing each column in the matrix A (dividing an indicator relative weight by the sum of relative weights in column), and then averaging the values across the rows; this average column is the normalized weight vector W containing weights (W_{ji}) of sustainability indicators selected.

The Matrices with Weightings towards SD of Remote Sensing Environmental Metrics are located in **Appendices 12, 13 and 14**. The Weightings' Matrices are represented by the **Appendix 12** for the 1984 year as:

1. Refer to Tab Weighting towards SD of ***Appendix 12.1*** – RS ENV Sparse Vegetation 1984 for Weighting towards SD of Sparse Vegetation for 1984.

2. Refer to Tab Weighting towards SD of ***Appendix 12.2*** – RS ENV Medium Vegetation 1984 for Weighting towards SD of Medium Vegetation for 1984.

3. Refer to Tab Weighting towards SD of ***Appendix 12.3*** – RS ENV Dense Vegetation 1984 for Weighting towards SD of Dense Vegetation for 1984.

4. Refer to Tab Weighting towards SD of ***Appendix 12.4*** – RS ENV Landscape 1984 for Weighting towards SD of Landscape for 1984.

The Weigtings' Matrices are represented by the **Appendix 13** for the 1990 year as:

1. Refer to Tab Weighting towards SD of ***Appendix 13.1*** – RS ENV Sparse Vegetation 1990 for Weighting towards SD of Sparse Vegetation for 1990.

2. Refer to Tab Weighting towards SD of ***Appendix 13.2*** – RS ENV Medium Vegetation 1990 for Weighting towards SD of Medium Vegetation for 1990.

3. Refer to Tab Weighting towards SD of ***Appendix 13.3*** – RS ENV Dense Vegetation 1990 for Weighting towards SD of Dense Vegetation for 1990.

4. Refer to Tab Weighting towards SD of ***Appendix 13.4*** – RS ENV Landscape 1990 for Weighting towards SD of Landscape for 1990.

The Weigtings' Matrices are represented by the **Appendix 14** for the 2002 year as:

1. Refer to Tab Weighting towards SD of ***Appendix 14.1*** – RS ENV Sparse Vegetation 2002 for Weighting towards SD of Sparse Vegetation for 2002.

2. Refer to Tab Weighting towards SD of ***Appendix 14.2*** – RS ENV Medium Vegetation 2002 for Weighting towards SD of Medium Vegetation for 2002.

3. Refer to Tab Weighting towards SD of ***Appendix 14.3*** – RS ENV Dense Vegetation 2002 for Weighting towards SD of Dense Vegetation for 2002.

4. Refer to Tab Weighting towards SD of ***Appendix 14.4*** – RS ENV Landscape 2002 for Weighting towards SD of Landscape for 2002.

11.4. AN INTEGRATED ASSESSMENT OF SUSTAINABLE DEVELOPMENT

11.4.1. Background

The proposed model reduces the number of indicators by aggregating them into a composite sustainable development index (ICSD). The basic hierarchy of composing indicators into the ICSD is shown by the Scheme for Calculation of the Composite Sustainable Development Index (See *Figure 4.16)* of *Section – 4.13 Combined / Composite Sustainable Development Index (CSDI)* of **Chapter 4 – The Sustainability Indices.** The procedure of calculating the CSDI is divided into several parts: selecting, grouping, weighting, judging, normalizing indicators, calculating sub-indices and combining them into the CSDI. These procedural parts are presented as:

1. **Selecting Indicators:**

   The description of Selected Indicators is given in **Chapter 6 – Theoretical Framework.**

2. **Grouping of Indicators:**

   Grouping of Indicators per theme and then each theme per dimension are shown by the three (3) Dimensions, i.e. Sub-Indices, of SD with Proposed Sub-classified six (6)Themes (See *Table 6.1*) and the Proposed Model with Dimensions, Themes and Indicators for SD (See *Figure 6.1*) of *Section 6.2 – Proposed Themes and Indicators for Sustainable Development* of **Chapter 6 – Theoretical Framework.**

3. Weighting and judging indicators:

The weighting and judging the indicators is described above in the current section.

4. Normalizing Indicators:

The normalization of Indicators is discussed in *Section 9.3 – Normalization* of Chapter 9 **– Data Preprocessing and Normalization for the GR Stat and RS dataset**.

5. Calculating the Sub-Indices:

The calculation of the CSDI is a step-by-step procedure of grouping various basic indicators into the sustainability sub-index ($I_{S,\ j}$) for each group of sustainability indicators j. *Sub-indices* can be derived as shown in *Equation 11.1.*

Equation 11.1: Calculating the Sub-Indices

$$I_{S,jt} = \sum_{jit}^{n} W_{ji} \cdot I_{N,jit}^{+} + \sum_{jit}^{n} W_{ji} \cdot I_{N,jit}^{-}$$

$$\sum_{ji}^{n} W_{ji} = 1, W_{ji} \geq 0$$

where $I_{S,\ jt}$ is the sustainability sub-index for a group of indicators j in time/year t. Wji is the weight of the indicator i for the group of sustainability indicators j and reflects the importance of this indicator in the sustainability assessment.

6. Combining the Sub-Indices into the CSDI:

Finally, the sustainability sub-indices are combined into the composite sustainable development index, CSDI *(Equation 11.2).*

Equation 11.2: Combining the Sub-Indices into the CSDI

$$I_{CSD,t} = \sum_{jt}^{n} W_{j} \cdot I_{S,jt}$$

Where W_j denotes the factor representing a priori weight given to the group j of SD indicators. These weights should reflect priorities on the opinion of the decision makers. In the final calculation of the CSDI, an approach that uses estimated weights can be considered. These weights reflect the importance given to the Society, Economy and Nature performances.

11.4.2. Implementation

To observe details of calculation of sub-indices according to each theme, as presented by the subsequent way:

1. Population

The Final Normalized Values of Population are located in **Appendix 10** and referred for the time series as.

- Refer to Tab Final Normalized Values of **Appendix 10.1** – *Original & Normalized & Final Values Population 1981* for Final Normalized Values of Population for the 1981 year.
- Refer to Tab Final Normalized Values of **Appendix 10.2** – *Original & Normalized & Final Values Population 1991* for Final Normalized Values of Population for the 1991 year.
- Refer to Tab Final Normalized Values of **Appendix 10.3** – *Original & Normalized & Final Values Population 2001* for Final Normalized Values of Population for the 2001 year.

2. Agriculture

The Final Normalized Values of Agriculture are located in **Appendix 6**.

- Refer to Tab Final Normalized Values of **Appendix 6.1** – *Original & Normalized & Final Values Agriculture 1981* for Final Normalized Values of Agriculture 1981.
- Refer to Tab Final Normalized Values of **Appendix 6.2** – *Original & Normalized & Final Values Agriculture 1991* for Final Normalized Values of Agriculture 1991.
- Refer to Tab Final Normalized Values of **Appendix 6.3** – *Original & Normalized & Final Values Agriculture 2001* for Final Normalized Values of Agriculture 2001.

3. Tourism

The Final Normalized Values of Tourism are located in **Appendix 7**.

- Refer to Tab Final Normalized Values of **Appendix 7.1** – *Original & Normalized & Final Values Tourism 1993* for Final Normalized Values of Tourism 1993.

- Refer to Tab Final Normalized Values of **Appendix 7.2** – *Original & Normalized & Final Values Tourism 2001* for Final Normalized Values of Tourism 2001.

4. Agricultural Goods

The Final Normalized Values of Agricultural Goods are located in **Appendix 8**.

- Refer to Tab Final Normalized Values of **Appendix 8.1** – *Original & Normalized & Final Values Agricultural Goods 1993* for Final Normalized Values of Agricultural Goods 1993.

- Refer to Tab Final Normalized Values of **Appendix 8.2** – *Original & Normalized & Final Values Agricultural Goods 2001* for Final Normalized Values of Agricultural Goods 2001.

5. Industry

The Final Normalized Values of Industry, which are generally related to the constructions of buildings, are located in Appendix 9.

- Refer to Tab Final Normalized Values of **Appendix 9.1** – *Original & Normalized & Final Values Industry 1993* for Final Normalized Values of Industry 1993.

- Refer to Tab Final Normalized Values of **Appendix 9.2** – *Original & Normalized & Final Values Industry 2001* for Final Normalized Values of Industry 2001.

6. Remote Sensing Metrics for Nature

The Final Normalized Values of Remote Sensing Metrics for Nature are located in **Appendices 12, 13 and 14.** Specifically, the RS Metrics for Nature are presented by **Appendix 12** for the 1984 year as:

- Refer to Tab Final Normalized Values of **Appendix 12.1** – *RS ENV Sparse Vegetation 1984* for Final Normalized Values of Sparse Vegetation for 1984.

- Refer to Tab Final Normalized Values of **Appendix 12.2** – *RS ENV Medium Vegetation 1984* for Final Normalized Values of Medium Vegetation for 1984.

- Refer to Tab Final Normalized Values of **Appendix 12.3** – *RS ENV Dense Vegetation 1984* for Final Normalized Values of Dense Vegetation for 1984.

- Refer to Tab Final Normalized Values of **Appendix 12.4** – *RS ENV Landscape 1984* for Final Normalized Values of Landscape for 1984.

The RS Metrics for Nature are presented by **Appendix 13** for the 1990 year as:

- Refer to Tab Final Normalized Values of **Appendix 13.1** – *RS ENV Sparse Vegetation 1990* for Final Normalized Values of Sparse Vegetation for 1990.

- Refer to Tab Final Normalized Values of **Appendix 13.2** – *RS ENV Medium Vegetation 1990* for Final Normalized Values of Medium Vegetation for 1990.

- Refer to Tab Final Normalized Values of **Appendix 13.3** – *RS ENV Dense Vegetation 1990* for Final Normalized Values of Dense Vegetation for 1990.

- Refer to Tab Final Normalized Values of **Appendix 13.4** – *RS ENV Landscape 1990* for Final Normalized Values of Landscape for 1990.

The RS Metrics for Nature are presented by **Appendix 14** for the 2002 year:

- Refer to Tab Final Normalized Values of **Appendix 14.1** – *RS ENV Sparse Vegetation 2002* for Final Normalized Values of Sparse Vegetation for 2002.

- Refer to Tab Final Normalized Values of **Appendix 14.2** – *RS ENV Medium Vegetation 2002* for Final Normalized Values of Medium Vegetation for 2002.

- Refer to Tab Final Normalized Values of **Appendix 14.3** – *RS ENV Dense Vegetation 2002* for Final Normalized Values of Dense Vegetation for 2002.

- Refer to Final Normalized Values of **Appendix 14.4** – *RS ENV Landscape 2002* for Final Normalized Values of Landscape for 2002.

11.4.3. Results

11.4.3.1. Results of Calculation of the Sub-Indices

All the Final Normalized Values were computed. *Sub-Indices* can be derived as shown in *Equation 11.1* of this chapter. By the term of our computation each sub-index is the sum of Final Normalized Values of each dimension. Separately, the sub-index for each dimension is observed.

1. **Social Indicators (S)** (**Appendix 1** - **Social Indicators (S)** and *Section 6.2.1 – Social Indicators* of **Chapter 6** **– Theoretical Framework**):

   Social Sustainability Sub-index equals to the sum of Final Normalized Values of Social Dimensions and equals to the sum of Final Normalized Values of Population Sub-index.

   SOCIAL SUSTAINABILITY SUB-INDEX 1981 = 0.01354

   SOCIAL SUSTAINABILITY SUB-INDEX 1991 = 0.01493

   SOCIAL SUSTAINABILITY SUB-INDEX 2001 = 0.01374

   Social Sustainability Sub-Index is prescribed by the Society SD Sub-Index way.

2. **Economic Indicators (EC)** (**Appendix 2** - **Economic Indicators (EC)** and *Section 6.2.2 – Economic Indicators* of **Chapter 6** **– Theoretical Framework**):
   Economic Sustainability Sub-index equals to the sum of Final Normalized Values of the Economic Dimension and equals to the sum of ¼ of Final Normalized Values of Each Theme. The sub-index each theme is perceived:

   - ➢ **Agriculture Sustainability Sub-Index** equals to the sum of Final Normalized Values of *Agriculture Theme (EC4)*:

AGRICULTURE SUSTAINABILITY SUB-INDEX 1981 = 0.13659

AGRICULTURE SUSTAINABILITY SUB-INDEX 1991 = 0.12309

AGRICULTURE SUSTAINABILITY SUB-INDEX 2001 = 0.08879

Agriculture Sustainability Sub-Index is prescribed by the Agriculture Sub-Index way.

- **Tourism Sustainability Sub-Index** equals to the sum of Final Normalized Values of *Tourism Theme (EC6)*:

TOURISM SUSTAINABILITY SUB-INDEX 1981 = 0

TOURISM SUSTAINABILITY SUB-INDEX 1991 = 0.02893

TOURISM SUSTAINABILITY SUB-INDEX 2001 = 0.05674

Tourism Sustainability Sub-Index is prescribed by the Tourism Sub-Index way.

- **Agricultural Goods Sustainability Sub-Index** equals to the sum of Final Normalized Values of *Agricultural Goods Theme (EC4)*:

AGRICULTURAL GOODS SUSTAINABILITY SUB-INDEX 1981 = 0

AGRICULTURAL GOODS SUSTAINABILITY SUB-INDEX 1991 = 0.03635

AGRICULTURAL GOODS SUSTAINABILITY SUB-INDEX 2001 = 0.03309

Agricultural Goods Sustainability Sub-Index is prescribed by the Agricultural Goods SD Sub-Index way.

- **Industry Sustainability Sub-Index** equals to the sum of Final Normalized Values of *Industry Theme (EC4)*:

INDUSTRY SUSTAINABILITY SUB-INDEX 1981 = 0

INDUSTRY SUSTAINABILITY SUB-INDEX 1991 = 0.08902

INDUSTRY SUSTAINABILITY SUB-INDEX 2001 = 0.07796

Industry Sustainability Sub-Index is prescribed by the Industry Sub-Index way.

Finally, ***Economic Sustainability Sub-index*** is equal to ¼ of Final Normalized Values of Agriculture Sustainability Sub-Index + ¼ of Final Normalized Values of Tourism Sustainability Sub-Index + ¼ of Final Normalized Values of Agricultural Goods Sustainability Sub-Index + ¼ of Final Normalized Values of Industry Sustainability Sub-Index.

ECONOMIC SUSTAINABILITY SUB-INDEX 1981 = 0.03415

ECONOMIC SUSTAINABILITY SUB-INDEX 1991 = 0.06935

ECONOMIC SUSTAINABILITY SUB-INDEX 2001 = 0.06415

Economic Sustainability Sub-Index is prescribed as Economy Sub-Index way.

3. **Environmental Indicators (EN)** (**Appendix 3** - **Environmental Indicators (EN)** and *Section 3.2 - Landscape metrics* of **Chapter 3 – Landscape Metrics based on Remote Sensing Data** and *Section 6.3 – Environmental Indicators* of **Chapter 6 – Theoretical Framework**):

Environmental Sustainability Sub-index equals to the sum of the Final Normalized Values of Environmental Dimensions and equals to the sum of ¼ of Final Normalized Values of Each Theme. In the present case, each theme represents the type of vegetation on Class or the Landscape Level. The sub-index of each theme is observed by the subsequent way:

- **Sparse Vegetation Sustainability Sub-Index** equals to the sum of Final Normalized Values of Sparse Vegetation Theme (Class 1):

SPARSE VEGETATION SUSTAINABILITY SUB-INDEX 1981 = 0.01404

SPARSE VEGETATION SUSTAINABILITY SUB-INDEX 1991 = 0.02051

SPARSE VEGETATION SUSTAINABILITY SUB-INDEX 2001 = 0.01583

Sparse Vegetation Sub-Index is prescribed by Vegetation of Sparse Sub-Index way.

- **Medium Vegetation Sustainability Sub-Index** equals to the sum of Final Normalized Values of Medium Vegetation Theme (Class 2):

MEDIUM VEGETATION SUSTAINABILITY SUB-INDEX 1981 = 0.01555

MEDIUM VEGETATION SUSTAINABILITY SUB-INDEX 1991 = 0.01572

MEDIUM VEGETATION SUSTAINABILITY SUB-INDEX 2001 = 0.01548

Medium Vegetation Sustainability Sub-Index is prescribed by Vegetation of Medium Sub-Index way.

- **Dense Vegetation Sustainability Sub-Index** equals to the sum of Final Normalized Values of Dense Vegetation Theme (Class 3):

DENSE VEGETATION SUSTAINABILITY SUB-INDEX 1981 = 0.01588

DENSE VEGETATION SUSTAINABILITY SUB-INDEX 1991 = 0.01917

DENSE VEGETATION SUSTAINABILITY SUB-INDEX 2001 = 0.01022

Dense Vegetation Sustainability Sub-Index is prescribed by Vegetation Dense Sub-Index way.

- **Landscape Sustainability Sub-Index** equals to the sum of Final Normalized Values of Landscape Theme (Landscape):

LANDSCAPE SUSTAINABILITY SUB-INDEX 1981 = 0.01535

LANDSCAPE SUSTAINABILITY SUB-INDEX 1991 = 0.01588

LANDSCAPE SUSTAINABILITY SUB-INDEX 2001 = 0.01547

Landscape Sustainability Sub-Index is prescribed by Landscape Sub-Index way.

Finally, ***Environmental Sustainability Sub-index*** is equal to ¼ of Final Normalized Values of Sparse Vegetation Sustainability Sub-Index + ¼ of Final Normalized Values of Medium Vegetation Sustainability Sub-Index +

¼ of Final Normalized Values of Dense Vegetation Sustainability Sub-Index + ¼ of Final Normalized Values of Landscape Sustainability Sub-Index.

ENVIRONMENTAL SUSTAINABILITY SUB-INDEX 1981 = 0.01520

ENVIRONMENTAL SUSTAINABILITY SUB-INDEX 1991 = 0.01782

ENVIRONMENTAL SUSTAINABILITY SUB-INDEX 2001 = 0.01425

Environmental Sustainability Sub-Index is prescribed by Nature Sub-Index Way.

11.4.3.2. Results of Combination of the sub-indices into the CSDI

Sub-indices of each dimension, which are derived according to *Equation 11.1*, are illustrated by the *Results of Sustainability Sub-Indices Per Dimension or Sub-Index* (See *Table 11.3*) of this chapter.

Table 11.3: Results of Sustainability Sub-Indices per Dimension or Sub-Index

	1981	**1991**	**2001**
Society Sub-Index	0.01354	0.01493	0.01374
Economy Sub-Index	0.03415	0.06935	0.06415
Nature Sub-Index	0.01520	0.01782	0.01425

As a final stage, the Composite Sustainable Development Index (CSDI) is equal to ⅓ of Society Sub-Index + ⅓ of Economy Sub-Index + ⅓ of the Nature Sub-Index.

COMPOSITE SUSTAINABLE DEVELOPMENT INDEX 1981 = 0.02096

COMPOSITE SUSTAINABLE DEVELOPMENT INDEX 1991 = 0.03403

COMPOSITE SUSTAINABLE DEVELOPMENT INDEX 2001 = 0.03071

For the Discussions, Conclusions and Recommendations refer to **Chapter 12** - **General Conclusions and Recommendations of the current PhD Doctorate.**

CHAPTER 12

GENERAL CONCLUSIONS AND RECOMMENDATIONS

General Conclusions, i.e. Preferences and Recommendations, i.e. Future Works are proposed in the current chapter to make inferences and to suggest further works. The preferences are marked to calculate and perform the CSDI equals to sum of ⅓ Society Sub-Index, ⅓ Economy Sub-Index and ⅓ Nature Sub-Index. Further on, three (3) recommendations, where the last one has four (4) further inferences, are suggested for the future works as:

1. Due to the hugeness of the work and time pressure, the CSDI are calculated based on the key concept for the time series of three (3) years rather than of ten (10) years.

2. Economic Assessment, i.e. TEV, is appraised to calculate the biodiversity for the Mediterranean Forest.

3. Further four (4) inferences are suggested as:

    - Fuzzy Set Theory;

    - Significance-Acceptability Transformation (SAT);

    - Fuzzy Mathematical Models;

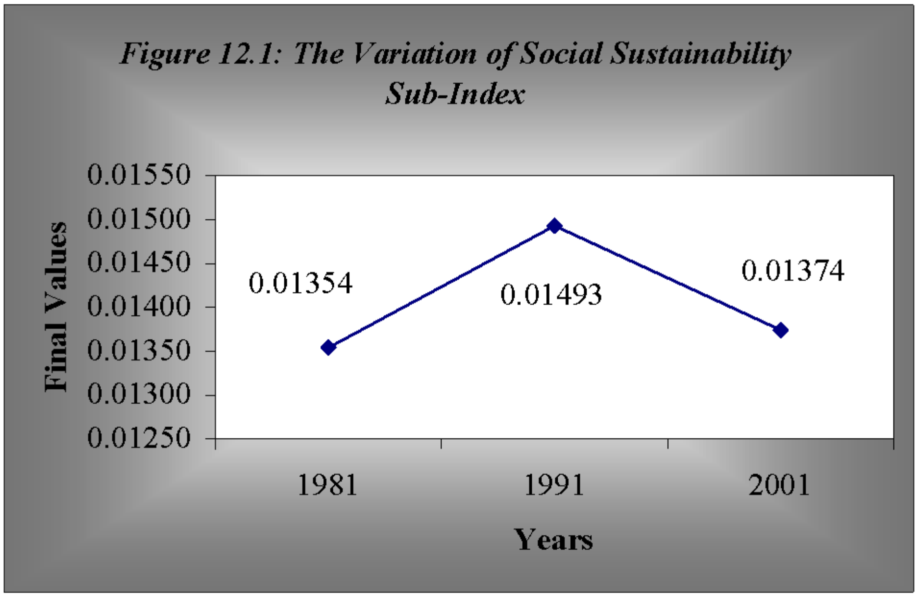
    - Fuzzy Analytic Network Process (FANP).

The afore-marked three (3) targets are suggested for the future works.

12.1. GENERAL CONCLUSIONS

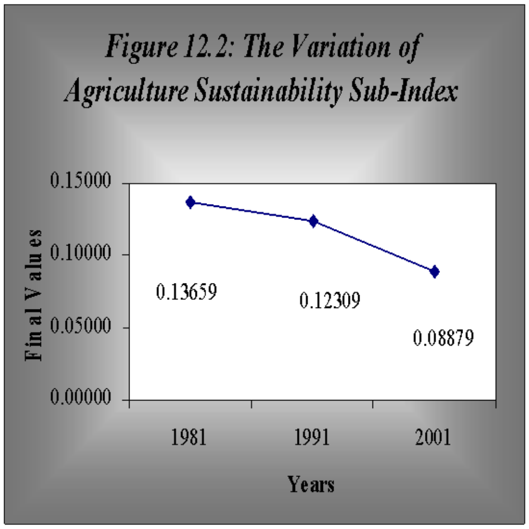
Several conclusions on each sub-index or sub-indices are carried out.

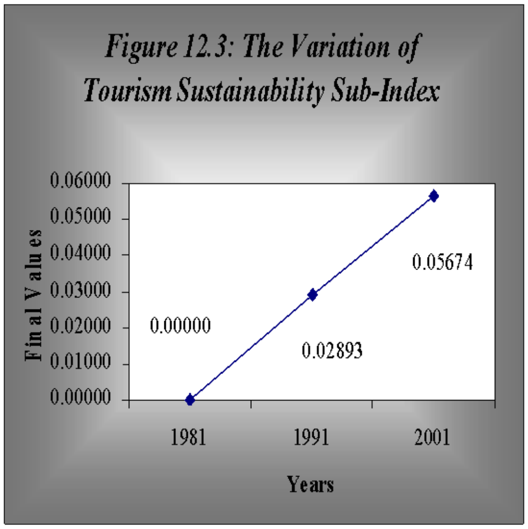
1. **The Social Sustainability Sub-Index consists of a mainly Population Sustainability Sub-Index.** The graph in *Figure 12.1* illustrates the Variation of the Social Sustainability Sub-Index, **i.e. Society Sub-Index.**



As can be seen from *The Variation of Social Sustainability Sub-Index* (See *Figure 12.1*), the Social Sustainability Sub-Index reached its highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is an increase of the Social Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Social Sustainability Sub-Index, Society Sub-Index for the 1991 to 2001 years.

2. **Economic Sustainability Sub-Index, i.e. Economy Sub-Index,** consists of the four following Sustainability Sub-Indices: Agriculture, Tourism, Agricultural Goods and Industry. The graph in *Figure 12.2* illustrates the Variation of the Agriculture Sustainability Sub-Index, i.e. Agriculture Sub-Index. The graph in *Figure 12.3* illustrates the Variation of the Tourism Sustainability Sub-Index, Tourism Sub-Index.

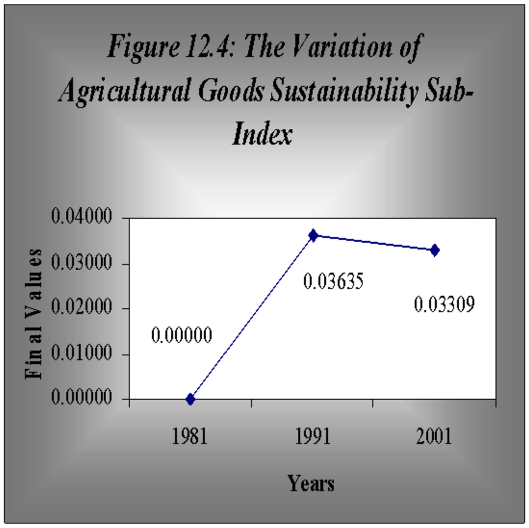


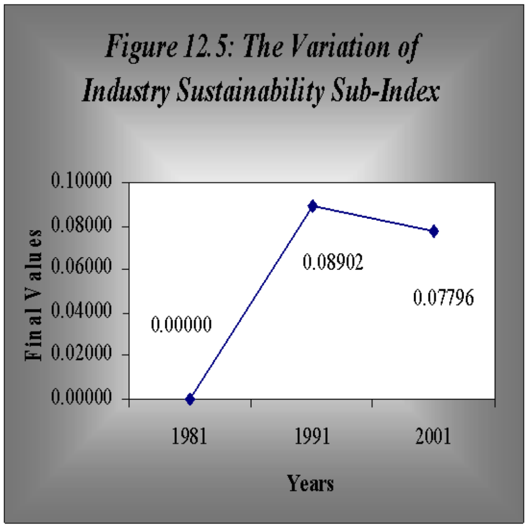


As is obvious from *The Variation of Agriculture Sustainability Sub-Index* (See *Figure 12.2*), the Agriculture Sustainability Sub-Index, i.e. Agriculture Sub-Index, reached its highest value in the year 1981, while in the years 1991 and 2001 it decreased. In other words, there is only a decrease of the Agricultural Sustainability Sub-Index for the period of 1981 to 1991 and for the periods of 1991 to 2001. This happens generally because of the movement of the population from villages (small areas) to cities (large areas).

As can be seen in *The Variation of Tourism Sustainability Sub-Index* (See *Figure 12.3*), the Tourism Sustainability Sub-Index reached the highest value in the year 2001, while in the years 1981 and 1991 it decreased. In other words, there is only an increase of the Tourism Sustainability Sub-Index for the period of 1981 to 1991 and for the periods of 1991 to 2001. Even statistical data were collected after the year 1993, which is why the value for the year 1981 was given 0. Definitely, the Tourism Sustainability Sub-Index for the year 1981 will be more than 0 but less than the value of the Tourism Sustainability Sub-Index for the year 1991. This happens essentially because the tourism in Greece was given more attention after 1980s.

The graph in *Figure 12.4* illustrates *the Variation of Agricultural Goods Sustainability Sub-Index,* **i.e. Agricultural Goods Sub-Index**. The graph in *Figure 12.5* illustrates *the Variation of the Industry Sustainability Sub-Index,* **i.e. Industry Sub-Index.**



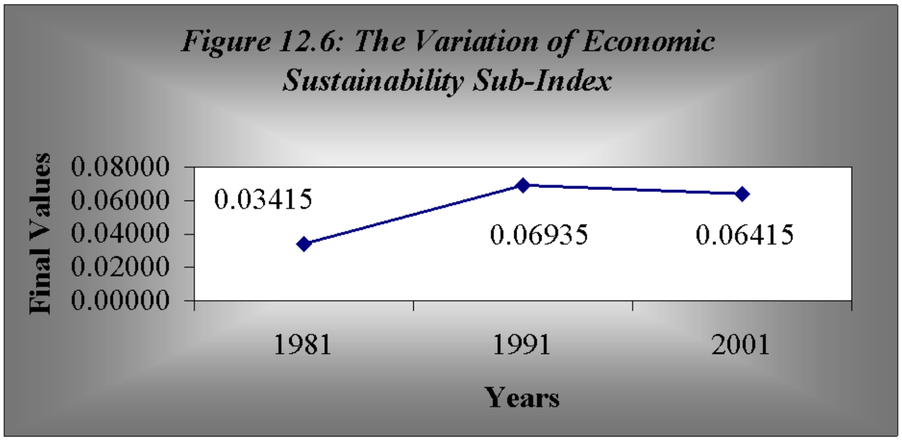


As it is visible from *The Variation of Agricultural Goods Sustainability Sub-Index* (See *Figure 12.4)*, the Agricultural Goods Sustainability Sub-Index reached its highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is a decrease of the Agricultural Goods Sustainability Sub-Index for the period of 1991 to 2001. Even statistical data were collected after the year 1993 that is why the value for the year 1981 was given 0. Definitely, the Agricultural Goods Sustainability Sub-Index for the year 1981 will be even more the value of the Agricultural Goods Sustainability Sub-Index for the year 1991. This conclusion is offered because of the movement of population from villages (small areas) to cities (large areas).

As is seen in *The Variation of Industry Sustainability Sub-Index* (See *Figure 12.5*), the Industry Sustainability Sub-Index reached the highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is a decrease of the Industry Sustainability Sub-Index for the period of 1991 to 2001. Even statistical data were collected after the year 1993, which is why the value for the year 1981 was given 0. Supposedly, the Industry Sustainability Sub-Index for the year 1981 will be more than 0 but less than the value of the Industry Sustainability Sub-Index for the year 1991. This conclusion is offered because of the movement of population from villages to cities. This happens essentially because tourism in Greece was given more attention after the 1980s and the Municipality of Nea Makri is a tourist area.

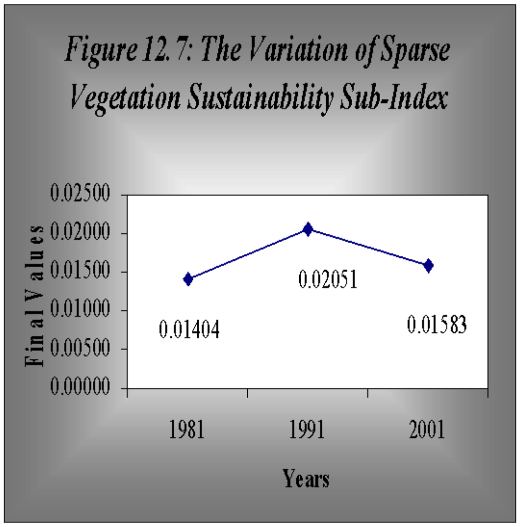
Economic Sustainability Sub-Index consists of the four following Sustainability Sub-Indices: Agriculture presented by *The Variation of Agriculture Sustainability Sub-Index* (See *Figure 12.2*), Tourism presented by *The Variation of Tourism Sustainability Sub-Index* (See *Figure 12.3*), Agricultural Goods presented by *The Variation of Agricultural Goods*

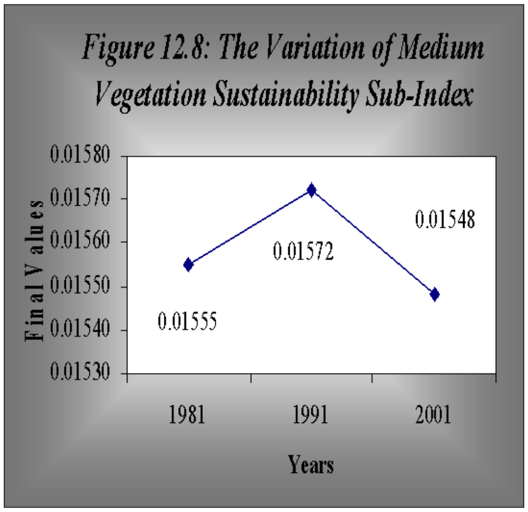
Sustainability Sub-Index (See *Figure 12.4*) and Industry presented by *The Variation of Industry Sustainability Sub-Index* (See *Figure 12.5*). The graph in *Figure 12.6* illustrates *the Variation of the Economic Sustainability Sub-Index,* **i.e. Economy Sub-Index.**



As is obvious from *The Variation of Economic Sustainability Sub-Index* (See *Figure 12.6*), the Economic Sustainability Sub-Index reached its highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is an increase of the Economic Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Economic Sustainability Sub-Index for the period of 1991 to 2001. A better conclusion could be derived in the case of the existence of statistical data for the year 1981.

3. **The Environmental Sustainability Sub - Index consists of the four following Sustainability Sub-Indices: Sparse, Medium and Dense Vegetation, Landscape.** The graph in *Figure 12.7* illustrates *the Variation of the Sparse Vegetation Sustainability Sub-Index,* **i.e. Vegetation of Sparse Sub-Index.** The graph in *Figure 12.8* illustrates *the Variation of the Medium Sustainability Sub-Index,* **i.e. Vegetation of Medium Sub-Index.**





As is apparent from *The Variation of Sparse Vegetation Sustainability Sub-Index* (See *Figure 12.7*), the Sparse Vegetation Sustainability Sub-Index reached the highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is an increase of the Sparse Vegetation Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Sparse Vegetation Sustainability Sub-Index for the 1991 – 2001 years.

As can be seen from *The Variation of Medium Vegetation Sustainability Sub-Index* (See *Figure 12.8*), the Medium Vegetation Sustainability Sub-Index reached its highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words there is an increase of the Medium Vegetation Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Medium Vegetation Sustainability Sub-Index for the 1991 – 2001 years.

The graph in *Figure 12.9* illustrates the Variation of the Dense Vegetation Sustainability Sub-Index, **i.e. Vegetation of Dense Sub-Index.** The graph in *Figure 12.10* illustrates the Variation of the Landscape Sustainability Sub-Index, **i.e. Landscape Sub-Index.**

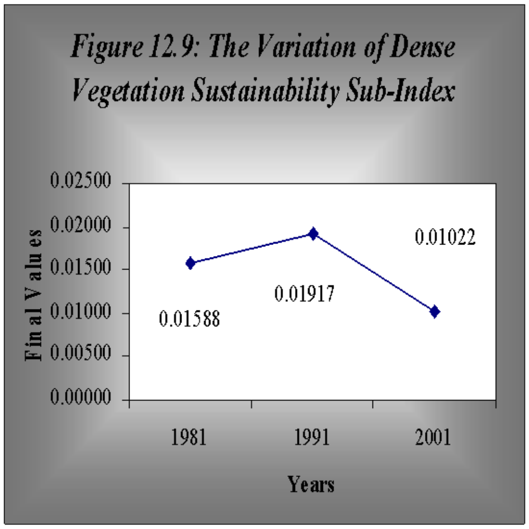


Figure 12.9: The Variation of Dense Vegetation Sustainability Sub-Index

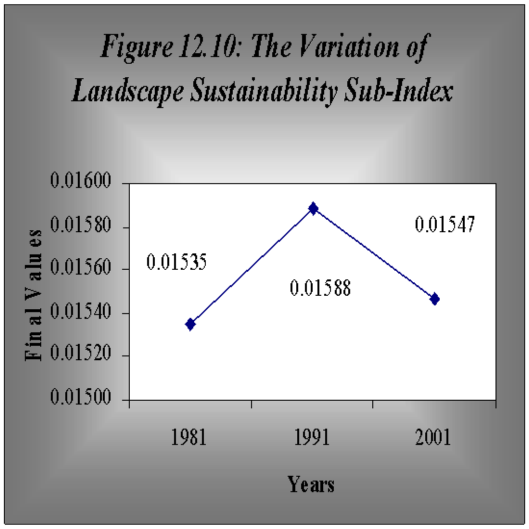


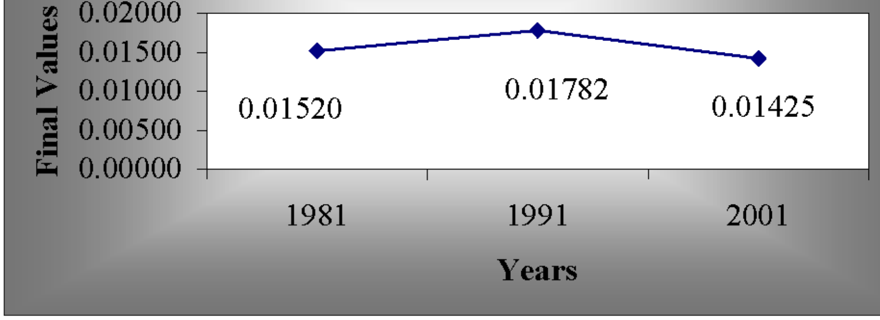
Figure 12.10: The Variation of Landscape Sustainability Sub-Index

As can be seen from *The Variation of Dense Vegetation Sustainability Sub-Index* (See *Figure 12.9*), the Dense Vegetation Sustainability Sub-Index reached its highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is an increase of the Dense Vegetation Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Dense Vegetation Sustainability Sub-Index for the period of 1991 to 2001. It is even much more less the Dense Vegetation for the year 2001. This happens, as due to the increase of Tourists for the period of 1991 to 2001, there was more construction to enlarge the capability of Touristy places and the vegetation has been reduced.

As is apparent in *The Variation of Landscape Sustainability Sub-Index* (See *Figure 12.10*), the Landscape Sustainability Sub-Index reached its highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is an increase of the Landscape Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Landscape Sustainability Sub-Index for the period of 1991 to 2001. This happened due to the increase of Tourists for the period of 1991 to 2001, there was more construction to enlarge the capacity of Tourist places and the vegetation at the Landscape level has been lost.

Environmental Sustainability Sub-Index consists of the four following Sustainability Sub-Indices: Sparse Vegetation presented by *The Variation of Sparse Vegetation Sustainability Sub-Index* (See *Figure 12.7*), Medium Vegetation presented by *The Variation of Medium Vegetation Sustainability Sub-Index* (See *Figure 12.8*), Dense Vegetation presented by *The Variation of Dense Vegetation Sustainability Sub-Index (See Figure 12.9*) and Landscape presented by *The Variation of Landscape Sustainability Sub-Index* (See *Figure 12.10*). The graph in *Figure 12.11* illustrates *the Variation of the Environmental Sustainability Sub-Index*, **i.e. Nature Sub-Index.**

Figure 12.11: The Variation of Environmental Sustainability Sub-Index



As is obvious in *The Variation of Environmental Sustainability Sub-Index* (See *Figure 12.11*), the Environmental Sustainability Sub-Index reached the highest value in the year 1991, while in the years 1981 and 2001 it decreased. In other words, there is an increase of the Economic Sustainability Sub-Index for the period of 1981 to 1991 and there is a decrease of the Economic Sustainability Sub-Index for the period of 1991 to 2001. This happened due to the increase of Tourists for the period of 1991 to 2001; there was more construction to enlarge the facilities for Tourism and the vegetation at both levels, i.e. Class and Landscape, have vanished.

4. **The composite Sustainable Development Index** consists of the three following Sustainability Sub-Indices: Social presented by *The Variation of Social Sustainability Sub-Index* (See *Figure 12.1*), Economic presented by *The Variation of Economic Sustainability Sub-Index* (See *Figure 12.6*) and Environmental presented by *The Variation of Environmental Sustainability Sub-Index* (See *Figure 12.11*). The graph in *Figure 12.12* illustrates *the Variation of the Composite Sustainable Development Index.*

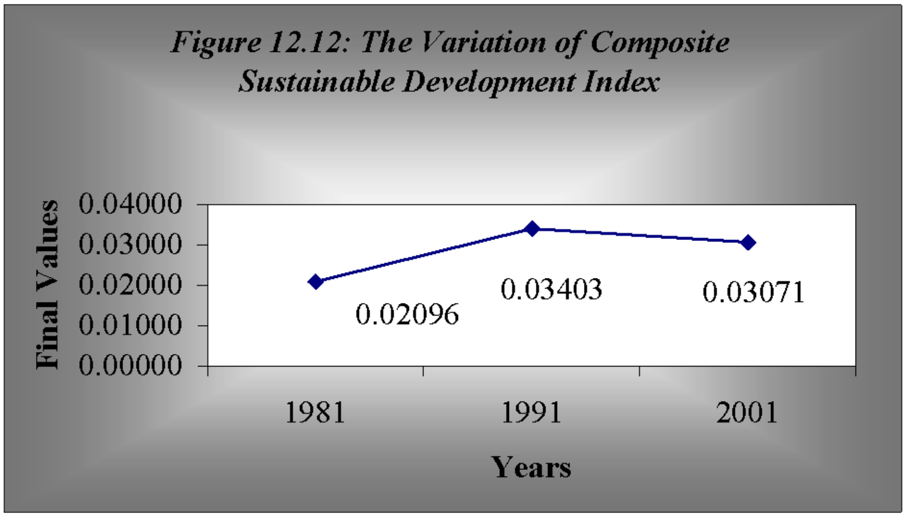


Figure 12.12: The Variation of Composite Sustainable Development Index

12.2. RECOMMENDATIONS

Discussions and conclusions were given for the Composite Sustainable Development Indices presented by *The Variation of Composite Sustainable Development Index* (See *Figure 12.12*) with the Social Sustainability Sub-Indices presented by *The Variation of Social Sustainability Sub-Index* (See *Figure 12.1*), Economic Sustainability Sub-Indices *The Variation of Economic Sustainability Sub-Index* (See *Figure 12.6*) and Environmental Sustainability Sub-Indices presented by *The Variation of Environmental Sustainability Sub-Index* (See *Figure 12.11*). Presently, three (3) recommendations will be given for the further work.

RECOMMENDATION 1:

Due to the enormity of the work and because of time limitations, the Composite Sustainable Development Indices were calculated only for the years of 1981, 1991 and 2001. Studying the Existing Remote Sensing Data, the following seven (7) time periods are suggested to be computed. For the combinations, see below:

$$CSDI = \frac{1}{3}S + \frac{1}{3}EC + \frac{1}{3}EN$$

$$EC = \frac{1}{4}Agriculture + \frac{1}{4}Tourism + \frac{1}{4}AgriculturalGooods + \frac{1}{4}Industry$$

$$EN = RSMetrics = \frac{1}{4}SparseVegetation + \frac{1}{4}MediumVegetation + \frac{1}{4}DenseVegetation + \frac{1}{4}Landscape$$

1. **CSDI for the year of 1981**

$$CSDI(1981) = \frac{1}{3}Population(1981) + \frac{1}{3}Agriculture(1981) + \frac{1}{3}RSMetrics(1984)$$

2. **CSDI for the year of 1991**

$$CSDI(1991) = \frac{1}{3}Population(1991) + \frac{1}{3}EC(1991) + \frac{1}{3}RSMetrics(1990)$$

$$EC(1991) = \frac{1}{4}Agriculture(1991) + \frac{1}{4}Tourism(1993) + \frac{1}{4}AgriculturalGooods(1993) + \frac{1}{4}Industry(1993)$$

3. **CSDI for the year of 1993**

$$CSDI(1993) = \frac{1}{3}Population(GEN) + \frac{1}{3}EC(1994) + \frac{1}{3}RSMetrics(1993)$$

$$EC(1994) = \frac{1}{4}Agriculture(GEN) + \frac{1}{4}Tourism(1994) + \frac{1}{4}AgriculturalGooods(1994) + \frac{1}{4}Industry(1994)$$

4. **CSDI for the year of 1996**

$$CSDI(1996) = \frac{1}{3}Population(GEN) + \frac{1}{3}EC(1996) + \frac{1}{3}RSMetrics(1996)$$

$$EC(1996) = \frac{1}{4}Agriculture(GEN) + \frac{1}{4}Tourism(1996) + \frac{1}{4}AgriculturalGooods(1996) + \frac{1}{4}Industry(1996)$$

5. **CSDI for the year of 1999**

$$CSDI(1999) = \frac{1}{3}Population(GEN) + \frac{1}{3}EC(1999) + \frac{1}{3}RSMetrics(1999)$$

$$EC(1999) = \frac{1}{4}Agriculture(GEN) + \frac{1}{4}Tourism(1999) + \frac{1}{4}AgriculturalGooods(1999) + \frac{1}{4}Industry(1999)$$

6. **CSDI for the year of 2001**

$$CSDI(2001) = \frac{1}{3}Population(2001) + \frac{1}{3}EC(2001) + \frac{1}{3}RSMetrics(2002)$$

$$EC(2001) = \frac{1}{4}Agriculture(2001) + \frac{1}{4}Tourism(2001) + \frac{1}{4}AgriculturalGooods(2001) + \frac{1}{4}Industry(2001)$$

RECOMMENDATION 2:

The “provisions’ of valuations presented by *Proposed “Provisions” of Mediterranean Fores*t (See *Figure 2.12* in *Section 2.3.10 – Proposed “Provisions” of Mediterranean Forest in* **Chapter 2** **– Economic valuation of Biodiversity Loss**) are proposed, emphasizing the Mediterranean Forest. The concept of total economic value (TEV) is central to valuation as it captures all possible values of a resource. The idea behind TEV is to go beyond the traditional practice of valuation, which normally captures only direct uses, thus leaving out (and thus undervaluing) other benefits and costs. TEV includes option values and existence values in consideration of future values of environmental resources. The following formula is applied to define total economic value (TEV):

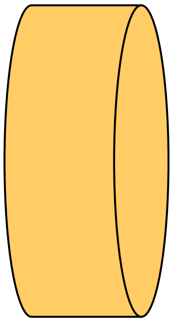
TEV = Use Value (UV) + Non Use value (NUV)

Where UV = Direct Use Value (DUV) + Indirect Use Value (IUV)
DUV= Direct Market Use Value (DMUV) + Direct Market Non Use Value (DMNUV)

➡ **TEV= DMUV + DMNUV + IUV + NUV**

RECOMMENDATION 3:

This paper recommends an attempt to propose an integrated decision-support framework that employs fuzzy logic (FL) to manipulate the subjectivity as decision makers do in appraising the facts and values, significance-acceptability transformation (SAT) to incorporate standards and decision makers’ risk attitude about the decision-making process, and fuzzy analytic network process (FANP) to manage the dependencies between social, economic and environmental factors and suggest an overall acceptability of the proposal. Cornelissen et al. (2001); Phillis and Andriantiatsaholiniaina (2001); Andriantiatsaholiniaina et al. (2004); Zavadskas and Antucheviciene (2006); Kangas et al. (2007); Nasiri and Huang (2007) and Liu and Lai (2009) worked with Fuzzy Logic and Fuzzy Set Theory and further developed Fuzzy Mathematical Models, which are recommended suggestion for the future works.



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APPENDIX 1 - SOCIAL INDICATORS (S)

A.1 S1 – Social – Population

Table A.1: S1 – Social – Population

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Population Changes or Density / Increasing / Positive Impact	Population / State	Andriantiatsa-holiniaina et al. (2005)	Population density (per square kilometer). Obtained from the midyear population number divided by the land area. It is assumed that high population density exerts stress on land sustainability. Population growth rate (percentage). Average annual exponential rate of population change for given periods of years. Small or zero population growth rates are perceived as influencing positively land sustainability but not always.
		Fahy and Cinneide (2008)	Population data
		Goncalves et al. (2009)	Evolution of the population
		Huang et al. (2009)	Metropolitan population density
		Hutchins and Sutherland (2008)	Population growth rate; The population of urban formal and informal settlements
		Kuo and Chiu (2006)	Population within the 65 dB (A)-isophon (Leq) at night; Dynamic change of population structure
		Nader et al. (2008)	Population density
		Nijkamp and Vindigni (2003)	Total Population
		Petanidou et al. (2008)	Population changes
		Russell and Thomson (2009)	Population

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Saifi and Drake (2008a)	Total population
		Salter et al. (2009)	Population
		Salvati and Zitti (2009)	Population density (POP)
		Sarda et al. (2005)	Resident population density, i.e. inhabitants per km2 (1999); Base population (Pb, resident plus average seasonal population) Inhabitants (1999); Population density (Pb)
		Scipioni et al. (2009)	Population density
		Scipioni et al. (2008)	Population
		Shi et al. (2005)	Area under high human population pressure (%)
		Spangenberg (2002)	Population
		Spilanis et al. (2009)	Active inhabitants/population; Active women/total women; Population
		Troyer (2002)	Growth Rate = Birth Rate -Death Rate + Immigration - Emigration
		Wang et al. (2007)	Agricultural population; Non-agricultural population; Total population
		Wijewardana (2008)	Population
		Yuan et al. (2003)	Population size
		Zhang and Guindon (2006)	Urban population density $\sigma_U = \frac{P_U}{L_U}$ Where P_U is the population in the urban area and L_U is the total land used for urban activities.
		Scipioni et al. (2009)	Average stay

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Ageing / Increasing / Positive Impact	Population / State	Nader et al. (2008)	Population distribution per age group
		Russell and Thomson (2009)	Population age profile; Larger % of population of working age; Larger % of those aged 16+ who have given up time on an unpaid basis for an organization
		Spilanis et al. (2009)	Ageing indicator
		Troyer (2002)	The age structure of the population
Old Age Rate / Decreasing / Positive Impact	Population / State	Bohringer and Loschel (2006)	Age of withdraw from labour market
		Scipioni et al. (2009)	Old Age rate
		Troyer (2002)	Dignified Old Age
Human Resources / Increasing / Positive Impact	Population / State	Bohringer and Loschel (2006)	Spending on human resources
		Pulido and Bocco (2003)	Human Consumption
		Spangenberg (2002)	Human and Man-made capital
Death Rate / Decreasing / Positive Impact	Population / State	Andriantiatsa-holiniaina et al. (2005)	Maternal mortality rate
		Huang et al. (2009)	No. of deaths due to an urban hazard
		Russell and Thomson (2009)	Avoidable deaths
		Scipioni et al. (2009)	Death rate; Causes of death
		Troyer (2002)	Decent burial; Death rate
Migratory Balance / Increasing / Positive Impact	Population / State	Bohringer and Loschel (2006)	Migrations
		Nader et al. (2008)	Net migration rate
		Scipioni et al. (2009)	Migratory balance

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Stork et al. (1997)	Migrations
Immigration Rate / Increasing / Positive Impact	Population / State	Scipioni et al. (2009)	Immigration rate; Foreign immigration rate
		Troyer (2002)	Immigration rate
Birth Rate / Increasing / Positive Impact	Population / State	Hutchins and Sutherland (2008)	Life expectancy at birth
		Scipioni et al. (2009)	Birth rate
		Troyer (2002)	Birth rate
Residential Density / Increasing / Positive Impact	Population / State	Nader et al. (2008)	Residence occupancy rate
		Salter et al. (2009)	Residential density
		Sarda et al. (2005)	Resident population
		Zellner et al. (2008)	Residential-density restriction (zoning)
		Zhang and Guindon (2006)	Residential density
Nationalized Foreign Residents / Increasing / Positive Impact	Population / State	Scipioni et al. (2009)	Nationalized foreign residents
Premature Mortality / Decreasing / Positive Impact	Population / State	Andriantiatsa-holiniaina et al. (2005)	Number of infants who die before reaching 1 year of age, expressed per 1000 live births in a given year.
		Bohringer and Loschel (2006)	Premature mortality
		Hutchins and Sutherland (2008)	The mortality rate under 5 years old
		Nader et al. (2008)	Infant mortality rate

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Fertility / Increasing / Positive Impact	Population / State	Bohringer and Loschel (2006)	Fertility
		Pulido and Bocco (2003)	Fertility
Pension / Increasing / Positive Impact	Population / State	Azapagic (2003)	Pension
		Bohringer and Loschel (2006)	Pensions adequacy
Demographic Change / Increasing / Positive Impact	Population / Response	Bohringer and Loschel (2006)	Demographic change
		Salvati and Zitti (2009)	Demographic variation
Ratio of Males to Females / Sable / Positive Impact	Population / State	Andriantiatsa-holiniaina et al. (2005)	Expected years of schooling for males and females
		Hutchins and Sutherland (2008)	The ratio of average female wage of male wage
		Nader et al. (2008)	Ratio of males to females
Chief Town Attraction Rate / Increasing / Positive Impact	Population / State	Scipioni et al. (2009)	Chief town attraction rate
		Van Delden et al. (2007)	Land use-specific attractiveness
		Yuan et al. (2003)	The attraction to investors
Floor Area Per Person / Increasing / Positive Impact	Population / State	Huang et al. (2009)	Per capita residential floor area
		Hutchins and Sutherland (2008)	Floor area per person

A.1.2 S2 – Social – Social Conditions

Table A.1.2: S2 – Social – Social Conditions

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Performance / Increasing / Positive Impact	Social Condition/ Response	Gomez-Sal et al. (2003)	Mean agricultural performance/ha
		Lopez-Ridaura et al. (2002)	The permanence of coffee producers in the system
		Makropoulos et al. (2008)	Performance
		Whitford et al. (2001)	Ecological performance
Diversity: In the System Components & Actors Involved / Increasing / Positive Impact	Social Condition/ State	Gomez-Sal et al. (2003)	Local diversity; Diversity in the municipal area
		Korhonen (2007a)	System structure and system components: It is important to calculate how many different components and actors are involved in the system and the study what kind of actors there are, e.g. large or small, public or private, what industrial sectors, etc.?
		McGinley and Finegan (2003)	Changes in the diversity of habitats as a result of human interventions are monitored to determine their direction, magnitude and importance, and the necessity to take corrective actions.
		Van Cauwenbergh et al. (2007)	The flow of biotic resources is adequately buffered
Freedom for Poverty, Racism, Classism or Loss of Culture & Language / Increasing / Positive Impact	Social Condition/ Response	Olsen (2003)	Reduced poverty, greater life expectancy, and better employment opportunities.
		Spangenberg (2002)	Freedom of information
		Troyer (2002)	Intra- and inter- generational equity

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Intra- & Inter-Generational Equity / Increasing / Positive Impact	Social Condition/ State	Olsen (2003)	Greater equity in access to coastal resources and the distribution of benefits from their use.
		Russell and Thomson (2009)	Social inequality
		Troyer (2002)	Intra- and inter- generational equity
		Van Cauwenbergh et al. (2007)	Equity is maintained or increased
Gender Equality / Increasing / Positive Impact	Social Condition/ State	Hutchins and Sutherland (2008)	Gender equality
		Nader et al. (2008)	Difference between male and female school enrollment rate
		Spangenberg (2002)	UNDP Gender Empowerment Measure GEM
		Van Cauwenbergh et al. (2007)	Internal family situation, including equality with the man–woman relation is acceptable
Individuals versus Social Preferences / Increasing / Positive Impact	Social Condition/ Pressure	Huang et al. (2009)	Social anomie
		Russell and Thomson (2009)	Poor social infrastructure
		Troyer (2002)	Individuals versus social preferences
Peace, Free of Crime, Drugs, Disease / Increasing / Positive Impact	Social - Condition/ Response	Fahy and Cinneide (2008)	Perception of improving crime control
		Troyer (2002)	Peace, free of crime, drugs, disease
		Yuan et al. (2003)	Illustration of the social problems caused by various reasons
Criminality / Decreasing / Positive Impact	Social Condition/ State	Hutchins and Sutherland (2008)	Number of recorded crimes per 100,000 populations
		Russell and Thomson (2009)	Recorded crimes
		Scipioni et al. (2009)	Juvenile criminality
		Zellner et al. (2008)	Crime rate

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Yuan et al. (2003)	Level of crime
Social Inclusion & Exclusion / Stable / Positive Impact	Social Condition/ Response	Makropoulos et al. (2008)	Social inclusion
		Russell and Thomson (2009)	Social exclusion; Social inclusion, cohesion, development
		Spangenberg (2002)	Societal structure
Social Programs / Increasing / Positive Impact	Social Condition/ Response	Nader et al. (2008)	Forest-fire fighting and prevention activities
		Troyer (2002)	Social programs (e.g. welfare, pregnancy prevention, foster care)
		Yuan et al. (2003)	Level of social welfare provision
Availability of Basic Material Needs / Increasing / Positive Impact	Social Condition/ State	Carvalho et al. (2008)	Material
		Russell and Thomson (2009)	Taking care of the needs of all
		Troyer (2002)	Availability of basic material needs
Justice & Fairness / Increasing / Positive Impact	Social Condition/ Response	Scipioni et al. (2009)	Number of persons with substandard lodging; Number of persons without fixed abode; Suicide rate
		Troyer (2002)	Justice and fairness
Integration versus Segregation / Stable/ Positive Impact	Social Condition/ Response	Fahy and Cinneide (2008)	Perceptions of integration
		Gomez-Sal et al. (2003)	Social integration
		Hiscock et al. (2003)	Becoming more integrated
		Troyer (2002)	Integration versus segregation
		Van Cauwenbergh et al. (2007)	Family integration in the local and an agricultural society is acceptable

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Family & Home Conditions/ Increasing / Positive Impact	Social Condition/ State	Troyer (2002)	Family and home conditions
		Van Cauwenbergh et al. (2007)	Internal family situation
Well-being of Family, Friends, Community, Culture & World / Increasing / Positive Impact	Social Condition/ State	Fahy and Cinneide (2008)	Perception of sense of belonging in a neighborhood
		Kuo and Chiu (2006)	Opportunity for contacting diverse culture
		Parr et al. (2003)	Well-being of family, friends, community, culture and the world
		Russell and Thomson (2009)	Higher % of adults rating their neighborhood as a good place to live; Alienated communities
		Troyer (2002)	Well-being of family, friends, community, culture and the world
Damages to Cultural Sites / Decreasing / Positive Impact	Social Condition/ State	Kuo and Chiu (2006)	Whether irreversible damages to important cultural sites will occur
		Piorr (2003)	Loss of cultural features
History & Culture / Increasing / Positive Impact	Social Condition/ State	Gomez-Sal et al. (2003)	Culture
		Ko (2005)	Socio-cultural Aspects
		Piorr (2003)	Change of historical—cultural landscape area, linear, point features; Inventory of cultural landscape features: architectural, historic, hedgerows, stone walls, etc.
		Russell and Thomson (2009)	History and culture
Opportunities for Recreation, Entertainment & Leisure / Increasing / Positive Impact	Social Condition/ State	Russell and Thomson (2009)	Seize the economic opportunity of SD
		Spangenberg (2002)	Leisure
		Troyer (2002)	Opportunities for recreation, entertainment and leisure

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Affordability / Increasing / Positive Impact	Social Condition / Response	Fahy and Cinneide (2008)	Availability of affordable housing
		Makropoulos et al. (2008)	Affordability
Riskiness Rate / Decreasing / Positive Impact	Social Condition / State	Andriantiatsa-holiniaina et al. (2005)	ICRG risk rating
		Markopoulos et al. (2008)	Financial risk exposure
		Scorpion et al. (2009)	Riskiness rate
Acceptability / Increasing / Positive Impact	Social Condition / Response	Makropoulos et al. (2008)	Acceptability
		Palme et al. (2005)	General acceptance of the use of P products produced from sewage
		Van Cauwenbergh et al. (2007)	Cultural acceptability
Public Parks & Gardens / Increasing / Positive Impact	Social Condition / State	Nader et al. (2008)	An area of public gardens
		Scipioni et al. (2009)	Public parks & gardens
Park Area / Increasing / Positive Impact	Social Condition / State	Huang et al. (2009)	Park area per person
		Li (2004)	Automobile park area (km^2); Daily visitors/parking area (Annual average and peak period average) (Persons/km^2)
Sport & Recreation Facilities / Increasing / Positive Impact	Social Condition / Response	Fahy and Cinneide (2008)	Perceptions of accessibility of facilities
		Huang et al. (2009)	The ratio of public facility area
		Jaeger et al. (2008)	Facilities
		Li (2004)	New built artificial tourist facilities (all-year) include hotels, recreational facilities, artificial scenery, etc.
		Scipioni et al. (2009)	Sport and recreation facilities

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Dependence Rate / Decreasing / Positive Impact	Social Condition / State	Korhonen (2007a)	Unhealthy dependencies or power relations
		Lopez-Ridaura et al. (2002)	Degree of dependency from external inputs
		Scipioni et al. (2009)	Dependence rate
		Van Cauwenbergh et al. (2007)	Dependency on direct and indirect subsidies is minimized
Murders / Decreasing / Positive Impact	Social Condition / State	Andriantiatsa-holiniaina et al. (2005)	Murders (per 100,000 people)
		Scipioni et al. (2009)	Murders
Thefts / Decreasing / Positive Impact	Social Condition / State	Scipioni et al. (2009)	Thefts
Bag-Snatchings & Pickpocketing / Decreasing / Positive Impact	Social Condition / State	Scipioni et al. (2009)	Bag-snatchings and pickpocketing
Social Infrastructure / Increasing / Positive Impact	Social Condition / State	Russell and Thomson (2009)	Poor social infrastructure
		Van Cauwenbergh et al. (2007)	Family access to and use of social infrastructures and services is acceptable
Sewer Coverage / Increasing / Positive Impact	Social Condition / State	Andriantiatsa-holiniaina et al. (2005)	Access to sanitation
		Hutchins and Sutherland (2008)	Percent of population with adequate sewage disposal facilities
		Nader et al. (2008)	Public sewerage system
		Olsen (2003)	Sewage
		Palme et al. (2005)	Sewage
		Zellner et al. (2008)	Municipal sewer coverage

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Safety / Increasing / Positive Impact	Social Condition / State	Azapagic (2003)	Health and safety
		Carvalho et al. (2008)	Safety at work
		Fahy and Cinneide (2008)	Perception of the city as a safe city
		Li (2004)	Visitor safety
Quality of Life / Increasing / Positive Impact	Social Condition / State	Bohringer and Loschel (2006)	Lifestyles
		Fahy and Cinneide (2008)	Perception of standard of living
		Goncalves et al. (2009)	Deterioration of the quality of life
		Hutchins and Sutherland (2008)	Quality of life
		Kuo and Chiu (2006)	Quality of life of local people
		Olsen (2003)	Increases in indices of quality of life, such as the Human Development Index.
		Scipioni et al. (2008)	Quality of Life Indicators
		Van Cauwenbergh et al. (2007)	Quality of life; Physical well-being of the farming community function
		Yuan et al. (2003)	A measure of whether economic growth can bring a better quality of life for local people
Access to Amenities / Increasing / Positive Impact	Social Condition / Response	Andriantiatsa-holiniaina et al. (2005)	Access to sanitation
		Bohringer and Loschel (2006)	Access to housing
		Nader et al. (2008)	Household access to phone networks
		Nijkamp and Vindigni (2003)	Access to amenities
		Spangenberg (2002)	Access to common goods

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Van Cauwenbergh et al. (2007)	Amenities are maintained or increased
		Yuan et al. (2003)	An indication of the condition of government management, public communication and community amenity
Conflict / Decreasing / Positive Impact	Social Condition / Response	Kuo and Chiu (2006)	Conflict between agro-tourism with other agricultures; Conflict between agro-tourism development with the local community
		Olsen (2003)	Successful application of conflict mediation activities
Prosperous Future / Increasing / Positive Impact	Social Condition / State	Olsen (2003)	Greater confidence in the future and hope
		Russell and Thomson (2009)	Prosperous future for all
		Yuan et al. (2003)	A reflection of confidence for future development conditions
Precautionary Principle / Increasing / Positive Impact	Social Condition / Pressure	Hiscock et al. (2003)	The precautionary principle
		Russell and Thomson (2009)	Precautionary principle
Behaviour / Increasing / Positive Impact	Social Condition / Response	Fahy and Cinneide (2008)	Problems with antisocial behavior
		Palme et al. (2005)	Aware and responsible users
Stress / Decreasing / Positive Impact	Social Condition/ Response	Palme et al. (2005)	The employees feel adequately stressed
Security / Increasing / Positive Impact	Social Condition/ Response	Huang et al. (2009)	Human security
		Hutchins and Sutherland (2008)	Security
		Korhonen (2007a)	Security and availability of supply and demand of/for resources
		Olsen (2003)	Greater security, including food security.

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Russell and Thomson (2009)	Security
		Spangenberg (2002)	Reliability of the social security system
		Troyer (2002)	Individual Security
Equal Opportunities & Non-Discrimination / Increasing / Positive Impact	Social Condition/ State	Azapagic (2003)	Equal opportunities and non-discrimination; Percentage of women / ethnic minorities in middle / senior positions (%)
		Kuo and Chiu (2006)	Opportunity for contacting diverse culture
Socialization & Life Skills / Increasing / Positive Impact	Social Condition / Response	Carvalho et al. (2008)	Society
		Huang et al. (2009)	Social living
		Kuo and Chiu (2006)	Material life improvement of the local population
		Russell and Thomson (2009)	Strong, healthy and just society; Strong, stable and prosperous
		Scipioni et al. (2008)	Society
		Spangenberg (2002)	Societal structure
		Troyer (2002)	Socialization and life skills
		Zellner et al. (2008)	Socialization and life skills
Identity / Increasing / Positive Impact	Social Condition / State	Fahy and Cinneide (2008)	Community Identity
		Troyer (2002)	Individual, Ethnic, Community and National
Garbage Collection / Increasing / Positive Impact	Social Condition / Response	Andriantiatsa-holiniaina et al. (2005)	Urban households with garbage collection (percentage)
		Li (2004)	The amount of garbage/visitors (Annual average and peak period average) (tons/person); Indicates the response on garbage problems

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Recycling of Materials / Increasing / Positive Impact	Nature / Response	Bland and Bell (2007)	Recycled materials
		Fahy and Cinneide (2008)	Recycling service
		Korhonen (2007a)	Substituting for natural resources, increasing materials and energy efficiency, is reducing waste and emissions.
		Kuo and Chiu (2006)	Ratios of recycle
		Lenz and Beuttler (2003)	The amount of waste and the potential of recycling
		Palme et al. (2005)	P and N that is recycled and thereby forms a potential substitute for artificial fertilizers
		Russell and Thomson (2009)	Larger % of municipal waste recycled; % municipal waste recycled; Recover what is useful
		Scipioni et al. (2009)	Recyclable waste
		Troyer (2002)	Assimilation of wastes

A.1.3 S3 – Social – Knowledge / Wisdom

Table A.1.3: S3 – Social – Knowledge / Wisdom

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
No. of SD Plans & Agendas / Increasing / Positive Impact	Knowledge & Wisdom / State	Foody (2003)	Recovery plans; Monitor land cover; Estimate biophysical variables
		Hiscock et al. (2003)	Sustainable development
		Jaeger et al. (2008)	Monitoring systems of sustainable development
		Nader et al. (2008)	Number of sustainable development plans/agendas adopted and implemented by the municipality
		Olsen (2003)	A plan of action constructed around unambiguous goals.
		Russell and Thomson (2009)	Powerful approach to policy formulation and development collective responsibility for SD issues
No of Scientists & Engineers in R&D / Increasing / Positive Impact	Knowledge & Wisdom / State	Andriantiatsa-holiniaina et al. (2005)	A number of scientists and engineers in research and development (R&D)
		Azapagic (2003)	Percentage of employees that are sponsored by the company for further education (%)
		Hiscock et al. (2003)	Improved marine scientific research
Information & Technology / Increasing / Positive Impact	Knowledge & Wisdom / Pressure	Bohringer and Loschel (2006)	Technology; Consumer information
		Huang et al. (2009)	Information
		Lopez-Ridaura et al. (2002)	Ability to change and to adopt new technology
		Parr et al. (2003)	Measures of environmental information
		Spangenberg (2002)	Freedom of information
		Troyer (2002)	Technology

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Cauwenbergh et al. (2007)	Information function
Scientific Paradigm & Theories / Increasing / Positive Impact	Knowledge & Wisdom / Pressure	Hiscock et al. (2003)	Robust science
		Russell and Thomson (2009)	Strong scientific evidence
		Troyer (2002)	Scientific paradigm and theories
		Van Cauwenbergh et al. (2007)	Scientific value features are maintained or increased
Educational Attainment / Increasing / Positive Impact	Knowledge & Wisdom / Response	Andriantiatsa-holiniaina et al. (2005)	Ratio of students to teaching staff (primary, secondary, and tertiary education)
		Azapagic (2003)	Employee training and education; Percentage of hours of training relative to the total hours worked (%); Percentage of employees that are sponsored by the company for further education (%)
		Bohringer and Loschel (2006)	Access to education
		Hutchins and Sutherland (2008)	Education level; Children reaching grade 5 of primary education; Adult secondary education achievement level
		Lopez-Ridaura et al. (2002)	Quantification of training courses
		Nader et al. (2008)	Level of education
		Russell and Thomson (2009)	Low educational attainment
		Troyer (2002)	Educational attainment
		Van Cauwenbergh et al. (2007)	Education of farmers and farm workers is optimal; Educational value features are maintained or increased

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Experience / Increasing / Positive Impact	Knowle-dge & Wisdom / Response	Kuo and Chiu (2006)	The Recreation experience of tourists
		Troyer (2002)	Experience
Literacy / Increasing / Positive Impact	Knowle-dge & Wisdom / Response	Andriantiatsa-Helena et al. (2005)	Nationals are studying abroad
		Gomez-Sal et al. (2003)8	Knowledge
		Hutchins and Sutherland (2008)	Adult literacy rate
		Troyer (2002)	Literacy
Life-long Learning / Increasing / Positive Impact	Knowle-dge & Wisdom / Response	Bohringer and Loschel (2006)	Life-long Learning
		Kuo and Chiu (2006)	Aspiration for lifelong learning of local people
		Russell and Thomson (2009)	Learning and capacity building
Ranking of Schools / Increasing / Positive Impact	Knowle-dge & Wisdom / State	Andriantiatsa-holiniaina et al. (2005)	Expected years of schooling
		Zellner et al. (2008)	Ranking of schools
School Enrollment Rate / Increasing / Positive Impact	Knowle-dge & Wisdom / State	Andriantiatsa-holiniaina et al. (2005)	Net school enrollment rate; primary and secondary
		Nader et al. (2008)	Difference between male and female school enrollment rate (private and public); Public school enrollment rate
Thinking / Increasing / Positive Impact	Knowle-dge & Wisdom / State	Russell and Thomson (2009)	Holistic thinking; Radical thinking; Long term thinking
Prosperity / Increasing / Positive Impact	Knowle-dge & Wisdom / Response	Russell and Thomson (2009)	Prosperity not at the expense of others
		Yuan et al. (2003)	Economic prosperity

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Creative, Innovative & Inspiring / Increasing / Positive Impact	Knowledge & Wisdom / Response	Korhonen (2007a)	Innovations and creativity
		Russell and Thomson (2009)	Creative, innovative and inspiring
		Lopez-Ridaura et al. (2002)	Institutional innovation/adaptation
Fair, Effective & Informative Decision-making/ Increasing / Positive Impact	Knowledge & Wisdom / Response	Gough et al. (2008)	Fair and effective decision making; Informed decision-making
		Hiscock et al. (2003)	Assessing progress
		Lopez-Ridaura et al. (2002)	Degree of participation in the decision-making process; Decision-making mechanisms
		Olsen (2003)	Collaborative planning and decision making through task forces, commissions, civic associations and the like. Greater order, transparency and accountability in how do planning and decision making processes occur.
No. of Libraries / Increasing / Positive Impact	Knowledge & Wisdom / State	Andriantiatsaholiniaina et al. (2005)	Libraries serving the population of a community or a region free of charge or for a nominal fee; they may service the general public or special categories of users such as children, members of the armed forces, hospital patients, prisoners, workers, and employees. United Nations Education, Scientific, and Cultural Organization (UNESCO) counts libraries in numbers of administrative units and service points. An administrative unit is any independent library or group of libraries under a single director or a single administrator; a service point is any library that provides in separate quarters a service for users, whether it is an independent library or a part of a larger administrative unit.

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Computers & Internet / Increasing / Positive Impact	Knowledge & Wisdom / Pressure	Andriantiatsa-holiniaina et al. (2005)	Personal computers (per thousand people), i.e. estimated numbers of self-contained computers used by a single person. Access to personal computers promotes knowledge development and educational sustainability. Internet hosts, i.e. number of computers directly connected to the worldwide network of interconnected computer systems per 10,000 people. Access to the Internet facilitates knowledge acquisition.
Qualifications of the Population / Increasing / Positive Impact	Knowledge & Wisdom / Response	Salter et al. (2009)	Qualifications of the population
		Yuan et al. (2003)	Qualifications of the population
Effective Monitoring / Increasing / Positive Impact	Knowledge & Wisdom / Response	Foody (2003)	Monitoring of environmental resources for sustainable development
		Hiscock et al. (2003)	Effective monitoring
		Jaeger et al. (2008)	Monitoring systems of sustainable development
		Li (2004)	The existence of regular environmental monitor (Yes/No)
		McGinley and Finegan (2003)	A monitoring plan
Environmental Education Activity / Increasing / Positive Impact	Knowledge & Wisdom / Response	Gough et al. (2008)	Aboriginal traditional land-use and forest-based ecological knowledge
		Huang et al. (2009)	Frequency of environmental education activity
		Kuo and Chiu (2006)	Direct participation of local people in conservation activities
		Li (2004)	The existence of environmental education to visitors (Yes/No)
		Lopez-Ridaura et al. (2002)	Quantification of training courses

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Nader et al. (2008)	Number and % of households complaining about environmental issues; A number of environmental clubs in schools
		Olsen (2003)	Use of new school curricula on integrated coastal management topics.
		Russell and Thomson (2009)	Larger % of schools registered as eco-schools; Larger % of schools awarded green flag status
		Scipioni et al. (2008)	Environmental education activities
No. of Environmental NGO / Increasing / Positive Impact	Knowle-dge & Wisdom / State	Huang et al. (2009)	A number of environmental NGO
		Nader et al. (2008)	The number of associations involved in the environment and sustainable development issues
		Olsen (2003)	The creation of commissions, working groups, user organizations and nongovernmental organizations (NGOs) dedicated to the advancement of an integrated coastal management agenda.
		Scipioni et al. (2008)	A number of environmental NGO
		Spangenberg (2002)	NGO right to file suit

A.1.4 S4 – Social – Health

Table A.1.4: S4 – Social – Health

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Self-Esteem & Self-Reliance / Increasing / Positive Impact	Health / Response	Huang et al. (2009)	Self-reliance on local expenditure
		Lopez-Ridaura et al. (2002)	Self-reliance (Organisation and participation); Reliance on external resources
		Russell and Thomson (2009)	Less selfish more caring
		Troyer (2002)	Self-Esteem
Child Development / Increasing / Positive Impact	Health / State	Hutchins and Sutherland (2008)	Nutritional status of children
		Troyer (2002)	Child development
Physical Fitness / Increasing / Positive Impact	Health / Response	Russell and Thomson (2009)	Physical health problems
		Troyer (2002)	Physical fitness
		Van Cauwenbergh et al. (2007)	Physical well-being of the farming community function
Life Expectancy & Longevity / Increasing / Positive Impact	Health / State	Andriantiatsa-holiniaina et al. (2005)	Number of years a newborn infant would live if patterns of mortality prevailing at the time of its birth were to stay the same throughout its life. Life expectancy reflects the sustainability of a health system.
		Bohringer and Loschel (2006)	Life expectancy; Disability-free life expectancy
		Hutchins and Sutherland (2008)	Life expectancy at birth
		Olsen (2003)	Greater life expectancy
		Russell and Thomson (2009)	Higher life expectancy

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Troyer (2002)	Life Expectancy or Longevity
Health Care / Increasing / Positive Impact	Health / State	Andriantiatsa-holiniaina et al. (2005)	Percentage of one-year-old infants immunized against measles, polio, and diphtheria–pertussis–tetanus (DPT).
		Azapagic (2003)	Health
		Bohringer and Loschel (2006)	Access to health care
		Carvalho et al. (2008)	Health at work
		Fahy and Cinneide (2008)	Satisfaction with health services
		Gomez-Sal et al. (2003)	Health
		Hutchins and Sutherland (2008)	Percent of population with access to primary health care facilities; Immunization against infectious childhood diseases; Contraceptive prevalence rate
		Russell and Thomson (2009)	Healthy and just society
		Spangenberg (2002)	Reliability of the health care
		Troyer (2002)	Health care (e.g. prenatal, physical, nutrition and special health care services)
		Van Cauwenbergh et al. (2007)	Health of the farming community is acceptable
		Yuan et al. (2003)	Expected years of healthy life
Healthy Spirituality / Increasing / Positive Impact	Health / Response	Russell and Thomson (2009)	Mental health problems
		Troyer (2002)	Healthy Spirituality
		Van Cauwenbergh et al. (2007)	Spiritual heritage value features are maintained or increased

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Risks to Human Health / Decreasing / Positive Impact	Health / Pressure	Bohringer and Loschel (2006)	Risks to human health
		Kuo and Chiu (2006)	Morbidity of pollution-induced diseases
		Makropoulos et al. (2008)	Risks to human health
No. of Health Issues / Increasing / Positive Impact	Health / State	Nader et al. (2008)	% households are benefiting from health services
		Russell and Thomson (2009)	No. of health issues
		Scipioni et al. (2009)	No. of health issues
Balance & Centeredness / Increasing / Positive Impact	Health / Response	Nader et al. (2008)	The current balance due to tourism activities
		Scipioni et al. (2009)	Nature balance
		Troyer (2002)	Balance and centeredness
Personal Satisfaction / Increasing / Positive Impact	Health / Pressure	Azapagic (2003)	Customer satisfaction
		Fahy and Cinneide (2008)	Satisfaction with the neighborhood as a place to live; Satisfaction with leisure facilities
		Li (2004)	Visitors' satisfaction (based on questionnaire survey)
		Palme et al. (2005)	Employees that are satisfied with their working situation
		Russell and Thomson (2009)	Personal well being
		Troyer (2002)	Personal satisfaction
		Yuan et al. (2003)	Resident satisfaction
Positive Emotional & Cognitive Functioning / Increasing / Positive Impact	Health / Response	Fahy and Cinneide (2008)	Feelings of empowerment
		Palme et al. (2005)	The employees that feel that they can influence their working situation
		Troyer (2002)	Positive emotional and cognitive functioning

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Cauwenbergh et al. (2007)	A farmer's feeling of independence is satisfactory
Injury Rate / Decreasing / Positive Impact	Health / State	Scipioni et al. (2009)	Injury Rate
Hospital Admissions / Decreasing / Positive Impact	Health / State	Scipioni et al. (2009)	Hospital admissions
Average Stay In Hospital / Decreasing / Positive Impact	Health / State	Scipioni et al. (2009)	The average stay in hospital
No. of Inhabitants Per Doctor / Decreasing / Positive Impact	Health / Response	Andriantiatsa-holiniaina et al. (2005)	Number of people per doctor
		Scipioni et al. (2009)	No. of inhabitants per doctor
No. of Inhabitants Per Hospital Attendant / Decreasing / Positive Impact	Health / Response	Andriantiatsa-holiniaina et al. (2005)	Number of people per nurse
		Scipioni et al. (2009)	No. of inhabitants per hospital attendant
Hygiene / Increasing / Positive Impact	Health / Pressure	Kuo and Chiu (2006)	Food safety and hygiene promotion
		Palme et al. (2005)	Hygiene
Cases of Infectious Diseases / Increasing / Positive Impact	Health / Pressure	Andriantiatsa-holiniaina et al. (2005)	Cases of infectious diseases Measles and tuberculosis per million people.
		Bohringer and Loschel (2006)	Infectious diseases
		Hutchins and Sutherland (2008)	Infectious childhood diseases

A.1.5 S5 – Social – Political Conditions

Table A.1.5: S5 – Social – Political Conditions

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Cooperation / Increasing / Positive Impact	Political Condition / Response	Hiscock et al. (2003)	Better international co-operation
		Korhonen (2007a)	Cooperation and inter-organizational activities can lead into unhealthy dependencies, or power relations, discrimination, or into path dependency and lock-in situations that prevent innovations and hamper creativity.
		Nader et al. (2008)	Individuals registered in agricultural cooperative
		Saifi and Drake (2008a)	Cooperation between crop and milk farmers; Cooperation between animal and crop farms with respect to manure distribution and to the production of lea and legumes
Locality / Increasing / Positive Impact	Political Condition / Response	Barrios et al. (2006)	Local indicators of soil quality (LISQ) are often more variable and include crop yield and vigor, soil color, soil texture and structure, and the presence/ absence or abundance of local plant and soil invertebrate species.
		Bland and Bell (2007)	A locality in the spatial scale of the system
		Fahy and Cinneide (2008)	Volunteerism and involvement in local groups
		Gomez-Sal et al. (2003)	Local diversity

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Korhonen (2007a)	If the product life cycle from 'cradle to grave' is local, the energy consumption and associated emissions are reduced and the life cycle and its environmental effects are easier to monitor and control. In the global market economy of today, there are no locally 'closed' systems. Also inter-regional cooperation and partnerships can be very important for sustainable development.
		Kuo and Chiu (2006)	Direct participation of local people in conservation activities; The production capability of the local community; Material life improvement of the local population; Aspiration for lifelong learning of local people
		Li (2004)	Indicates the pressures and impacts on the local community
		Lopez-Ridaura et al. (2002)	High indebtedness of local farmers
		Pulido and Bocco (2003)	Local Market
		Russell and Thomson (2009)	Global impacts of local action; Local based solutions
		Saifi and Drake (2008a)	Food production consumed locally
		Stork et al. (1997)	Local extinction
		Termorshuizen et al. (2007)	European, national and regional targets for local plans and European and national targets for regional plans
		Van Cauwenbergh et al. (2007)	Family access to and participation in local activities are acceptable; Family integration in the local and agricultural society is acceptable

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Inadequate Regulatory & Planning Structures / Decreasing / Positive Impact	Political Condition / Response	Olsen (2003)	The institutional capacity necessary to implement the plan of action.
		Russell and Thomson (2009)	Inadequate regulatory and planning structures
		Spangenberg (2002)	Natural regulation processes
Right to Action to Ensure Needs / Increasing / Positive Impact	Political Condition / State	Bohringer and Loschel (2006)	Citizen’s adh. & support for EU actions; Sustainability of EU actions and measures
		Gough et al. (2008)	Aboriginal and treaty rights
		Russell and Thomson (2009)	All things have a right to exist
		Troyer (2002)	Right of action to ensure the needs
Human Rights / Increasing / Positive Impact	Political Condition / State	Andriantiatsa-holiniaina et al. (2005)	Human rights
		Spangenberg (2002)	Co-decision rights of workers
		Troyer (2002)	Human rights; Right to an opinion
		Van Cauwenbergh et al. (2007)	A farmer's feeling of independence is satisfactory
Membership & Participation & Responsibility / Increasing / Positive Impact	Political Condition / Response	Bohringer and Loschel (2006)	Social participation; Corporate responsibility
		Fahy and Cinneide (2008)	Volunteerism and involvement in local groups
		Huang et al. (2009)	Information and Participation
		Kuo and Chiu (2006)	Participate public affairs voluntarily
		Lopez-Ridaura et al. (2002)	Participation in the design/implementation and evaluation of alternatives, degree of participation in the decision-making process

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Makropoulos et al. (2008)	Participation and responsibility
		Palme et al. (2005)	Responsible users
		Russell and Thomson (2009)	Non-participative governing processes; Individual responsibility for the SD issues
		Troyer (2002)	Membership and participation
		Van Cauwenbergh et al. (2007)	Family access to and participation in local activities are acceptable
		Yuan et al. (2003)	Participation in community activities
Government Sector / Increasing / Positive Impact	Political Condition / Response	Andriantiatsa-holiniaina et al. (2005)	Central government finance
		Hiscock et al. (2003)	Improving co-ordination in Government
		Learmonth et al. (2007)	Government Sector
		Russell and Thomson (2009)	Good government; The participative government objective for civilized society
		Spangenberg (2002)	Voter turnout in elections; Institutions
		Yuan et al. (2003)	An indication of the condition of government management
Government Owned Properties / Increasing / Positive Impact	Political Condition / Response	Nader et al. (2008)	Government owned properties
Legislative Compliance / Increasing / Positive Impact	Political Condition / Response	Azapagic (2003)	Cost of non-compliance
		Bohringer and Loschel (2006)	Legislative compliance

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Trust in Neighbors & Elected Officials / Increasing / Positive Impact	Political Condition / Response	Fahy and Cinneide (2008)	Satisfaction with the neighborhood as a place to live; Trust in neighborhoods; Trust in local elected officials
		Russell and Thomson (2009)	% of adults rating their neighborhood as a good place to live
State Involvement / Increasing / Positive Impact	Political Condition / Response	Olsen (2003)	Within the governmental institutions involved in the program.
		Russell and Thomson (2009)	Connect and involve
		Saifi and Drake (2008a)	State involvement
		Troyer (2002)	Interactions between State and Society
Collaborative Actions / Increasing / Positive Impact	Political Condition / Response	Olsen (2003)	Collaborative actions of user groups
		Russell and Thomson (2009)	Connecting currently unrelated issues and actions
Meet Global Treaties / Increasing / Positive Impact	Political Condition / Response	Gough et al. (2008)	Aboriginal and treaty rights
		Russell and Thomson (2009)	Meet global treaties
Regime / Increasing / Positive Impact	Political Condition / State	Andriantiatsa-holiniaina et al. (2005)	Fuzzy subjective measurement of the state of the regime based on the report of the International Helsinki Federation for Human Rights and the knowledge of the authors. Measurements range from perfect democratic (ideal regime with measurement equal to one) to a fully nondemocratic regime (dictatorial with measurement equal to zero).
Partnerships / Increasing / Positive Impact	Political Condition / Response	Azapagic (2003)	Social partnership and sponsorship
		Bohringer and Loschel (2006)	Global partnership

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Korhonen (2007a)	Inter-regional cooperation and partnerships can be very important for sustainable development
		Olsen (2003)	Evidence of functional public-private partnerships
Corruption Rate / Decreasing / Positive Impact	Political Condition / State	Spangenberg (2002)	Corruption rate
Public Awareness / Increasing / Positive Impact	Social Condition / Response	Bohringer and Loschel (2006)	Consumer awareness
		Makropoulos et al. (2008)	Public awareness
		Nader et al. (2008)	Annual environmental awareness activities
		Olsen (2003)	Within the general public.
		Palme et al. (2005)	Aware and responsible users

A.1.6 S6 – Social – Transport

Table A.1.6: S6 – Social – Transport

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
No. of Cars / Stable / Positive Impact	Transport / State	Fahy and Cinneide (2008)	Problems with abandoned cars
		Huang et al. (2009)	Car ownership
		Nader et al. (2008)	Number of passenger cars per 100 inhabitants
		Spilanis et al. (2009)	Number of cars per km
Motorization Rate / Decreasing / Positive Impact	Transport / Pressure	Huang et al. (2009)	Motorbike Ownership
		Li (2004)	Length of road for motor vehicles (km)
		Sarda et al. (2005)	Motorization coefficient
		Scipioni et al. (2009)	Motorization rate
Public Transport Services / Increasing / Positive Impact	Transport / Pressure	Bohringer and Loschel (2006)	Volume of transport; Transport growth
		Fahy and Cinneide (2008)	Perception of bus service
		Goncalves et al. (2009)	Transportation sector
		Huang et al. (2009)	The efficiency of public transit
		Sarda et al. (2005)	Boat transit; Public transport
		Scipioni et al. (2009)	Public transport services; Seats available on public transport
		Spangenberg (2002)	Transport intensity
		Zhang and Guindon (2006)	Transportation

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Public Transport Coverage/ Increasing / Positive Impact	Transport / Pressure	Andriantiatsa-holiniaina et al. (2005)	Public transportation (percent of work trips by public transport)
		Azapagic (2003)	Number of kilometers travelled (km/yr)
		Bohringer and Loschel (2006)	Land use of transportation systems
		Nader et al. (2008)	The number and occupancy of public transport vehicles
		Russell and Thomson (2009)	Vehicle kilometers
		Sarda et al. (2005)	Bus circulation
		Scipioni et al. (2009)	Public transport coverage
		Spangenberg (2002)	Transport
		Zhang and Guindon (2006)	Transportation land area
Bicycle Lanes / Increasing / Positive Impact	Transport / State	Fahy and Cinneide (2008)	Perception of cycle lanes
		Scipioni et al. (2009)	Bicycle lanes
Accident Rate / Decreasing / Positive Impact	Transport / State	Azapagic (2003)	Lost-time accidents
		Li (2004)	Accidents of poaching or others destroying the environment caused by tourists (all-year); Accidents pertaining to visitor safety
		Scipioni et al. (2009)	Road accident rate
		Scipioni et al. (2008)	Car accidents
Pedestrian Areas / Increasing / Positive Impact	Transport / State	Scipioni et al. (2009)	Pedestrian areas

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Infrastructure / Increasing / Positive Impact	Transport / State	Gomez-Sal et al. (2003)	Infrastructures
		Mortberg et al. (2007)	Infrastructure
		Olsen (2003)	Construction of port facilities and other transportation related infrastructure. Infrastructure to enhance and protect public access to the shore including rights of way, boardwalks, signage programs.
		Russell and Thomson (2009)	Poor transport infrastructure
		Spangenberg (2002)	Transport and production infrastructure
		Stork et al. (1997)	Infrastructure such as skid trails, roads, river landings, etc.
		Van Brusselen and Schuck (2005)	Transport infrastructure
		Van Delden et al. (2007)	Construction of infrastructure (dams, roads, channels)
		Zellner et al. (2008)	Infrastructure
Presence of Roads / Increasing / Positive Impact	Transport / State	Bohringer and Loschel (2006)	Road to rail, water and public transport
		Jaeger et al. (2008)	A new road has been built or an old road has been removed; Railways
		Nader et al. (2008)	An area of agricultural land doesn't connect to road networks; Length and state of road networks
		Piorr (2003)	Presence of roads

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Stork et al. (1997)	Roads are a special case, for they are linear changes in the pattern of forests. Some roads are established for the purpose of moving people into the forest Đ largely for colonization purposes Đ but forest managers may not be able to control such developments. In these cases, as for large-scale conversion projects, Environmental Impact Assessments are the appropriate tool for assessing impact.
		Van Delden et al. (2007)	Roads
		Verboom et al. (2007)	Roads
		Zellner et al. (2008)	Presence of roads
		Zhang and Guindon (2006)	Road length density; Road-stream cross ratio
Road Traffic / Decreasing / Positive Impact	Transport / State	Fahy and Cinneide (2008)	Perceptions of traffic
		Goncalves et al. (2009)	Traffic congestions
		Li (2004)	Indicates traffic state
		Russell and Thomson (2009)	Less vehicle kilometers
		Sarda et al. (2005)	Traffic mobility inside population; Traffic congestion (morning/afternoon)
		Zhang and Guindon (2006)	Potential traffic loading; Road accessibility
Communi-cation & Mobilization / Increasing / Positive Impact	Transport / State	Bohringer and Loschel (2006)	Communication and mobilization
		Nader et al. (2008)	Daily population movement
		Sarda et al. (2005)	Forced mobility

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Scipioni et al. (2008)	Mobility
		Yuan et al. (2003)	Public communication
Travel Distance / Decreasing / Positive Impact	Transport / State	Andriantiatsa-holiniaina et al. (2005)	Work trips
		Azapagic (2003)	Number of kilometers travelled (km/yr)
		Goncalves et al. (2009)	Commuter trips: home, work and school
		Sarda et al. (2005)	People travels
		Zhang and Guindon (2006)	Trip distance probability
Service Provision / Increasing / Positive Impact	Transport / State	Goncalves et al. (2009)	Better service quality
		Ko (2005)	Service quality
		Makropoulos et al. (2008)	Service provision
		Russell and Thomson (2009)	Care about the origins of goods and services

APPENDIX 2 - ECONOMIC INDICATORS (EC)

A.2.1 EC1 – Economic – Investment

Table A.2.1: EC1 – Economic – Investment

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Research & Development Expenditure / Increasing / Positive Impact	Invest-ment / Response	Andriantiatsa-holiniaina et al. (2005)	Public expenditure on education
		Bohringer and Loschel (2006)	Research and development expenditure
Tax / Decreasing / Positive Impact	Invest-ment / State	Bohringer and Loschel (2006)	Energy taxes
		Carvalho et al. (2008)	Tax
		Nader et al. (2008)	Efficiency of tax collection
		Saifi and Drake (2008a)	Tax bases
		Sarda et al. (2005)	IBI evolution (private-owner tax); IAE evolution (economic activity tax)
		Spangenberg (2002)	The share of taxes on labor, capital and the environment in total tax revenues
		Spilanis et al. (2009)	The amount of the added value tax; Tax per capita
GDP per capita/ Increasing / Positive Impact	Invest-ment / Response	Andriantiatsa-holiniaina et al. (2005)	Military spending (percent of Gross Domestic Product (GDP)); The average annual growth rate of GDP (percent per year)
		Azapagic (2003)	The ratio of value-added to GDP (%)
		Bohringer and Loschel (2006)	GDP per capita
		Fahy and Cinneide (2008)	National GDP

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Learmonth et al. (2007)	GDP per head
		Russell and Thomson (2009)	Higher GDP per capita
		Scipioni et al. (2009)	GDP per capita
		Spangenberg (2002)	Growth of GDP/capita
		Spilanis et al. (2009)	Gross Product; Gross Product per capita
		Wang et al. (2007)	Gross domestic product value; The gross production value of primary and secondary industries; The gross production value of tertiary industries
Government Expenditure's Allocation / Increasing / Positive Impact	Invest-ment / Response	Andriantiatsa-holiniaina et al. (2005)	Government expenditure for social services; General government consumption; Public health expenditure
		Bohringer and Loschel (2006)	Pension expenditures
		Huang et al. (2009)	Government expenditure allocation; % of public expenditure on environment protection
		Learmonth et al. (2007)	Government demand $G_i = g_i\overline{POP}$
		Lopez-Ridaura et al. (2002)	Self-reliance on local expenditure
		Nader et al. (2008)	Number of projects and initiatives at the municipality level
		Olsen (2003)	Within the governmental institutions involved in the program.
		Piorr (2003)	Change in the percentage of financial expenditure of agro-environmental schemes

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Inflation / Decreasing / Positive Impact	Invest-ment / Pressure	Andriantiatsa-holiniaina et al. (2005)	The GDP implicit deflator is derived as the ratio of current to constant-price GDP. It is known as the inflation indicator affecting the sustainability of a national economy.
		Bohringer and Loschel (2006)	Inflation
		Scipioni et al. (2009)	Inflation
		Spangenberg (2002)	Inflation rate
Profit / Increasing / Positive Impact	Invest-ment / Response	Azapagic (2003)	Annual profit (Monetary units/yr)
		Carvalho et al. (2008)	Profit
		Gomez-Sal et al. (2003)	Gross profit margin of agriculture; Gross profit margin per total subsidy; Gross profit margin per working person; Gross profit margin/km2 agricultural area
		Hutchins and Sutherland (2008)	Profit
		Van Delden et al. (2007)	Profit
Investment / Increasing / Positive Impact	Invest-ment / Response	Andriantiatsa-holiniaina et al. (2005)	Institutional investor credit ranking
		Azapagic (2003)	Capital investment (Monetary units); Human capital investment (Monetary units); R&D investment (Monetary units); Human capital investment as a percentage of profit (%)
		Bohringer and Loschel (2006)	Investment in R&D; Investment in EFT; Foreign Direct Investment in developing countries
		Carvalho et al. (2008)	Investment

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Goncalves et al. (2009)	Investment restrictions
		Hutchins and Sutherland (2008)	Investment
		Learmonth et al. (2007)	Investment demand $I_i = I_i(p_i, \overline{p}_i^{UK}, \overline{p}_i^{ROW}, \sum_i b_{i,j} \Delta K_j)$
		Lopez-Ridaura et al. (2002)	Initial investment costs
		Olsen (2003)	Investments in habitat protection and restoration including the purchase of protected areas and conservation easements, construction of artificial reefs, installation of mooring buoys.
		Wang et al. (2007)	The total value of fixed assets investment
		Yuan et al. (2003)	Total investment in fixed assets
Value / Increasing / Positive Impact	Invest-ment / State	Andriantiatsa-holiniaina et al. (2005)	Present value of external debt
		Azapagic (2003)	Share value or annual returns (Monetary units); Value added (Monetary units)
		Carvalho et al. (2008)	Value
		Hutchins and Sutherland (2008)	Value/cost
		Kuo and Chiu (2006)	Values change of the local people
		Piorr (2003)	Landscape costs and benefits (values)
		Russell and Thomson (2009)	Less importance on shareholder value
Economic Efficiency & Benefits / Increasing / Positive Impact	Invest-ment / State	Gough et al. (2008)	Economic benefits; Distribution of benefits; Sustainability of benefits
		Hutchins and Sutherland (2008)	Benefits

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Kuo and Chiu (2006)	Benefit from agro-tourism to conservation programs
		Li (2004)	Indicates tourism's economic benefits to the locals
		Lopez-Ridaura et al. (2002)	Cost/benefit ratio; Unequal distribution of benefits and costs; Cost-benefit analysis; Distribution of returns and benefits
		Piorr (2003)	Landscape costs and benefits
		Scipioni et al. (2008)	Economic efficiency and benefits
		Yuan et al. (2003)	Economic efficiency and benefits; A measure of the efficiency of economic growth and the attraction to investors
Stakeholder Involvement & Liaison / Increasing / Positive Impact	Invest-ment / Response	Azapagic (2003)	Number of consultative meetings with stakeholders (Number)
		Hiscock et al. (2003)	Stakeholder involvement; Involving stakeholders
		Van Cauwenbergh et al. (2007)	Stakeholder involvement is maintained or increased
Saving & Borrowing / Stable / Positive Impact	Invest-ment / State	Andriantiatsa-holiniaina et al. (2005)	External borrowings and grants
		Bohringer and Loschel (2006)	Saving and borrowing
Banks / Increasing / Positive Impact	Invest-ment / State	Andriantiatsa-holiniaina et al. (2005)	International banks
		Nader et al. (2008)	Number and geographic distribution of banks

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
GNP per Capita/ Increasing / Positive Impact	Invest-ment / State	Andriantiatsa-holiniaina et al. (2005)	GNP is the sum of two components: GDP and net income from abroad. Net income from abroad is income in the form of compensation of employees, interests on loans, profits, and other factor payments that residents receive from abroad. GDP measures the final output of goods and services produced by the domestic economy. This indicator is commonly used to evaluate The status of wealth sustainability at the national level.
Revenues / Increasing / Positive Impact	Invest-ment / Response	Andriantiatsa-holiniaina et al. (2005)	Current and capital revenue
		Spangenberg (2002)	Revenues
Financial Contributions to Environmental Issues / Increasing / Positive Impact	Invest-ment / Response	Huang et al. (2009)	% of public expenditure on environment protection
		Nader et al. (2008)	Municipality spending on environmental issues; External financial contributions to environmental issues
		Piorr (2003)	Change in the percentage of financial expenditure of agro-environmental schemes
		Scipioni et al. (2008)	Financial contributions to environmental issues

A.2.2 EC2 – Economic – Standard of Living

Table A.2.2: EC2 – Economic – Standard of Living

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Employment / Increasing / Positive Impact	Standard of Living / Response	Azapagic (2003)	Number of employees relative to the total number of people employed in a certain region or a country (%); Employee retention rates (%); Wealth created per employee (Monetary unit/employee)
		Bohringer and Loschel (2006)	Employment rate; The employment rate of older workers
		Carvalho et al. (2008)	Employment situation
		Fahy and Cinneide (2008)	Ease of employment attainment
		Gomez-Sal et al. (2003)	% family work units; % family and in ownership work units; No. of work units/exploitation; No. of work units /area; % work units in ownership
		Kuo and Chiu (2006)	Employment capacity increase
		Learmonth et al. (2007)	Total employment
		Nader et al. (2008)	Number of employees of the municipality
		Nijkamp and Vindigni (2003)	Employment in primary sector as a percentage of total employees
		Petanidou et al. (2008)	Employment in agriculture
		Russell and Thomson (2009)	Larger % employed; % employed

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Spilanis et al. (2009)	Employed; Most important employment branch/total number of employed; Second most important employment branch/total number of employed; Third most important employment branch/total number of employed; The sum of the people employed in ‘‘competitive’’ branches/total employed; Employers/employed; Seasonal workers/employed
		Troyer (2002)	Employment
		Yuan et al. (2003)	Employment
		Zhang and Guindon (2006)	Employment density
Regional Income / Increasing / Positive Impact	Standard of Living / Response	Bohringer and Loschel (2006)	The income of older generations
		Gomez-Sal et al. (2003)	Available family income/capita
		Kuo and Chiu (2006)	Average income of the local population
		Learmonth et al. (2007)	Household income $Y = \psi_n N w_n + \psi_k \sum_i K_i w_{k,i}$ Real Household income and expend
		Li (2004)	Reserve annual income from tourism/total income (%); Local community’s annual income from tourism/total income (%)
		Lopez-Ridaura et al. (2002)	Low income farmers; Net income/total income; Income from non-coffee crops
		Nader et al. (2008)	Income distribution; Municipality income from sustainable ecotourism
		Nijkamp and Vindigni (2003)	Average income of agricultural activity

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Prato (2005)	Regional Income
		Sarda et al. (2005)	income rent per family
		Spangenberg (2002)	Income distribution per decentile
		Spilanis et al. (2009)	Income declared to tax services
		Troyer (2002)	Income; Income Wealth
		Van Cauwenbergh et al. (2007)	Farm income is ensured
		Wang et al. (2007)	Total income of rural economy; The income of agriculture, forestry, animal husbandry and fishery; The income of non-agriculture, non-forestry, non-animal husbandry and non-fishery; The total income of the farmers
Working Environments / Increasing / Positive Impact	Standard of Living / State	Carvalho et al. (2008)	Workplace
		Gomez-Sal et al. (2003)	% family work units
		Hiscock et al. (2003)	Working more effectively
		Palme et al. (2005)	Working environment
		Troyer (2002)	Indoor and Working Environments
No. of Jobs / Increasing / Positive Impact	Standard of Living / State	Gomez-Sal et al. (2003)	No. of jobs in agriculture; No. of jobs in extraction activities; % of branches of active jobs; No. of jobs in industry; No. of jobs in construction; No. of jobs in service sector; No. of jobs in industry/no. of the industrial establishments; No. of jobs in public administration; No. of the work units /agricultural area
		Spangenberg (2002)	Jobs

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Green Jobs / Increasing / Positive Impact	Standard of Living / State	Russell and Thomson (2009)	Green jobs; A leader in green enterprise
		Spangenberg (2002)	Green jobs
Unemploy-ment Rate / Decreasing / Positive Impact	Standard of Living / Sate	Bohringer and Loschel (2006)	Long-term unemployment; Unemployment rate
		Fahy and Cinneide (2008)	Unemployment figures
		Hutchins and Sutherland (2008)	Unemployment rate
		Nader et al. (2008)	Unemployment rate
		Russell and Thomson (2009)	% of 16–19s not in education, employment, training; Unemployment
		Sarda et al. (2005)	Unemployment rate
		Scipioni et al. (2009)	Unemployment rate
		Spangenberg (2002)	Unemployment rate
		Spilanis et al. (2009)	Unemployed women/active women; Unemployed/population; New unemployed/unemployed
Willingness to Pay / Increasing / Positive Impact	Standard of Living / Response	Makropoulos et al. (2008)	Willingness to pay
Poverty Thresholds / Increasing / Positive Impact	Standard of Living / State	Bohringer and Loschel (2006)	At risk-of-poverty rate; Poverty-in-work
		Hutchins and Sutherland (2008)	Percent of population living below the poverty line
		Russell and Thomson (2009)	Poverty
		Scipioni et al. (2009)	Poverty Thresholds

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Spangenberg (2002)	UNDP Human Poverty Index
Distance to the Centre of Employment / Decreasing / Positive Impact	Standard of Living / State	Bohringer and Loschel (2006)	Dispersion of regional employment rates
		Goncalves et al. (2009)	Concentration of employment in the central cores with dependent periphery
		Zellner et al. (2008)	Distance to center of employment
Wages & Salaries / Increasing / Positive Impact	Standard of Living / State	Azapagic (2003)	The ratio of the lowest wage to a national legal minimum (%)
		Gomez-Sal et al. (2003)	% salaried work units
		Hutchins and Sutherland (2008)	The ratio of average female wage of male wage
		Learmonth et al. (2007)	Real wage
		Pulido and Bocco (2003)	Wages
		Russell and Thomson (2009)	Low wages
		Spangenberg (2002)	Salaries
Households / Increasing / Positive Impact	Standard of Living / State	Fahy and Cinneide (2008)	Availability of affordable housing
		Learmonth et al. (2007)	Households
		Russell and Thomson (2009)	Households
		Yuan et al. (2003)	Housing stock condition
Homeless Households / Decreasing / Positive Impact	Standard of Living / State	Fahy and Cinneide (2008)	Figures for residents in homeless shelters
		Russell and Thomson (2009)	Fewer homeless households;

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Poor Households / Decreasing / Positive Impact	Standard of Living / State	Andriantiatsa-holiniaina et al. (2005)	Poor households Percentage of population living below the national poverty line. National estimates are based on population-weighted subgroup estimates from household surveys. Reducing poor households improves wealth sustainability.
		Russell and Thomson (2009)	Less children living in low income households; Poor housing
Income Inequality / Decreasing / Positive Impact	Standard of Living / State	Andriantiatsa-holiniaina et al. (2005)	The Gini index measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution. A GINI index of zero would represent perfect equality and an index of 100 would imply perfect inequality—a single person or household accounting for all income or consumption.
		Bohringer and Loschel (2006)	Income inequality
		Hutchins and Sutherland (2008)	Gini index of income inequality
		Yuan et al. (2003)	Disposable income per household

A.2.3 EC3 – Economic – Production & Consumption

Table A.2.3: EC3 – Economic – Production & Consumption

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Financial Sustainability / Increasing / Positive Impact	Production and Consumption / State	Bohringer and Loschel (2006)	Financial sustainability; Financing for SD
		Gough et al. (2008)	Sustainability of benefits
		Russell and Thomson (2009)	Seize the economic opportunity of SD; SD at the heart of sound governance
Sustainable and Profitable Food & Drink / Increasing / Positive Impact	Production and Consumption / Response	Andriantiatsa-holiniaina et al. (2005)	Daily per capita calorie supply (percentage of total requirements)
		Russell and Thomson (2009)	Sustainable and profitable food and drink
		Saifi and Drake (2008a)	Food standard; Balanced food diet
Development vs. Growth / Stable / Positive Impact	Production and Consumption / State	Andriantiatsa-holiniaina et al. (2005)	Official development assistance (dollars per capita)
		Bohringer and Loschel (2006)	Decoupling economic growth; Production and consumption patterns; Official Development Assistance
		Fahy and Cinneide (2008)	Perception of building development; Planning and development
		Goncalves et al. (2009)	Implement development in the area of influence branch line
		Hiscock et al. (2003)	Delivering development goals
		Russell and Thomson (2009)	Powerful approach to policy formulation and development collective responsibility for SD issues. Need for economic growth.
		Sarda et al. (2005)	Built houses per 100 inhabitants last 5 years; Home construction (constriction coefficient)

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Troyer (2002)	Development vs. growth
		Yuan et al. (2003)	A reflection of confidence for future development conditions
Prices, Supply & Demand / Stable / Positive Impact	Production and Consumption / Response	Andriantiatsa-holiniaina et al. (2005)	Reflects changes in prices for all final demand categories, such as government consumption, capital formation, and international rate, as well as the main component, private final consumption. It is derived as the ratio of current to constant-price GDP. It is known as the inflation indicator affecting the sustainability of a national economy.
		Learmonth et al. (2007)	Commodity price $p_i = p_i(w_n, w_{ki})$ Consumer price index $cpi = \sum \theta_i p_i + \sum \theta_i^{UK} p_i^{-UK} + \sum \theta_i^{RO}$ Capital price index $kpi = \sum \gamma_i p_i + \sum \gamma_i^{UK} p_i^{-UK} + \sum \gamma_i^{RO}$ Labor supply $N^S = N^S(\overline{L}, w_n, cpi)$ Labor demand $N_i^D = N_i^D(Q_i, w_n, w_{k,i})$ Capital demand $K_i^D = K_i^D(Q_i, w_n, w_{k,i})$ Commodity demand $Q_i = C_i + I_i + G_i + Xi$ Consumption demand $C_i = C_i(p_i, \overline{p}_i^{UK}, \overline{p}_i^{ROW}, Y, cpi)$
		Lopez-Ridaura et al. (2002)	Variation of input and output prices (e.g. coefficient of variation of input/output); Labor demand
		Troyer (2002)	Prices, supply and demand

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Delden et al. (2007)	Represents water usage per function based on the demands from the functions and the availability of water on the resources, taking into account the restrictions regarding water availability imposed by policy-makers as well as the price of water from different sources.
Imports & Exports / Stable / Positive Impact	Production and Consumption / State	Andriantiatsa-holiniaina et al. (2005)	Imports; Exports; Resource balance, i.e. this indicator provides the difference between exports of goods / services and imports of goods / services for each country.
		Learmonth et al. (2007)	Export demand $X_i = X_i(p_i, \overline{p}_i^{UK}, \overline{p}_i^{ROW}, \overline{D}^{UK}, \overline{D}^{ROW})$
		Troyer (2002)	Imports and exports
Financial Market Integration / Increasing / Positive Impact	Production and Consumption / Response	Bland and Bell (2007)	Consumption and markets
		Bohringer and Loschel (2006)	Financial market integration
		Lopez-Ridaura et al. (2002)	Market diversification
		Van Cauwenbergh et al. (2007)	Dependency on external finance is optimal
Market Activities / Increasing / Positive Impact	Production and Consumption / State	Bohringer and Loschel (2006)	Market access for LDC
		Lopez-Ridaura et al. (2002)	Coffee marketing process
		Nader et al. (2008)	Distribution area and activity of quarries
		Pulido and Bocco (2003)	Local Market
		Russell and Thomson (2009)	Market

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Cauwenbergh et al. (2007)	Market activities are optimal
Labour & Capital Market Clearing / Increasing / Positive Impact	Production and Consumption / Response	Bohringer and Loschel (2006)	Age of withdraw from labour market
		Learmonth et al. (2007)	Labor market clearing $\sum_i N_i^D = N^S = N$ Capital market clearing $K_i^S = K_i^D$
		Spangenberg (2002)	Financial capital
Per Capita Urban Productivity / Increasing / Positive Impact	Production and Consumption / Pressure	Gomez-Sal et al. (2003)	Gross municipal product per capita
		Huang et al. (2009)	Per capita urban productivity
		Scipioni et al. (2008)	Per capita urban productivity
		Spangenberg (2002)	Resource productivity
Urban Productivity Growth / Increasing / Positive Impact	Production and Consumption / Pressure	Huang et al. (2009)	Urban productivity growth
		Russell and Thomson (2009)	Productivity
		Scipioni et al. (2008)	Urban productivity growth
Production Capacity / Increasing / Positive Impact	Production and Consumption / State	Kuo and Chiu (2006)	The production capability of the local community
		Parr et al. (2003)	Marine production
		Van Cauwenbergh et al. (2007)	Production capacity is compatible with society’s demand for food
Product Quality/ Increasing / Positive Impact	Production and Consumption / Response	Lopez-Ridaura et al. (2002)	Quality of products; Produce quality
		Palme et al. (2005)	Heavy metals and organic contaminants in the product

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Type of Consumption / Decreasing / Positive Impact	Production and Consumption / Pressure	Bland and Bell (2007)	Consumption and markets
		Huang et al. (2009)	Type of consumption
		Pulido and Bocco (2003)	Human Consumption
		Russell and Thomson (2009)	Western consumption patterns
Private Consumption / Decreasing / Positive Impact	Production and Consumption / Pressure	Andriantiatsa-holiniaina et al. (2005)	Private consumption
		Bohringer and Loschel (2006)	Consumption and inflation
		Learmonth et al. (2007)	Consumption demand $C_i = C_i(p_i, \overline{p}_i^{UK}, \overline{p}_i^{ROW}, Y, cpi)$
Food Production / Increasing / Positive Impact	Production and Consumption / Response	Nader et al. (2008)	Annual fish production
		Nijkamp and Vindigni (2003)	Production of cereal; Production of meat; Production of permanent crop
		Parr et al. (2003)	Marine production
		Saifi and Drake (2008a)	Food production consumed locally
		Van Cauwenbergh et al. (2007)	Production capacity is compatible with society’s demand for food
Quality of Food & Raw Materials / Increasing / Positive Impact	Production and Consumption / Response	Bohringer and Loschel (2006)	Food safety and quality
		Kuo and Chiu (2006)	Food safety and hygiene promotion
		Lopez-Ridaura et al. (2002)	Quality of products
		Saifi and Drake (2008a)	Food standard
		Spangenberg (2002)	Biotic raw materials; Wood, straw, food, feed

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Cauwenbergh et al. (2007)	Quality of food and raw materials is increased; Quality and taste of food is increased
Subsidies / Decreasing / Positive Impact	Production and Consumption / Response	Gomez-Sal et al. (2003)	Gross profit margin per total subsidy; Total subsidy for crops/ha; Livestock subsidies/stock-rearing unity; Subsidy per capita; Subsidy per employed person; Subsidy per agricultural area
		Van Cauwenbergh et al. (2007)	Dependency on direct and indirect subsidies is minimized
Fuel Use & Consumption / Decreasing / Positive Impact	Production and Consumption / Response	Andriantiatsa-holiniaina et al. (2005)	Fossil fuel use (percent of total energy production)
		Azapagic (2003)	The amount of fossil fuel used (t/yr)
		Kuo and Chiu (2006)	Total petroleum consumption
		Learmonth et al. (2007)	Total automotive fuel use
		Palme et al. (2005)	The fuels used
		Saifi and Drake (2008a)	Fuel consumption; Fossil fuel use
Sales / Increasing / Positive Impact	Production and Consumption / State	Azapagic (2003)	Tones or number of products sold (t/yr or number)
		Stork et al. (1997)	Sale in local markets
		Yuan et al. (2003)	Retail sales of consumer goods
Economic Output / Increasing / Positive Impact	Production and Consumption / Response	Scipioni et al. (2008)	Economic output
		Yuan et al. (2003)	Total economic output
Diversity of Food & Raw Materials / Increasing / Positive	Production and Consumption / State	Russell and Thomson (2009)	Food shortages
		Spangenberg (2002)	Biotic raw materials

Impact		Van Cauwenbergh et al. (2007)	Diversity of food and raw materials is increased

A.2.4 EC4 – Economic – Agriculture

Table A.2.4: EC4 – Economic – Agriculture

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Cultivated & Utilized Land / Increasing / Positive Impact	Agri-culture / State	Andriantiatsa-holiniaina et al. (2005)	Domesticated land (percent of land area). Includes cropland and permanent pasture area, which maintain land sustainability.
		Gomez-Sal et al. (2003)	% exploitations of worked land + pastures + others; % exploitations of worked land + others; % exploitations of worked land; % exploitations of pasture land + others; % exploitations of pastures; % exploitations of other lands
		Lopez-Ridaura et al. (2002)	Producers and area cultivated per system
		Petanidou et al. (2008)	Cultivated and Utilized Land; Numbers of abandoned cultivated fields
		Saifi and Drake (2008a)	Arable lands; Arable land per person; Cultivation system
		Salvati and Zitti (2009)	Changes in cultivated land surface (LOS)
		Spangenberg (2002)	Anthropogenically cultivated eco-systems with low external inputs. Cultivation sets some framework conditions and uses the natural regulation mechanisms to produce the harvest.
		Spilanis et al. (2009)	Cultivated area per category of intensity/total area

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Agricultural Area / Stable / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	% fallow/agricultural area; % agricultural area
		Huang et al. (2009)	Metropolitan agricultural area
		Nijkamp and Vindigni (2003)	An agricultural area in use
		Nader et al. (2008)	Number and % of households owning agricultural land; Types of agricultural land; % of agricultural land
		Petanidou et al. (2008)	Agricultural area
		Piorr (2003)	Patch shape of agricultural parcels; The share of the area covered by agro-environmental schemes from total UAA
		Pulido and Bocco (2003)	Farmable Land
		Saifi and Drake (2008a)	Food cereal area
		Salvati and Zitti (2009)	Agricultural intensity (INT)
		Spangenberg (2002)	Intensive agriculture
		Van Brusselen and Schuck (2005)	Agricultural land in designated areas; Agriculture land cover changes
		Van Cauwenbergh et al. (2007)	Adequate amount of agricultural land is maintained
		Wang et al. (2007)	Farmland area ; Changes in the agricultural landscape
		Zellner et al. (2008)	Agricultural land
No. of Farms / Stable / Positive Impact	Agri-culture / State	Nijkamp and Vindigni (2003)	Number of market-based farms; Number of family farms
		Petanidou et al. (2008)	Number of farms
		Piorr (2003)	Number of farms

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Saifi and Drake (2008a)	Number of farms; Farms without cattle; Farms without lea product; No. of farms with lea cultivation; No. of farms with cattle husbandry; Changes in number of farms
		Wang et al. (2007)	Farmland area
Average Farm Size / Stable / Positive Impact	Agri-culture / State	Nijkamp and Vindigni (2003)	Average Farm Size
		Petanidou et al. (2008)	Average Farm Size
		Spilanis et al. (2009)	Organic farming area/total cultivated area
Change in the Number of Animal Units / Increasing / Positive Impact	Agri-culture / State	Parr et al. (2003)	Change in the number of animal units
		Petanidou et al. (2008)	Change in the number of animal units
		Russell and Thomson (2009)	Increase in composite indicators of bird populations
		Saifi and Drake (2008a)	Cattle units; No. of work horses and oxen
Irrigated Agricultural Land / Increasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	% area irrigated cropland
		Nader et al. (2008)	% of irrigated agricultural land
		Van Delden et al. (2007)	Irrigation water used from different sources for sustainable farming
Change of Habitats in Agricultural Landscapes / Increasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	No. of herbaceous crops
		Parr et al. (2003)	Broad-scale environmental change
		Piorr (2003)	Change of valuable, linear, point biotopes and habitats in agricultural landscapes (area features) managed by farmers
		Spangenberg (2002)	Intensive agriculture, dependent on the hands-on steering of the system dynamics

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Van Brusselen and Schuck (2005)	Diversity of linear features and a diversity of crops in farmlands
		Van Delden et al. (2007)	Crop type
Diversity of Agricultural Uses / Increasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	Diversity of agricultural uses
		Lopez-Ridaura et al. (2002)	Highly diversified systems (or poorly diversified systems) (Agro-diversity)
		Nader et al. (2008)	Types of agriculture
		Spangenberg (2002)	Intensive agriculture, dependent on the hands-on steering of the system dynamics, humans dominating natural regulation processes.
		Van Brusselen and Schuck (2005)	Diversity of linear features and a diversity of crops in farmlands
Total Output of Agriculture, Forestry, Animal & Fishery / Increasing / Positive Impact	Agri-culture / State	Bland and Bell (2007)	Total output of agriculture, forestry, animal husbandry and fishery
		Bohringer and Loschel (2006)	Over-fishing
		Gomez-Sal et al. (2003)	Potential forestry production m3/ha/year
		Hiscock et al. (2003)	Marine habitats if 40% or more of the northeast Atlantic s occurrence of the habitat is located in the UK.
		Nader et al. (2008)	Annual fish production
		Nijkamp and Vindigni (2003)	Production of cereal; Production of meat; Production of permanent crop
		Parr et al. (2003)	Total output of agriculture, forestry, animal husbandry and fishery

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Russell and Thomson (2009)	Larger % of commercial marine fish stocks at full reproductive capacity; Composite indicators of bird populations
		Sarda et al. (2005)	Fisheries landings
		Spangenberg (2002)	Resource productivity
		Stork et al. (1997)	Total output of agriculture, forestry, animal husbandry and fishery
		Wang et al. (2007)	Total output of agriculture, forestry, animal and fishery
Agricultural Activities / Increasing / Positive Impact	Agri-culture / State	Bland and Bell (2007)	Agricultural activities
		Gomez-Sal et al. (2003)	Mean agricultural performance/ha
		Kuo and Chiu (2006)	Contribution to special agricultural skills succession
		Nader et al. (2008)	Individuals registered in agricultural cooperative
		Lopez-Ridaura et al. (2002)	Adoption of new alternatives and/or farmers permanence within a system, capacity building activities, the proportion of the area with an adopted technology
		Russell and Thomson (2009)	Agricultural practices
		Spangenberg (2002)	Intensive agriculture, dependent on the hands-on steering of the system dynamics, humans dominating natural regulation processes.
		Van Cauwenbergh et al. (2007)	Agricultural activities are economically efficient; Agricultural activities are technically efficient; Inter-generational continuation of farming activity is ensured

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Farmer's Professional Training / Increasing / Positive Impact	Agri-culture / Pressure	Lopez-Ridaura et al. (2002)	Adoption of new alternatives and/or farmers permanence within a system, capacity building activities, the proportion of the area with an adopted technology
		Piorr (2003)	The number of farmers participating in training programs concerned environmentally friendly management practices, landscape conservation, etc.
		Saifi and Drake (2008a)	Farmers position
		Van Cauwenbergh et al. (2007)	Farmer's professional training is optimal; Education of farmers and farm workers is optimal
Environmental-Friendly Farming / Increasing / Positive Impact	Agri-culture / State	Bohringer and Loschel (2006)	Environmentally-friendly farming
		Lenz and Beuttler (2003)	Site adequate farming
		Lopez-Ridaura et al. (2002)	Environmentally-friendly farming
		Piorr (2003)	Area under specific farming or management practices aiming at landscape conservation (traditional agricultural land use practices)
		Pulido and Bocco (2003)	Farmable Land
		Saifi and Drake (2008a)	Farmers ownership of farms
		Van Cauwenbergh et al. (2007)	Adaptability of the farm is sufficient
		Van Delden et al. (2007)	Sustainable farming

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Income Farmers / Increasing / Positive Impact	Agri-culture / State	Lopez-Ridaura et al. (2002)	Low income farmers
		Van Cauwenbergh et al. (2007)	Farm income is ensured
Adaptability of Farms / Increasing / Positive Impact	Agri-culture / Response	Lopez-Ridaura et al. (2002)	Adaptability of farms (Ability to change and to adopt new technology)
		Van Cauwenbergh et al. (2007)	Adaptability of the farm is sufficient
Pesticides Use / Decreasing / Positive Impact	Agri-culture / Pressure	Bohringer and Loschel (2006)	Pesticides use
		Kuo and Chiu (2006)	The amount of pesticides used per unit area
		Nader et al. (2008)	Use of agricultural pesticides; Use of fertilizers
Yields / Increasing / Positive Impact	Agri-culture / Response	Barrios et al. (2006)	Yield
		Lenz and Beuttler (2003)	Ecological yield potential
		Lopez-Ridaura et al. (2002)	Yields
		McGinley and Finegan (2003)	Forest product yield
		Saifi and Drake (2008a)	Food cereal yield; Lea yield
		Spangenberg (2002)	Yield
		Van Delden et al. (2007)	Plant structural properties (biomass, leaf area index, vegetation cover fraction) as well as their yields (Mulligan and Reaney, 2000)

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
No. of Machines / Stable / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	No. of machines/exploitation; No. of machines/area; No. of machines/agricultural area
		Saifi and Drake (2008a)	Number of tractors
Exploitations / Decreasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	% exclusive use exploitations ; % exploitations with 2 uses ; % multiple use exploitations ; % exploitations of worked land + pastures + others
		Sarda et al. (2005)	% multiple use exploitations
Parcels / Increasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	No. of parcels/km^2; No. of parcels/exploitation; No. of parcels/agricultural area
		Piorr (2003)	Patch shape of agricultural parcels
Threshing / Increasing / Positive Impact	Agri-culture / State	Saifi and Drake (2008a)	Threshing
Growing Stock / Increasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	Livestock subsidies / stock-rearing unity; Diversity of livestock; % livestock unit intensive / livestock unit total; The livestock unit total; Livestock unit pasture area; Livestock unit /agricultural area; Livestock unit /total area
		Learmonth et al. (2007)	Desired capital stock: $K_i^* = K_i^D(Q_i, w_n, uck)$ Capital stock adjustment: $\Delta K_i = \lambda i(K_i^* - K_i)$

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Piorr (2003)	Stock of UAA; Stock of arable land; Stock of grassland; Stock of forest areas; Stock of semi-natural and natural land; Stock of built up areas; Stock of broad, semi-natural and natural habitats / biotopes; Stock of valuable, linear and point biotopes and habitats in agricultural landscapes; Stock of the historical — cultural landscape area, linear and point features; Stock of broad land cover categories; Stock and flow land cover/land use matrices; Stock of biotopes and habitats
		Russell and Thomson (2009)	Larger % of commercial marine fish stocks at full reproductive capacity
		Van Brusselen and Schuck (2005)	Growing stock on forest and other wooded land, classified by forest type and by availability for wood supply.
		Van Cauwenbergh et al. (2007)	Stock of biotic resources functions; Stock of habitat function; Stock of quality habitat function
Silvi-Pasture / Increasing / Positive Impact	Agri-culture / State	Gomez-Sal et al. (2003)	% slopes up to 5^o in silvi-pasture or silvicultural usage; Total silvicultural production/area

A.2.5 EC5 – Economic – Industry

Table A.2.5: EC5 – Economic – Industry

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Capital Cost / Decreasing / Positive Impact	Industry / State	Learmonth et al. (2007)	User cost of capital uck=uck(kpi) Capital sock $K_{i,t}^{S} = (1 - d_i)K_{i,t-1}^{S} + \Delta K_{i,t-1}$
		Lopez-Ridaura et al. (2002)	Cost of external inputs, use of external resources
		Makropoulos et al. (2008)	Capital cost
		Piorr (2003)	Landscape costs
Operational Cost / Decreasing / Positive Impact	Industry / State	Lopez-Ridaura et al. (2002)	Cost/benefit ratio
		Makropoulos et al. (2008)	Operational cost
		Van Delden et al. (2007)	Total cost of dredging
Unit Labor Costs / Decreasing / Positive Impact	Industry / State	Bohringer and Loschel (2006)	Unit labor costs
		Lopez-Ridaura et al. (2002)	The high opportunity cost of labor
		Spangenberg (2002)	Unit labor costs
Labor Productivity / Increasing / Positive Impact	Industry / Response	Bohringer and Loschel (2006)	Labor productivity
		Lopez-Ridaura et al. (2002)	Productivity (Return to Labor)
		Spangenberg (2002)	Labor productivity

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Structure of Industries / Increasing / Positive Impact	Industry / Pressure	Gomez-Sal et al. (2003)	Industrial establishments
		Huang et al. (2009)	The structure of industries
		Nader et al. (2008)	Classification of establishments; Number and category of industries in non-categorized industrial zones
		Russell and Thomson (2009)	Inefficient industrial practices
Industrial Concentration / Increasing / Positive Impact	Industry / Pressure	Gomez-Sal et al. (2003)	Industrial density index
		Huang et al. (2009)	The ratio of the service industry to urban productivity
		Russell and Thomson (2009)	Inefficient industrial practices; Unlicensed industries
		Salvati and Zitti (2009)	Industrial concentration
Industry Economy / Increasing / Positive Impact	Industry / State	Ko (2005)	Economic Aspects
		Nader et al. (2008)	Distribution area and activity of quarries in the industry
		Russell and Thomson (2009)	Industry economy both the cause and solution
Organization & Policies / Increasing / Positive Impact	Industry / Response	Azapagic (2003)	A ranking of the organization as an employer in internal surveys
		Huang et al. (2009)	Specific policies; Organization and policies
		Saifi and Drake (2008a)	Organization
		Zellner et al. (2008)	Policy
New Companies / Increasing / Positive Impact	Industry / Pressure	Scipioni et al. (2009)	New Companies
Labor Conditions / Increasing / Positive Impact	Industry / State	Nijkamp and Vindigni (2003)	Increase in labor requirement
		Spangenberg (2002)	Labor conditions

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Cauwenbergh et al. (2007)	Labor conditions are optimal
New Accountability Concepts / Increasing / Positive Impact	Industry / Response	Olsen (2003)	Accountability
		Russell and Thomson (2009)	New accountability concepts
Warehouses/ Increasing / Positive Impact	Industry / State	Nader et al. (2008)	Number and distribution of warehouse
New Enterprises / Increasing / Positive Impact	Industry / Pressure	Andriantiatsa-holiniaina et al. (2005)	Government enterprises
		Russell and Thomson (2009)	New enterprises
		Spilanis et al. (2009)	New enterprises
Natural Capital / Increasing / Positive Impact	Industry / State	Andriantiatsa-holiniaina et al. (2005)	Capital formation
		Learmonth et al. (2007)	Desired capital stock: $K_i^* = K_i^D(Q_i, w_n, uck)$ Capital stock adjustment: $\Delta K_i = \lambda i(K_i^* - K_i)$
		Spangenberg (2002)	Social capital; Human and Man-made capital; Natural capital
Reliability / Increasing / Positive Impact	Industry / Response	Lopez-Ridaura et al. (2002)	Stability, resilience, reliability of agro-diversity, economic diversity, biological diversity
		Makropoulos et al. (2008)	Reliability
		Palme et al. (2005)	Reliability
		Spangenberg (2002)	Reliability of the health care and social security system
Durability / Increasing / Positive Impact	Industry / Response	Andriantiatsa-holiniaina et al. (2005)	Durable products
		Makropoulos et al. (2008)	Durability

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Flexibility & Adaptability / Increasing / Positive Impact	Industry / Response	Lopez-Ridaura et al. (2002)	Adaptability (Ability to change and to adopt new technology)
		Makropoulos et al. (2008)	Flexibility and adaptability
		Van Cauwenbergh et al. (2007)	Adaptability of the farm is sufficient

A.2.6 EC6 – Economic – Tourism

Table A.2.6: EC6 – Economic – Tourism

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Tourist Bed Quality & Price / Increasing / Positive Impact	Tourism / Response	Li (2004)	Percent of tourist beds utilization (Annual average and peak period average) (%)
		Sarda et al. (2005)	Tourist bed quality; Tourist bed price (maximum at the seasonal peak)
		Scipioni et al. (2008)	Tourist bed quality and price
Cost for Maintaining Tourism Operation / Decreasing / Positive Impact	Tourism / Response	Li (2004)	The cost for maintaining tourism operation indicator includes manager's salary, the cost for repairing facilities and ecosystem restoration, etc.
		Scipioni et al. (2008)	The cost for maintaining the tourism operation
Visiting Area / Increasing / Positive Impact	Tourism / State	Li (2004)	Visiting the area is the acreage of sites opening to visitors, including all scenery spots and trails. This indicator is used to indicate spatial carrying capacity for visitors. Visitor number in unit area can reflect the pressures and impacts on the natural environment caused by tourism
		Nader et al. (2008)	Number of visitors of tourist sites

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Scipioni et al. (2009)	Visitors to museums
		Spangenberg (2002)	Nature reserves and other protected or unused areas
Tourist Arrivals / Increasing / Positive Impact	Tourism / State	Learmonth et al. (2007)	Tourist arrivals
		Scipioni et al. (2009)	Tourist arrivals
		Scipioni et al. (2008)	Tourist arrivals
Tourist Presence / Increasing / Positive Impact	Tourism / State	Learmonth et al. (2007)	Tourist presence
		Li (2004)	Daily visitors/tourism area (Annual average and peak period average) (Persons/km^2); Daily visitors/hotel beds (Annual average and peak period average) (Persons/beds)
		Scipioni et al. (2009)	Tourist presence
		Scipioni et al. (2008)	Tourist presence
Issues About Tourism & Local Communities / Decreasing / Positive Impact	Tourism / State	Ko (2005)	Tourism's contribution to the needs of local residents
		Kuo and Chiu (2006)	Conflict between agro-tourism development with the local community
		Li (2004)	Local population participating in tourism business (Persons); Local community's annual income from tourism/total income (%); Interference to locals
		Scipioni et al. (2008)	Issues about tourism and local communities
Eco-Tourism / Increasing / Positive Impact	Tourism / Response	Ko (2005)	Tourism's contribution to the needs of the natural environment
		Lenz and Beuttler (2003)	Eco-tourism

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Li (2004)	The integrated tourism and environment plan are the basis of tourism development and management. It is a necessity for any successful ecotourism operation
		Nader et al. (2008)	Municipality income from sustainable ecotourism
		Russell and Thomson (2009)	Eco-tourism
		Scipioni et al. (2008)	Eco-tourism
Tourism Activities / Increasing / Positive Impact	Tourism / State	Ko (2005)	Tourism's contribution to the needs of tourists
		Lenz and Beuttler (2003)	Tourism activities
		Li (2004)	Indicates the contribution of tourism to the reserve
		Nader et al. (2008)	The current balance due to tourism activities; The number and distribution of tourist sites and the institution
		Scipioni et al. (2008)	Tourism activities
Tourist Offer / Increasing / Positive Impact	Tourism / Response	Learmonth et al. (2007)	Tourist offer
		Sarda et al. (2005)	Tourist offer
		Scipioni et al. (2008)	Tourist offer
Hotel Use Rate / Increasing / Positive Impact	Tourism / State	Li (2004)	Including all hotel beds within the study area, which is used to indicate carrying capacity for night visitors
		Sarda et al. (2005)	Hotel beds per 100 inhabitants; Average price by the star at the peak season
		Scipioni et al. (2009)	Hotel use rate

APPENDIX 3 - ENVIRONMENTAL INDICATORS (EN)

A.3.1 EN1 – Environmental – Land / Soil

Table A.3.1: EN1 – Environmental – Land / Soil

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Change in the Amount of Land / Stable / Positive Impact	Land & Soil / Pressure	Barrios et al. (2006)	New land (land use change from pasture to crops, less than 10 years of use/more than 10 years of use)
		Foody (2003)	Changes in land use
		Nader et al. (2008)	Nader et al. (2008)
		Olsen (2003)	The enactment of land
		Parr et al. (2003)	Broad-scale environmental change
		Petanidou et al. (2008)	Change in the Amount of Land
		Piorr (2003)	Stock and change of UAA; Stock and change of arable land; Stock and change of grassland; Stock and change of forest areas; Stock and change of built up areas; Stock and change of broad land cover categories
		Saifi and Drake (2008a)	The rural landless
		Salvati and Zitti (2009)	Changes in cultivated land surface (LOS)
		Silva et al. (2006)	Flatland; <8% slope; 8–30% slope ; > 30% slope
		Stork et al. (1997)	Conversion; Area change
		Van Brusselen and Schuck (2005)	Landscape changes; Land cover changes in the surroundings of designated areas
		Van Cauwenbergh et al. (2007)	Land tenure arrangements are optimal

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Wang et al. (2007)	Changes in the agricultural landscape
Area / Stable / Positive Impact	Land & Soil / State	Aguilar-Amuchastegui and Henebry (2006)	Area
		Gomez-Sal et al. (2003)	% semi-natural area; % area with transhumance routes; % agrarian area; % area of linear corridors; % area with 0–3o slope; % area with 3–12o slope; % area >12o slope; % area with river channel; % area dry cropland; % area pastures; % area other crops
		Hiscock et al. (2003)	Areas, particularly marine areas, which may be functionally critical for organisms inhabiting wider ecosystems.
		Jaeger et al. (2008)	Primary area classes
		Lenz and Beuttler (2003)	Area consumption / Soil sealing
		Nader et al. (2008)	An area of land affected by high voltage power lines
		Petanidou et al. (2008)	Area
		Piorr (2003)	Area
		Saifi and Drake (2008a)	Fallow area
		Termorshuizen et al. (2007)	The adjacent areas are taken into account in the planning process.
		Wang et al. (2007)	Area
Urban Area / Increasing / Positive Impact	Land & Soil / Pressure	Gomez-Sal et al. (2003)	% urban/anthropic area
		Goncalves et al. (2009)	Urban area

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Huang et al. (2009)	The ratio of urban area; Rate of increase in urban area; Urban slum
		Kuo and Chiu (2006)	Ratios of urbanization
		Mortberg et al. (2007)	Urbanization
		Piorr (2003)	Urban Landscape
		Sarda et al. (2005)	Urban structure
		Scipioni et al. (2009)	Urban Ecosystem
		Spilanis et al. (2009)	Non built-up urban areas/total urban area
		Whitford et al. (2001)	The complexity of Urban Area
		Zhang and Guindon (2006)	Existing urban land area; Urban land contagion
Soil Condition / Increasing / Positive Impact	Land & Soil / State	Barrios et al. (2006)	Soil structure Loose soil porous, powdery/non-powdery
		Boer and Puigdefabregas (2005)	Soil condition
		Huang et al. (2009)	Soil condition
		Lenz and Beuttler (2003)	Area consumption / Soil sealing
		Lopez-Ridaura et al. (2002)	Biophysical characteristics of soils (i.e. compaction, percentage of organic matter)
		Parr et al. (2003)	Soil condition
		Pulido and Bocco (2003)	Soil condition
		Saifi and Drake (2008a)	Soil preparation
		Salvati and Zitti (2009)	Soil Texture
		Sarda et al. (2005)	An impervious soil

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Silva et al. (2006)	Topsoil texture; Subsoil texture
		Spangenberg (2002)	Soil condition
		Van Brusselen and Schuck (2005)	Chemical soil properties (pH, CEC, C/N, organic C, base saturation) on forest and other wooded land related to soil acidity and eutrophication, classified by main soil types.
		Verboom et al. (2007)	The abiotic conditions of soil are taken into account in the planning process.
Erosion Risk of Soils / Decreasing / Positive Impact	Land & Soil / Pressure	Foody (2003)	Potential for erosion
		Kuo and Chiu (2006)	The risk of disaster in the hillside fields
		Lopez-Ridaura et al. (2002)	Erosion risk of soils
		Van Brusselen and Schuck (2005)	Erosion risk of soils
Soil Erosion / Decreasing / Positive Impact	Land & Soil / Response	Bland and Bell (2007)	Soil loss
		Boer and Puigdefabregas (2005)	Soil erosion
		Bohringer and Loschel (2006)	Soil degradation
		Lenz and Beuttler (2003)	Soil erosion
		Lopez-Ridaura et al. (2002)	Soil erosion
		Pulido and Bocco (2003)	Soil erosion
		Salvati and Zitti (2009)	Estimated soil erosion rate
		Spangenberg (2002)	Soil erosion

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Van Brusselen and Schuck (2005)	Soil erosion
		Van Cauwenbergh et al. (2007)	Soil loss is minimized
		Van Delden et al. (2007)	Erosion rates
Soil Salinity / Decreasing / Positive Impact	Land & Soil / State	Van Delden et al. (2007)	Soil salinity calculates the amount of salt in the soil and the salt concentration in the aquifer. Soil salinity increases by infiltration of saline water. The origin of saline water can be irrigation or soil salt from upstream plots picked up by runoff and transported to downstream plots. Recharge and extraction influence the salt concentration in the aquifer.
Soil Quality / Increasing / Positive Impact	Land & Soil / State	Barrios et al. (2006)	Technical indicators of soil quality (TISQ) usually include basic parameters, such as, bulk density, pH, effective rooting depth, water content, soil temperature, total C and electrical conductivity (Doran and Parkin, 1994). Local indicators of soil quality (LISQ) are often more variable and include crop yield and vigor, soil color, soil texture and structure, and the presence/ absence or abundance of local plant and soil invertebrate species (Mairura et al., 2004).
		Boer and Puigdefabregas (2005)	Soil quality
		Lenz and Beuttler (2003)	Area consumption / Soil sealing
		Lopez-Ridaura et al. (2002)	Soil quality
		Piorr (2003)	Soil type

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Pulido and Bocco (2003)	Soil quality
		Salvati and Zitti (2009)	Soil quality
		Silva et al. (2006)	Topsoil and subsoil coarse material; Topsoil and subsoil pH; Topsoil and subsoil al saturation; Topsoil and subsoil exchangeable al; Topsoil and subsoil exchangeable Ca; Topsoil and subsoil total exchangeable bases; Topsoil and subsoil ECEC; Topsoil and subsoil organic matter; Topsoil and subsoil P; Soil P fixation
		Van Cauwenbergh et al. (2007)	Soil chemical quality is maintained or increased; Soil physical quality is maintained or increased
Soil Depth / Increasing / Positive Impact	Land & Soil / State	Barrios et al. (2006)	Effective soil depth Soil depth (half machete, 12 in.), thick/thin soil less than 4 in.
		Kuo and Chiu (2006)	Soil depth (half machete, 12 in.), thick/thin soil less than 4 in.
		Piorr (2003)	Landform (slope, elevation)
		Salvati and Zitti (2009)	Soil depth
		Sarda et al. (2005)	Percentage over total soil
		Silva et al. (2006)	Soil depth
		Van Delden et al. (2007)	Fertile soil depth
Landscape Pattern & Land Use / Stable / Positive Impact	Land & Soil / State	Barrios et al. (2006)	New land (land use change from pasture to crops, less than 10 years of use/more than 10 years of use)
		Boer and Puigdefabregas (2005)	Land use

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Bohringer and Loschel (2006)	Land use change
		Carvalho et al. (2008)	Land use
		Fischer and Lindenmayer (2007)	Landscape Pattern
		Foody (2003)	Changes in land use
		Huang et al. (2009)	Land use
		Hutchins and Sutherland (2008)	Land use
		Jaeger et al. (2008)	Land use change
		Kuo and Chiu (2006)	Harmony of the rural landscape
		Makropoulos et al. (2008)	Land use (m^2)
		Nijkamp and Vindigni (2003)	Agricultural area in use
		Nader et al. (2008)	Land use change
		Olsen (2003)	Land use practices that reduce contamination of water,
		Petanidou et al. (2008)	Land-use change
		Piorr (2003)	Land use patterns; Land cover / land use matrices
		Russell and Thomson (2009)	Better land use
		Salvati and Zitti (2009)	Changes in cultivated land surface
		Sarda et al. (2005)	Mosaic index (land-use index)
		Shi et al. (2005)	Land area (%)

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Silva et al. (2006)	Land use Poorly drained savannas; Grassland + grassland and shrubs; Open, well drained savanna; Dense savanna; Dense woodland savanna (cerradao)
		Spangenberg (2002)	Land use intensity
		Spilanis et al. (2009)	Land use area per land use/total area; Burnt area per land use/total area; Sparse built-up area/total area; Built-up coastal area (homes, holiday homes or tourism units)/total area
		Stork et al. (1997)	Landscape pattern is maintained.
		Van Brusselen and Schuck (2005)	Landscape-level spatial pattern of forest cover
		Van Delden et al. (2007)	Sustainable land use in the region
		Wang et al. (2007)	Land use
		Wijewardana (2008)	Land use
		Zellner et al. (2008)	Land use
		Zhang and Guindon (2006)	Spatial analysis characterization of spatial patterns and structure; calculation direct from geospatial data.
Wetland Sites / Increasing / Positive Impact	Land & Soil / State	Nijkamp and Vindigni (2003)	Wetland
		Van Brusselen and Schuck (2005)	Threats in and around wetland sites; A total area of wetlands (and other ecosystem types) reclaimed by country, biogeographic region, Europe.
		Yuan et al. (2003)	Wetland

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Land Quality / Increasing / Positive Impact	Land & Soil / State	Carvalho et al. (2008)	Impact to land
		Huang et al. (2009)	Land quality
		Pulido and Bocco (2003)	Land quality
		Russell and Thomson (2009)	Clean land
		Spangenberg (2002)	Land quality trend
		Zellner et al. (2008)	Agricultural quality; Septic quality
Mudflows & Landslides / Decreasing / Positive Impact	Land & Soil / Response	Boer and Puigdefabregas (2005)	Runoff
		Kuo and Chiu (2006)	Mudflows and landslides
		Lenz and Beuttler (2003)	Human and Eco toxicological Potential (sewage mud)
		Nader et al. (2008)	Land affected by landslides
		Van Cauwenbergh et al. (2007)	Soil mass flux (mudflows, landslides) is adequately buffered.
Rehabilitated Quarried Land / Decreasing / Positive Impact	Land & Soil / State	Hiscock et al. (2003)	Potential value of rehabilitation or recreation of habitats.
		Nader et al. (2008)	Rehabilitated quarried land
Protected Area / Increasing / Positive Impact	Land & Soil / Response	Andriantiatsa-holiniaina et al. (2005)	Nationally protected area (percent of total land area); Protected area (percent protected)
		Bohringer and Loschel (2006)	Protection of habitats and natural systems and biodiversity
		Foody (2003)	Terrestrial protected areas
		Gomez-Sal et al. (2003)	% catalogued as a protected natural area
		Hiscock et al. (2003)	Protecting important habitats
		Huang et al. (2009)	% of public expenditure on environment protection

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Kuo and Chiu (2006)	Ratios of important habitats under protection
		McGinley and Finegan (2003)	Habitats under protection (CNCF (1999))
		Nader et al. (2008)	Protected coastal area
		Olsen (2003)	Protected areas
		Piorr (2003)	UAA within protected sites (according to IUCN categories); Landscape protection areas
		Sarda et al. (2005)	Protected area index; Coastal protection index; Protected area in the municipality
		Shi et al. (2005)	Area under protection (%)
		Silva et al. (2006)	Percentage Protected
		Spangenberg (2002)	Protected reserves
		Spilanis et al. (2009)	Protected area/total area; Protected area per type of ecosystem / total area
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land designated to protect infrastructure and managed natural resources against natural hazards
Moisture / Increasing / Positive Impact	Land & Soil / State	Silva et al. (2006)	Moisture holding capacity; Moisture regime
		Van Cauwenbergh et al. (2007)	Adequate amount of soil moisture is supplied
		Van Delden et al. (2007)	Soil moisture
Mining / Decreasing / Positive Impact	Land & Soil / Pressure	Andriantiatsa-holiniaina et al. (2005)	Mining
		Olsen (2003)	Mining
		Spangenberg (2002)	Mining
		Stork et al. (1997)	Mining

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Grazing / Decreasing / Positive Impact	Land & Soil / Pressure	Fischer and Lindenmayer (2007)	Areas with extensive livestock grazing
		Stork et al. (1997)	Grazing of livestock occurs seasonally in many forests in Latin America, Africa and Asia.
Pollution / Decreasing / Positive Impact	Land & Soil / Response	Fahy and Cinneide (2008)	Unpolluted physical environment
		Lenz and Beuttler (2003)	Pollution risk through heavy metals
		Learmonth et al. (2007)	Pollutants $POL_k = \sum_i m_{i,k} Q_i = \sum_z m_{z,k} C_z$
		Russell and Thomson (2009)	Polluters pay
		Stork et al. (1997)	Pollution
		Troyer (2002)	Pollution
Pollution Reduction / Increasing / Positive Impact	Land & Soil / Response	Andriantiatsa-holiniaina et al. (2005)	Reduction of pollutants
		Olsen (2003)	Waste disposal and pollution reduction infrastructure including sewage treatment facilities, sanitary landfills, runoff retention basins.
		Van Cauwenbergh et al. (2007)	Pollution levels are reduced
		Yuan et al. (2003)	A measure of the potential to reduce pollution
Solid Waste Landfill Area / Decreasing / Positive Impact	Land & Soil / State	Andriantiatsa-holiniaina et al. (2005)	Solid and liquid waste generation (kilograms per day and capita)
		Azapagic (2003)	The amount of solid waste (hazardous and non-hazardous) (kg/yr or t/yr)
		Bohringer and Loschel (2006)	Decoupling economic growth and waste

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Huang et al. (2009)	Construction wastes
		Kuo and Chiu (2006)	The growth rate of solid waste
		Lenz and Beuttler (2003)	The amount of waste
		Nader et al. (2008)	Destination of household waste; Generation of municipal solid waste; Problems in disposing of household wastes; Generation of hospital waste; Composition of municipal waste; Generation and destination of agricultural waste
		Russell and Thomson (2009)	Waste; Municipal waste volume
		Salter et al. (2009)	Solid waste production
		Sarda et al. (2005)	Generation of household waste
		Scipioni et al. (2009)	Waste
		Spangenberg (2002)	The overburden from mining, erosion, excavation waste
		Spilanis et al. (2009)	Solid waste landfill area
Nuclear Waste / Decreasing / Positive Impact	Land & Soil / Pressure	Andriantiatsa-holiniaina et al. (2005)	Nuclear waste (tons of heavy metal per year and a thousand people)
		Bohringer and Loschel (2006)	Management of nuclear waste
Proper Treatment of Waste / Increasing / Positive Impact	Land & Soil / Response	Andriantiatsa-holiniaina et al. (2005)	Reducing uncontrolled waste improves land sustainability.
		Bohringer and Loschel (2006)	Resource management of waste
		Kuo and Chiu (2006)	The proper treatment rate of agro-tourism waste; The proper treatment rate of solid waste

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Li (2004)	Daily waste solid treatment capacity (ton/day)
		Nader et al. (2008)	Number and % of households experiencing problems in disposing of household wastes; Cost of management of municipal solid waste; Effectiveness of solid waste management
		Russell and Thomson (2009)	Less municipal waste volume; Larger % of municipal waste recycled; % municipal waste recycled
		Scipioni et al. (2009)	Recyclable waste
		Troyer (2002)	Assimilation of wastes
		Yuan et al. (2003)	Waste treatment and management
Emission of Toxic Waste / Decreasing / Positive Impact	Land & Soil / Pressure	Hutchins and Sutherland (2008)	Land Emissions
		Kuo and Chiu (2006)	Emission of toxic waste per year
		Nader et al. (2008)	Generation and destination of slaughterhouse waste; Generation and composition of industrial waste; Generation and composition of airport waste; Generation and composition of waste generated by ships
		Sarda et al. (2005)	Household and industrial wastes; Waste vaporization; Generation of industrial wastes
Chemical Use / Decreasing / Positive Impact	Land & Soil / Pressure	Bohringer and Loschel (2006)	Chemicals production and consumption Chemicals management
		Kuo and Chiu (2006)	Amount of chemical fertilizers used per unit area
		Makropoulos et al. (2008)	Chemical use
		Saifi and Drake (2008a)	Biocide consumption; Biocide use

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Sedimentation / Decreasing / Positive Impact	Land & Soil / Response	Van Delden et al. (2007)	Simulates erosion and sedimentation processes based on soil characteristics and information from the Hydrology model. With this information physical and financial impacts of erosion and sedimentation on the check dams and reservoirs are calculated to support management plans for the construction of new check dams and dredging of the reservoirs (Mulligan, 1998; Wesemael et al., 2000).
Pesticide Residues / Decreasing / Positive Impact	Land & Soil / Pressure	Bohringer and Loschel (2006)	Pesticide residues
		Lopez-Ridaura et al. (2002)	The incidence of pest
No. & Area of Illegal Discharges / Decreasing / Positive Impact	Land & Soil / State	Kuo and Chiu (2006)	BOD discharge per year; SS discharge per year
		Nader et al. (2008)	The number and area of illegal discharges
Coastline / Stable / Positive Impact	Land & Soil / State	Nader et al. (2008)	Artificial coastline per total coastline
		Olsen (2003)	Coastal resources
		Parr et al. (2003)	Coastal communities
		Sarda et al. (2005)	Coastal fringe artificialization; Beach frequentation (urban zones); Beach frequentation (non-urban zones); Beach nourishment
		Spilanis et al. (2009)	Built-up coastal area (homes, holiday homes or tourism units)/total area
Land Emissions/ Decreasing / Positive Impact	Land & Soil / Pressure	Hutchins and Sutherland (2008)	Land Emissions
		Palme et al. (2005)	Emissions to the ground

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Altitude Range/ Stable / Positive Impact	Land & Soil / State	Gomez-Sal et al. (2003)	Altitude range (m)
		Silva et al. (2006)	Altitude (m)
Nutrient Balance / Increasing / Positive Impact	Land & Soil / Pressure	Lopez-Ridaura et al. (2002)	Nutrient balance
		Silva et al. (2006)	Nutrient Status
		Stork et al. (1997)	Change in nutrients; The status of decomposition and nutrient cycling
Sources of Nitrogen & Phosphorus / Decreasing / Positive Impact	Land & Soil / Pressure	Bohringer and Loschel (2006)	Nitrogen balances
		Lenz and Beuttler (2003)	The potential input of total nitrogen into surface wastes
		Saifi and Drake (2008a)	Nitrogen consumption; Phosphorus consumption; Mineral phosphorous use; Mineral nitrogen use
		Scipioni et al. (2009)	Nitrogen dioxide (NO2)
		Van Brusselen and Schuck (2005)	Sources of nitrogen and phosphorus
		Verboom et al. (2007)	Nitrogen deposition and intensification of agriculture (Donald et al., 2001; Krebs et al., 1999).

A.3.2 EN2 – Environmental – Water

Table A.3.2: EN2 – Environmental – Water

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Water Quality / Increasing / Positive Impact	Water / State	Andriantiatsa-holiniaina et al. (2005)	Quality of water resources
		Bohringer and Loschel (2006)	Drinking water quality
		Carvalho et al. (2008)	Aquatic Impact
		Huang et al. (2009)	Water quality
		Hutchins and Sutherland (2008)	Water Emissions
		Kuo and Chiu (2006)	The ratio of meeting water quality standards in rivers; The ratio of meeting water quality standards in reservoirs
		Li (2004)	Indicates the impacts on water quality
		Nader et al. (2008)	Sea water quality; Drinking water quality index; Surface water quality index; Groundwater quality index
		Piorr (2003)	Water quality
		Prato (2005)	Water quality
		Russell and Thomson (2009)	Less kilometres of rivers identified as poor or seriously polluted; Clean water
		Sarda et al. (2005)	Water depuration intensity; Water depuration (Pb); River water quality
		Spilanis et al. (2009)	Quality of drinking and irrigation water according to EU directives 75/440 and 98/83/EU; Bathing water quality according to EU Directive 76/160/EEC
		Stork et al. (1997)	There is no significant change in the quality of water from the catchment

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Van Brusselen and Schuck (2005)	Bathing water quality
		Van Cauwenbergh et al. (2007)	Surface water of adequate quality is supplied; Soil water of adequate quality is supplied; Groundwater of adequate quality is supplied
Hydrology / Decreasing / Positive Impact	Water / State	Jaeger et al. (2008)	Hydrography
		Silva et al. (2006)	Hydraulic conductivity
		Termorshuizen et al. (2007)	Hydrology
		Van Delden et al. (2007)	Simulates for every bucket-tip time step, as determined in a number of different hydrological processes such as: interception, runoff, evapotranspi-ration, soil sealing, infiltration, soil moisture, aquifer recharge, river flow, and transmission loss. Calculations are carried out for every 1 ha cell and account for the impact of the upstream cells, locational (soil) characteristics, land use and land cover of the cell. At the end of the day all state variables calculated in the bucket-tip time steps are summed to daily totals (Mulligan, 1994, 1996a,b, 1998; Burke et al., 1998; Reaney and Mulligan, 1999; Wesemael et al., 2000; Ramos and Mulligan, 2005).

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Whitford et al. (2001)	A storm run-off coefficient is chosen as a performance indicator which would most readily show the effect of urbanization on hydrology. The approach used was that taken by the SCS (1972) and further developed by Pandit and Gopalakrishnan (1996). Their method is derived from theory about the fate of precipitation and the results of empirical studies on many small watersheds. These are combined together to give the equation for run-off, P_e: $P_e = \frac{(P-0.2S)^2}{P-0.8S}$ Where P is the precipitation, and S the maximum potential retention of the catchment (the greater the S the smaller is the run-off). S, in turn is given by the expression: $S = \frac{2540}{CN} - 25.4$ Where CN is the curve number of the particular type of watershed.
Protection of Water Resources / Increasing / Positive Impact	Water / Response	Bohringer and Loschel (2006)	Fresh water resources
		Hiscock et al. (2003)	Affording more protection to marine species and habitats on the high seas; Sustain fresh water inflows to estuaries.
		Sarda et al. (2005)	Recreational fleet in marinas
Water Emission/ Decreasing / Positive Impact	Water / Pressure	Andriantiatsa-holiniaina et al. (2005)	Decrease or increase (if negative) of emissions of organic pollutants between 1990 and 1995 measured in kilograms of biological oxygen demand per cubic kilometer of water.
		Azapagic (2003)	Emissions to water (g/l or kg/m^3)

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Hutchins and Sutherland (2008)	Water Emissions
		Van Brusselen and Schuck (2005)	Water Emissions
Water Resources / Increasing / Positive Impact	Water / State	Bohringer and Loschel (2006)	Fresh water resources
		Lenz and Beuttler (2003)	Substitution potential of drinking water
		Palme et al. (2005)	Resources
		Piorr (2003)	Water bodies
		Sarda et al. (2005)	Aquifer situation
		Spangenberg (2002)	Surface water, ground water, deep ground water, sea water
		Spilanis et al. (2009)	Maximum freshwater resources quantity
		Van Delden et al. (2007)	Simulates the water budget of the aquifer, the reservoirs and desalinated seawater, as well as the allocation of water based on availability and policy restrictions.
Water Pollution / Decreasing / Positive Impact	Water / Response	Andriantiatsa-holiniaina et al. (2005)	Water pollutants
		Huang et al. (2009)	The ratio of polluted stream length
		Li (2004)	Include health accidents caused by polluted water such as diarrhea and poisoning; The accident times that scenery spots have to be closed due to water pollution
		Nader et al. (2008)	Number and % of polluted artesian wells; Pollution determination methods
		Russell and Thomson (2009)	Kilometres of rivers identified as poor or seriously polluted

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Water Loss / Decreasing / Positive Impact	Water / Response	Makropoulos et al. (2008)	Water loss
		Russell and Thomson (2009)	Water scarcity
Water Quantity / Increasing / Positive Impact	Water / State	Spilanis et al. (2009)	Maximum freshwater resources quantity
		Stork et al. (1997)	There is no significant change in the quantity of water from the catchment
		Van Cauwenbergh et al. (2007)	Adequate amount of surface water is supplied; Adequate amount of groundwater is supplied
		Van Delden et al. (2007)	Change in the aquifer and reservoir budget
Availability of Water / Increasing / Positive Impact	Water / State	Andriantiatsa-holiniaina et al. (2005)	Gross freshwater abstractions as percentage of total available water resources
		Huang et al. (2009)	Availability of Water
		Hutchins and Sutherland (2008)	A population with access to safe drinking water
		Lenz and Beuttler (2003)	Substitution potential of drinking water
		Nader et al. (2008)	Household access to water networks
		Russell and Thomson (2009)	Water scarcity
		Spilanis et al. (2009)	Available water in storage reservoirs
Water Usage & Consumption / Decreasing / Positive Impact	Water / State	Andriantiatsa-holiniaina et al. (2005)	Urban per capita water use
		Azapagic (2003)	Amount of water used (m^3/yr)
		Bohringer and Loschel (2006)	Water extraction and use
		Carvalho et al. (2008)	Water usage and consumption

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Kuo and Chiu (2006)	Total water consumption; The ratio of groundwater consumption; Efficiency of agricultural water use; Efficiency of agro-tourism water use
		Lenz and Beuttler (2003)	Drinking water requirement; Sustainability of groundwater usage
		Li (2004)	Water-supplying capacity (both in rich and poor rain period) (ton/day); Daily water consumption/ visitors (Annual average and peak period average) (tons/person)
		Makropoulos et al. (2008)	Water usage and consumption
		Nader et al. (2008)	Total water demand per sector
		Russell and Thomson (2009)	Better water use
		Salter et al. (2009)	Water consumption
		Sarda et al. (2005)	Water consumption
		Scipioni et al. (2009)	Potable water consumption
		Van Delden et al. (2007)	Irrigation water used from different sources; Water demands and usage
		Zellner et al. (2008)	Water usage and consumption
% of Wastewater Treated / Increasing / Positive Impact	Water / Response	Andriantiatsa-holiniaina et al. (2005)	Urban wastewater treated
		Huang et al. (2009)	% of wastewater treatment
		Li (2004)	Daily wastewater treatment capacity (ton/day)

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Nader et al. (2008)	Household access to wastewater networks; The share of collected and treated / untreated wastewater by the public sewerage system
Amount & Cost of Waste & Irrigation Water / Decreasing / Positive Impact	Water / State	Nader et al. (2008)	Number and % of households having artesian wells; Number of artesian wells
		Palme et al. (2005)	Total cost of sludge handling / entire wastewater system
		Van Delden et al. (2007)	Amount and cost of irrigation water
Desalinated or Imported Water / Stable / Positive Impact	Water / Response	Spilanis et al. (2009)	Desalinated or imported water
		Van Delden et al. (2007)	Natural water input
Amount & Cost of Water Used / Decreasing / Positive Impact	Water / State	Bohringer and Loschel (2006)	Costs and amount of water used
		Van Delden et al. (2007)	Costs and amount of water used
Water Coverage/ Increasing / Positive Impact	Water / State	Carvalho et al. (2008)	Water
		Zellner et al. (2008)	Municipal water coverage
Flooding & Runoff / Decreasing / Positive Impact	Water / Response	Boer and Puigdefabregas (2005)	Runoff
		Lopez-Ridaura et al. (2002)	Measuring in runoff plots
		Olsen (2003)	Runoff retention basins
		Van Cauwenbergh et al. (2007)	Flooding and runoff regulation of the agro-ecosystem are maintained or enhanced
		Van Delden et al. (2007)	Runoff and recharge
Reservoirs / Stable / Positive Impact	Water / State	Kuo and Chiu (2006)	The ratio of meeting water quality standards in reservoirs; Average number of days when reservoir storages are at low level

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Spilanis et al. (2009)	Available water in storage reservoirs
		Van Delden et al. (2007)	Change in storage capacity of the reservoir; Change in the aquifer and reservoir budget
Aquifer Situation / Increasing / Positive Impact	Water / State	Sarda et al. (2005)	Aquifer situation
		Van Delden et al. (2007)	The salt concentration in the aquifer
Cesspools / Stable / Positive Impact	Water / State	Nader et al. (2008)	Number of cesspools; Number and compliance of septic tanks
% of Public Maritime Domain / Increasing / Positive Impact	Water / Response	Hiscock et al. (2003)	Improved marine scientific research
		Nader et al. (2008)	% of the public maritime domain
		Parr et al. (2003)	Marine production
		Russell and Thomson (2009)	Marine life
		Sarda et al. (2005)	Marine occupation

A.3.3 EN3 – Environmental – Air

Table A.3.3: EN3 – Environmental – Air

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Air Pollution / Decreasing / Positive Impact	Air / Response	Bohringer and Loschel (2006)	Air pollution from energy use; Air pollutants
		Huang et al. (2009)	Metropolitan air pollution
		Russell and Thomson (2009)	Polluted air
		Van Brusselen and Schuck (2005)	Deposition of air pollutants on forest and other wooded land, classified by N, S and base captions
Air Emissions / Decreasing / Positive Impact	Air / Pressure	Azapagic (2003)	Air emissions
		Bohringer and Loschel (2006)	Air emissions
		Hutchins and Sutherland (2008)	Air emissions
		Nader et al. (2008)	Air emissions from landfills
		Palme et al. (2005)	Emissions to air
		Russell and Thomson (2009)	Air emissions
Air Quality / Increasing / Positive Impact	Air / State	Bohringer and Loschel (2006)	Air quality
		Carvalho et al. (2008)	Atmospheric Impact
		Huang et al. (2009)	Atmosphere quality
		Li (2004)	The impacts on air quality, i.e. days of air quality exceeding standard (all-year) (days)
		Nader et al. (2008)	Air quality

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Russell and Thomson (2009)	Air quality management areas; Clean air
		Sarda et al. (2005)	Air quality
		Van Cauwenbergh et al. (2007)	Supply (flow) of quality air function . Air quality is maintained or enhanced.
Noise Pollution / Decreasing / Positive Impact	Air / Response	Azapagic (2003)	Noise (db. or number of complaints)
		Bohringer and Loschel (2006)	Noise exposure
		Huang et al. (2009)	Metropolitan noise pollution
		Lenz and Beuttler (2003)	Noise exposure
		Nader et al. (2008)	Noise pollution and its distribution
		Scipioni et al. (2008)	Soundness
Air Temperature / Decreasing / Positive Impact	Air / State	Piorr (2003)	Air temperature
		Scipioni et al. (2009)	Air temperature
		Spangenberg (2002)	Air (for covering the input–output balance)
Particulate Matter / Decreasing / Positive Impact	Air / State	Andriantiatsa-holiniaina et al. (2005)	Atmospheric concentrations of total suspended particulates and lead (Ag/m^3)
		Azapagic (2003)	Particles
		Lenz and Beuttler (2003)	Critical Loads, the Potential input of total acidity into the terrestrial ecosystem
		Nader et al. (2008)	Concentration of particulates
		Scipioni et al. (2009)	Particulate matter
		Spangenberg (2002)	Iron, oil, copper, gravel, sands

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Sulphur Dioxide (SO_2) / Decreasing / Positive Impact	Air / State	Andriantiatsa-holiniaina et al. (2005)	Atmospheric concentrations of SO_2
		Azapagic (2003)	Emissions of SO_2
		Hutchins and Sutherland (2008)	Sulfur dioxide (SO_2)
		Lenz and Beuttler (2003)	Critical levels SO_2
		Scipioni et al. (2009)	Sulfur dioxide (SO_2)
Ozone (O_3) / Decreasing / Positive Impact	Air / State	Hutchins and Sutherland (2008)	Ozone Depletion Potential; Photochemical Ozone Creation Potential
		Lenz and Beuttler (2003)	Critical levels Ozone
		Nader et al. (2008)	Consumption of ozone depleting substances
		Scipioni et al. (2009)	Ozone (O_3)
Wind Speed & Direction / Decreasing / Positive Impact	Air / State	Nader et al. (2008)	Wind speed and direction
		Van Cauwenbergh et al. (2007)	Wind speed is adequately buffered
Greenhouse Gases Emissions / Decreasing / Positive Impact	Air / Pressure	Andriantiatsa-holiniaina et al. (2005)	Greenhouse gas emissions (percentage) measure deviations from targets of the six gases addressed by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), HFCs, PFCs, and sulfur hexafluoride (SF_6). Expressed as CO_2 equivalents.
		Azapagic (2003)	Emissions of: SOx, NOx, particles etc. (t/yr or kg/yr)
		Bohringer and Loschel (2006)	GHG emission reduction
		Kuo and Chiu (2006)	Emission of PM10 per year

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Nader et al. (2008)	Emission and source of polluting gases
		Palme et al. (2005)	Emissions to air
		Russell and Thomson (2009)	Fewer greenhouse gas emissions (net);
		Sarda et al. (2005)	Gas emissions

A.3.4 EN4 – Environmental – Biodiversity

Table A.3.4: EN4 – Environmental – Biodiversity

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Biodiversity / Increasing / Positive Impact	Biodiversity / State	Andriantiatsa-holiniaina et al. (2005)	Forests maintain biodiversity
		Azapagic (2003)	Loss of biodiversity (e.g. rate of loss of a certain species in a certain region or globally) (% or number)
		Foody (2003)	Biodiversity
		Gough et al. (2008)	Genetic diversity
		Hiscock et al. (2003)	High natural biological diversity
		Huang et al. (2009)	Biodiversity
		Ko (2005)	Biodiversity
		Piorr (2003)	Biodiversity; Loss of biodiversity
		Prato (2005)	Biodiversity
		Russell and Thomson (2009)	Biodiversity loss; Biodiversity
		Shi et al. (2005)	Biodiversity

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Stork et al. (1997)	Biodiversity in natural forests is strongly controlled by natural disturbance regimes. Changes in the disturbance regime (intensity, frequency or pattern) may consequently affect biodiversity.
		Van Brusselen and Schuck (2005)	Habitats and biodiversity
		Van Cauwenbergh et al. (2007)	Planned biodiversity is maintained or increased; Functional part of spontaneous biodiversity is maintained or increased; Heritage part of spontaneous biodiversity is maintained or increased
		Verboom et al. (2007)	Biodiversity is affected by climate change. Climate change is expected to cause a significant biodiversity loss in the near future (Thomas et al., 2004; Pearson et al., 2002).
		Whitford et al. (2001)	Biodiversity
Heterogeneity / Increasing / Positive Impact	Biodiversity / State	Aguilar-Amuchastegui and Henebry (2006)	Heterogeneity
		Fischer and Lindenmayer (2007)	Landscape heterogeneity
		Silva et al. (2006)	Spatial heterogeneity

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Whitford et al. (2001)	Heterogeneity is formalized by an equation, first developed by Handley (1988): $D = -\sum_{i=1}^{5} p_i \log_2 p_i$ Where P1 is the proportion of bare ground and turf grass; P2 the proportion of rough grassland and herbs; P3 the proportion of shrubs; P4 the proportion of trees and P5 is the proportion of the built environment.
Connectivity of Green Space/ Increasing / Positive Impact	Biodiversity / State	Fischer and Lindenmayer (2007)	Connectedness of ecological processes at multiple spatial scales (see Soule et al., 2004, for details). The connectedness of habitat for a particular species; the opposite of habitat isolation. A human perception of the connectedness of native vegetation cover in a landscape
		Gomez-Sal et al. (2003)	% area of the stands of connecting woodland
		Lenz and Beuttler (2003)	Habitat sites, qualities, distances & interconnectivity
		Mortberg et al. (2007)	Connectivity of Green Space
		Stork et al. (1997)	The number, size and/or shape of patches of a vegetation type may change. These changes may result in modifications in patch connectivity across the landscape. A frequency distribution of patch sizes can be used to examine the connectivity or fragmentation of habitat. The percolation index measures the connectedness of a landscape from one edge to the other.
		Termorshuizen et al. (2007)	A functional ecological connection between the ecosystems in the planning area

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Whitford et al. (2001)	Connectivity of Green Space is the inverse of the number of linkages which must be added to have a connected system and varies from 0 to 1. Forman (1995) defines this as: $\Gamma = \frac{number\_of\_linkages}{\max\_possible\_number\_of\_linkages}$ Where L equals the number of linkages and V equals the number of nodes.
		Zhang and Guindon (2006)	Urban green-land ratio
Tree Species Composition / Increasing / Positive Impact	Nature / State	Aguilar-Amuchastegui and Henebry (2006)	Tree cuts
		Foody (2003)	Populations of selected species
		Li (2004)	The species include those protected at international, national and local levels.
		Lopez-Ridaura et al. (2002)	Number of species grown, income per species
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land, classified by number of tree species occurring and by forest type. Tree species composition in forests.
Threatened Species / Decreasing / Positive Impact	Nature / State	Andriantiatsa-holiniaina et al. (2005)	Threatened plant, fish, mammal, bird, amphibian, and reptile species (percentage)
		Fischer and Lindenmayer (2007)	Degree of isolation between habitat patches used by a particular species
		Foody (2003)	Native vegetation clearing
		Gomez-Sal et al. (2003)	% birds in the endangered category

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Hiscock et al. (2003)	Habitats which are rare. Threatened endemic and globally threatened species. A number or a range of species have declined by more than 25% in the last 25 years. Species found in fewer than 1510x10 km squares around the UK.
		Jaeger et al. (2008)	Landscape fragmentation has a number of detrimental effects. In particular, it is a major cause of the dramatic decrease of many wildlife populations and of the increasing endangerment of species; lost species are almost impossible to reintroduce once their habitats have become unsuitable; therefore, this problem has a high priority and cannot be postponed.
		Kuo and Chiu (2006)	Threatened species as a percent of total native species
		Nader et al. (2008)	Threatened species
		Li (2004)	The population of rare, endangered and typical species
		Shi et al. (2005)	Global endemic species (%)
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land dominated by introduced tree species .
Landscape Diversity / Increasing / Positive Impact	Biodiversity / State	Fischer and Lindenmayer (2007)	Landscape diversity
		Gomez-Sal et al. (2003)	Landscape simplification after hypothetical expansion of the anthropic matrix
		Gough et al. (2008)	Ecosystem diversity
		Hiscock et al. (2003)	A high proportion of the habitat, or population of a species (at any time of its life cycle) occurs within the UK.

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Lenz and Beuttler (2003)	Ecosystem potential and diversity
		Piorr (2003)	Diversity / Edges / Shape
		Silva et al. (2006)	Landscape diversity
		Spilanis et al. (2009)	Diversity of land use (Shannon's index (H(b) =-Σpi/j x ln pi/j; where H(b) stands for limit diversity between different land use patches, pi/j stands for the percentage of the limit between neighboring patches i and j for the total number N of limits in the area), number, 1996).
		Van Brusselen and Schuck (2005)	Landscape diversity
Habitat Diversity / Increasing / Positive Impact	Biodiversity / State	Aguilar-Amuchastegui and Henebry (2006)	The change in the diversity of habitats as a result of human interventions is maintained within critical limits as defined by natural variation and/or regional conservation objectives.
		Fischer and Lindenmayer (2007)	The range of environments suitable for a particular species; A subdivision of habitat for a particular species
		Gomez-Sal et al. (2003)	No. of lithologies/km^2; Diversity of lithologies; Diversity of livestock
		Gough et al. (2008)	Species diversity
		Hiscock et al. (2003)	Habitat diversity
		Jaeger et al. (2008)	Habitat sizes of viable populations
		Kuo and Chiu (2006)	Wild population numbers of target species
		Lenz and Beuttler (2003)	Habitat sites, distances & interconnectivity

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		McGinley and Finegan (2003)	The diversity of selected indicator groups of butterflies. Changes in the diversity of habitats as a result of human interventions are monitored to determine their direction, magnitude and importance, and the necessity to take corrective actions
		Mortberg et al. (2007)	Habitat diversity
		Piorr (2003)	Habitat/biotope diversity
		Scipioni et al. (2009)	Habitable space
		Stork et al. (1997)	Changes in habitat diversity as a result of human interventions should be maintained within critical limits.
		Van Brusselen and Schuck (2005)	A state of 10 main EUNIS habitats types per biogeographic region and per country; A change of 10 main EUNIS habitats types per biogeographic region and per country; Habitat diversity in designated areas
		Van Cauwenbergh et al. (2007)	Diversity of habitats is maintained or increased
Fragmentation of Ecosystems & Habitats / Decreasing / Positive Impact	Biodiversity / Response	Fischer and Lindenmayer (2007)	Fragmented landscape
		Foody (2003)	Loss of biodiversity
		Gomez-Sal et al. (2003)	Landscape fragmentation by infrastructures (no. of fragments)
		Hiscock et al. (2003)	Fragmentation of habitats
		Jaeger et al. (2008)	Landscape fragmentation is an important issue. meff provides an answer to the question of what the degree of landscape fragmentation is.
		Piorr (2003)	Fragmentation indices; Habitat/biotope fragmentation

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Stork et al. (1997)	When a forest becomes fragmented, there is a change in the spatial mosaic of the forest.
		Van Brusselen and Schuck (2005)	Fragmentation of ecosystems and habitats by transport infrastructure
		Verboom et al. (2007)	Fragmentation by roads and other land-use types has led to many small natural areas as 'islands' in a 'sea' of non-natural land-use types. Fragmentation leads to loss of biodiversity as populations become too small for long-term viability.
		Zhang and Guindon (2006)	Forest fragmentation index
Degradation of Habitats/ Decreasing / Positive Impact	Biodiversity / Response	Fischer and Lindenmayer (2007)	Degree of isolation between habitat patches used by a particular species; opposite of habitat connectivity
		Foody (2003)	Aquatic habitat destruction
		Hiscock et al. (2003)	Habitats at risk, such as those with a high rate of decline especially over the past 20 years. The significant decline in numbers, extent or quality of a species of habitat.
		Jaeger et al. (2008)	Scarcity of the goods
		Kuo and Chiu (2006)	Ratios of important habitats under irreversible destruction
		Lopez-Ridaura et al. (2002)	High degradation of natural resources
		Piorr (2003)	Change of biotopes and habitats
		Russell and Thomson (2009)	A legacy of social and ecological degradation

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Spilanis et al. (2009)	Environmentally Sensitive Areas to desertification (ESAI) ESAI = (SQI*CQI*VQI*MQI)1/4; where SQI stands for a quality indicator of soil, CQI for climate, VQI for vegetation and MQI for management, 8 classes: 3 critical; 3 sensitive; 1 possible and 1 neutral. (Kosmas et al., 1999) it expresses desertified area/total area (%, 1996);
		Troyer (2002)	Degradation of habitats
Habitat Quality / Increasing / Positive Impact	Biodiversity / State	Barrios et al. (2006)	Good plants, good crop, healthy looking, thick/bad plants
		Hiscock et al. (2003)	Habitat quality
		Kuo and Chiu (2006)	Habitat quality index
		Lenz and Beuttler (2003)	Habitat qualities
		Mortberg et al. (2007)	Habitat quality
		Piorr (2003)	Habitat/biotope quality
		Russell and Thomson (2009)	Clean air, land and water
		Termorshuizen et al. (2007)	The habitat quality is taken into account in the planning process. The (planned) habitat quality is appropriate for the conservation targets. The habitat quality is taken into account to calculate the quantitative spatial conditions that have to be realized.
		Van Cauwenbergh et al. (2007)	Functional quality of habitats is maintained or increased

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Richness & Composition/ Increasing / Positive Impact	Biodiversity / State	Gomez-Sal et al. (2003)	Mean richness in birds; Richness in endangered birds; Richness of crops
		Stork et al. (1997)	The richness/diversity of selected groups shows no significant change
		Van Brusselen and Schuck (2005)	Species richness by main 10 main EUNIS habitats types
		Verboom et al. (2007)	Species richness
Restoration / Increasing / Positive Impact	Biodiversity / Response	Li (2004)	The cost for repairing facilities and ecosystem restoration
		Olsen (2003)	Restoration of lost qualities.
		Piorr (2003)	Length of “green” linear landscape features maintained and/or restored by farmers
		Van Brusselen and Schuck (2005)	Restoration
Exotics / Decreasing / Positive Impact	Biodiversity / State	Kuo and Chiu (2006)	Distribution of exotic species
		Stork et al. (1997)	Introduction of exotic
Diversity Index of Terrestrial Fauna / Increasing / Positive Impact	Biodiversity / State	Andriantiatsa-holiniaina et al. (2005)	Endangered Species (CITES) of Wild Fauna
		Kuo and Chiu (2006)	The diversity index of the terrestrial fauna; The diversity index of the aquatic fauna
		McGinley and Finegan (2003)	Diversity index of the terrestrial fauna (Aguilar-Amuchastegui et al. (2000))
		Piorr (2003)	Diversity indices
		Nijkamp and Vindigni (2003)	Fauna

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Diversity Index of Terrestrial Flora / Increasing / Positive Impact	Biodiver-sity / State	Andriantiatsa-holiniaina et al. (2005)	Endangered Species (CITES) of the Wild and Flora
		Kuo and Chiu (2006)	The diversity index of the terrestrial flora
		Lopez-Ridaura et al. (2002)	Surveys of flora
		Piorr (2003)	Diversity indices
		Nijkamp and Vindigni (2003)	Flora
Sustainable Communities / Increasing / Positive Impact	Biodiver-sity / State	Russell and Thomson (2009)	Sustainable communities
		Spangenberg (2002)	Sustainable forestry or fishing. Cultivation sets some framework conditions and uses the natural regulation mechanisms to produce the harvest.
		Stork et al. (1997)	Community guild structures do not show significant changes in the representation of especially sensitive guilds, and pollinator and disperser guilds
Biological Resources Use / Decreasing / Positive Impact	Biodiver-sity / State	Bohringer and Loschel (2006)	Decoupling economic growth & resource use; Resource consumption
		Huang et al. (2009)	Biological Resources
		Hutchins and Sutherland (2008)	Resource Use
		Lopez-Ridaura et al. (2002)	Use of external resources
		Olsen (2003)	Resources
		Palme et al. (2005)	Resources
		Piorr (2003)	Biological resources use
		Russell and Thomson (2009)	Resource consumption; The best use of finite resources
		Spangenberg (2002)	Resources

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Troyer (2002)	Resource consumption of population's total size
		Van Cauwenbergh et al. (2007)	Supply (stock) of biotic resources function; Biotic resource flow buffering function
Resource Depletion / Decreasing / Positive Impact	Biodiver-sity / Response	Azapagic (2003)	The rate of non-renewable and renewable resource depletion relative to the total world=regional reserves (%); Sales and resource depletion
		Lopez-Ridaura et al. (2002)	High degradation of natural resources
		Sarda et al. (2005)	Resource exploitation
		Spangenberg (2002)	Resource depletion
Biodiversity Loss / Decreasing / Positive Impact	Biodiver-sity / Response	Azapagic (2003)	Loss of biodiversity (e.g. rate of loss of a certain species in a certain region or globally) (% or number)
		Foody (2003)	Loss of biodiversity
		Piorr (2003)	Loss of biodiversity
		Russell and Thomson (2009)	Biodiversity loss
		Stork et al. (1997)	Biodiversity loss
		Verboom et al. (2007)	Biodiversity Loss
Ecosystem Quality / Decreasing / Positive Impact	Biodiver-sity / State	Fahy and Cinneide (2008)	Quality of green areas
		Hiscock et al. (2003)	Ecological significance
		Hutchins and Sutherland (2008)	Ecosystem quality
		Ko (2005)	Ecosystem quality
		Kuo and Chiu (2006)	Environmental quality of local community
		Russell and Thomson (2009)	Clean air, land and water

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Salvati and Zitti (2009)	Vegetation quality
		Sarda et al. (2005)	Beach quality
		Termorshuizen et al. (2007)	The spatial conditions of the ecosystems in adjacent areas are known and (in combination with the conditions in the planning area) appropriate for the conservation targets.
		Yuan et al. (2003)	Environment quality
Spatial Population Distribution / Increasing / Positive Impact	Biodiversity / State	Boer and Puigdefabregas (2005)	Spatial patterns
		Hiscock et al. (2003)	Species where the UK has more than 25% of the world or the appropriate biographical population.
		Jaeger et al. (2008)	Spatial and temporal range
		Li (2004)	The population of rare, endangered and typical species (Population)
		McGinley and Finegan (2003)	Class size distribution
		Nader et al. (2008)	Spatial population distribution
		Stork et al. (1997)	Population sizes and demographic structures of selected species do not show significant changes, and demographically and ecologically critical life-cycle stages continue to be represented
		Termorshuizen et al. (2007)	Spatial information on target species is used to determine which spatial conditions have to be realized.
		Van Brusselen and Schuck (2005)	Landscape-level spatial pattern of forest cover

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Zhang and Guindon (2006)	Spatial patterns and structure
Maintaining the Carrying Capacity / Increasing / Positive Impact	Biodiversity / Response	Bohringer and Loschel (2006)	Maintaining the carrying capacity
		Li (2004)	Spatial carrying capacity

A.3.5 EN5 – Environmental – Climate / Energy

Table A.3.5: EN5 – Environmental – Climate / Energy

Indicator / Trend / Sustainability	Theme / Pressure-State-Response (PSR)	Authors	Description
Climate & Weather / Decreasing / Positive Impact	Climate & Energy / State	Bland and Bell (2007)	Atmosphere and Precipitation
		Parr et al. (2003)	Climate Change
		Piorr (2003)	Climate & Weather
		Russell and Thomson (2009)	Global climate change; Extreme weather
		Salvati and Zitti (2009)	Climate quality (CLI); Aridity index (ARI)
		Van Brusselen and Schuck (2005)	Snow cover; Permafrost

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Van Delden et al. (2007)	Simulates spatially distributed sub-hourly rainfall storms (calculated in variable ‘bucket-tip’ time steps), daily solar radiation, time of sunrise, time of sunset, and monthly air temperature, based on historic rainfall and temperature data from one or more Automatic Weather Stations and the position of the sun. Distance to the sea and elevation is additional factors in descaling general circulation model and meteorological station data to the 1 ha grid. Temperature and precipitation have corrected over time for climate change in the region as calculated by the HADCM2, GFDL or ECHAM4 Global Circulation Models. Scenarios can be chosen and adapted by the user (Mulligan, 1996 (a,b); Mulligan and Reaney, 2000).
		Verboom et al. (2007)	Climate change is starting to affect biodiversity and is expected to cause a significant biodiversity loss in the near future (Thomas et al., 2004; Pearson et al., 2002).

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Whitford et al. (2001)	Climate indicator, it is chosen to develop and customize the model of urban climate developed by Tso (1991). The model proceeds by expressing the surface energy balance of an area in terms of its surface temperature, T_0, and linearizing any non-linear equations to enable a set of simultaneous equations to be produced. It proceeds from the simple instantaneous energy balance equation: $R = H + LE + G + J$ R is the net radiation flux to the earth's surface; H is the sensible heat flux due to convection and LE is the latent heat flux due to evaporation; G is the conductive heat flux into the soil, through the intermediate layer, s, to the lower layer, b, which is assumed to have a constant temperature T_b; J is the heat flux to storage in concrete and other built environment.
Energy Use / Decreasing / Positive Impact	Climate & Energy / Pressure	Azapagic (2003)	The amount of energy used (MJ/yr)
		Bohringer and Loschel (2006)	Energy efficiency
		Carvalho et al. (2008)	Energy use
		Learmonth et al. (2007)	Physical energy use $FUEL_l = \sum_i \varepsilon_{i,l} Q_i + \sum_z \varepsilon_{z,l} C_z$
		Makropoulos et al. (2008)	Energy use
		Palme et al. (2005)	Energy used
		Van Cauwenbergh et al. (2007)	Energy use

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Environment & Energy Consumption / Decreasing / Positive Impact	Climate & Energy / Pressure	Bohringer and Loschel (2006)	Air emission and energy
		Huang et al. (2009)	Environment and energy consumption
		Hutchins and Sutherland (2008)	Energy consumption
		Kuo and Chiu (2006)	Total energy consumption of accommodation
		Lenz and Beuttler (2003)	Energy requirement
		Nader et al. (2008)	Annual energy consumption per household
		Russell and Thomson (2009)	Secure prosperity with less energy
		Salter et al. (2009)	Energy consumption
		Van Cauwenbergh et al. (2007)	Energy flow is adequately buffered
		Zhang and Guindon (2006)	Energy Consumption
Electrical Energy Consumption / Decreasing / Positive Impact	Climate & Energy / Pressure	Kuo and Chiu (2006)	Total electricity consumption
		Li (2004)	Electricity-supplying capacity (kw h/day); Daily electricity consumption/visitors (Annual average and peak period average) (kw h/person)
		Nader et al. (2008)	Household access to electricity networks; Number of electrical generators; The number of electricity distribution stations
		Palme et al. (2005)	Electricity; % of total use of electricity
		Russell and Thomson (2009)	% of electricity consumed

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Sarda et al. (2005)	Energy consumption (electricity)
		Scipioni et al. (2009)	Electrical energy consumption
Renewable Energy / Increasing / Positive Impact	Climate & Energy / Response	Andriantiatsa-holiniaina et al. (2005)	Increasing energy sources, such as wind, solar, geothermal and hydroelectric, improve land sustainability. Maximizing clean electricity production improves air quality.
		Bohringer and Loschel (2006)	Renewable energy resources
		Lenz and Beuttler (2003)	Energy substitution potential
		Nader et al. (2008)	Number of households using solar energy; Solar energy consumption
		Palme et al. (2005)	The energy recovered
		Russell and Thomson (2009)	Larger % of electricity consumed that is generated from renewable sources; Renewable energy
Annual Rainfall / Increasing / Positive Impact	Climate & Energy / State	Bland and Bell (2007)	Atmosphere and Precipitation
		Boer and Puigdefabregas (2005)	Rainfall
		Piorr (2003)	Rainfall
		Salvati and Zitti (2009)	Average annual rainfall; Rainfall variability; Rainfall concentration; Number of rainy days
		Scipioni et al. (2009)	Annual rainfall
Average Humidity / Decreasing / Positive Impact	Climate & Energy / State	Scipioni et al. (2009)	Average humidity (%)

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
Contribution to Global Warming / Decreasing / Positive Impact	Climate & Energy / Response	Azapagic (2003)	Contribution to global warming (kg/yr or t/yr CO_2 equivalent)
		Lenz and Beuttler (2003)	Global Warming - up potential / CO_2 emission
Sustainable Use of Renewables / Increasing / Positive Impact	Climate & Energy / Response	Bland and Bell (2007)	Renewable human inputs
		Bohringer and Loschel (2006)	Renewable energy resources
		Korhonen (2007a)	Substituting for natural resources, increasing materials and energy efficiency, is reducing waste and emissions
		Kuo and Chiu (2006)	Ratios of reuse
		Russell and Thomson (2009)	Fewer greenhouse gas emissions (net); Larger % of electricity consumed that is generated from renewable sources; % of electricity consumed that is generated from renewable sources; Use renewable materials and replenish resources
		Spilanis et al. (2009)	Renewable/conventional energy produced
		Troyer (2002)	Availability of non-renewable natural resources

A.3.6 **EN6 – Environmental – Nature**

Table A.3.6: EN6 – Environmental – Nature

Indicator / Trend / Sustainability	**Theme / Pressure-State-Response (PSR)**	**Authors**	**Description**
Carbon Fluxation / Decreasing / Positive Impact	Nature / Pressure	Gough et al. (2008)	Carbon cycle
		Huang et al. (2009)	% of CO_2 emission
		Hutchins and Sutherland (2008)	% of CO_2 emission
		Russell and Thomson (2009)	Low carbon economy
		Salvati and Zitti (2009)	Organic Carbon Content (CAR)
		Scipioni et al. (2009)	Carbon monoxide (CO)
		Van Brusselen and Schuck (2005)	Carbon stock of woody biomass and of soils of forest and other wooded land ; Net carbon uptake terrestrial biosphere
		Whitford et al. (2001)	A method is provided whereby the carbon stored and sequestered annually per unit area of tree crown can be easily estimated: carbon storage (tonnes ha^{-1}) = =1.063 x % tree cover carbon sequestration (tones ha^{-1} per year) = = 8.275×10^{-3} x % tree cover
Total Area of Green Space / Increasing / Positive Impact	Nature / State	Fahy and Cinneide (2008)	Perceptions of green areas
		Hiscock et al. (2003)	Areas important for rare species.
		Huang et al. (2009)	Green coverage ratio
		Nader et al. (2008)	Green area cover
		Piorr (2003)	Length of “green” linear landscape features maintained by farmers

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Saifi and Drake (2008a)	Lea and green fodder area
		Termorshuizen et al. (2007)	The planned configuration and area of nature are appropriate for the ambition level.
		Whitford et al. (2001)	Total area of green space captures the essence of the idea that patch size is important for biodiversity, and fits in with the evidence (Savard and Fall, 1991) that urban bird diversity increases with the extent of green space.
Natural Process / Increasing / Positive Impact	Nature / State	Fischer and Lindenmayer (2007)	Ecological processes
		Hiscock et al. (2003)	Ecological processes
		Lopez-Ridaura et al. (2002)	Coffee marketing process
		Spangenberg (2002)	Natural regulation processes
		Stork et al. (1997)	Ecological processes such as reproduction, predator-prey relationships and nutrient cycling (Primack, 1993). Trophic dynamic processes refer to the ways that species from different trophic levels interact. These include pollination, predation and herbivore. As each trophic level is dependent on other levels, impacts on trophic dynamics can be very serious.
		Van Delden et al. (2007)	The processes of biomass growth as well as the resource partitioning of crops and natural vegetation.
		Whitford et al. (2001)	Natural Process
		Zhang and Guindon (2006)	The modeled processes involved derivation from geospatial data

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Forest Area / Increasing / Positive Impact	Nature / State	Andriantiatsa-holiniaina et al. (2005)	Current forest (percent of original)
		Aguilar-Amuchastegui and Henebry (2006)	Forest canopy
		Bohringer and Loschel (2006)	Forests
		Foody (2003)	Forest environments
		Gomez-Sal et al. (2003)	% slope >12o with forest covering; % remnant forest vegetation after hypothetical expansion of the anthropic matrix; No. of woody crops; % area woody crops; % area forest
		Gough et al. (2008)	Forest community well-being and resilience
		McGinley and Finegan (2003)	Classification of forest species according of the forest use ((INAFOR (2000a); INAFOR (2000b))). The vertical structure of the forest (CIFOR C&I Team (1999)).
		Nader et al. (2008)	Forest area
		Nijkamp and Vindigni (2003)	Forest area
		Pulido and Bocco (2003)	Forest area
		Salvati and Zitti (2009)	Woodland cover (WOO)
		Shi et al. (2005)	Forest area
		Silva et al. (2006)	Tropical rain forest; Semi-evergreen seasonal forest; Semi-deciduous seasonal forest
		Stork et al. (1997)	Forest area

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land, classified by forest type and by availability for wood supply, and the share of forest and other wooded land in total land area .
		Van Delden et al. (2007)	Forested area
		Wijewardana (2008)	Forest area
		Zellner et al. (2008)	Forest covers
		Zhang and Guindon (2006)	Forest patch characteristics
Forest Damage / Decreasing / Positive Impact	Nature / Response	Andriantiatsa-holiniaina et al. (2005)	Average annual increase or decrease (if negative) of forest cover between 1990 and 1995. Because current forest (6) is less than 100% for all countries, a positive forest change improves land sustainability and biodiversity.
		Kuo and Chiu (2006)	The rate of afforestation
		Piorr (2003)	Change in forest areas; Extensification rate; Intensification rate; Afforestation rate
		Van Brusselen and Schuck (2005)	Forest and other wooded land with damage, classified by the primary damaging agent (abiotic, biotic and human induced) and by forest type.
Protected Forest / Increasing / Positive Impact	Nature / Response	Andriantiatsa-holiniaina et al. (2005)	Forest areas that fall within the protected areas.
		Kuo and Chiu (2006)	Percent of protected forest

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		McGinley and Finegan (2003)	Rare, threatened and endangered forest species and their habitats are protected. Monitoring and Evaluation: Forest condition, forest product yield, chain of custody and the social and environmental impacts of management activities will be monitored and evaluated in ways appropriate to the scale of forest management.
		Nader et al. (2008)	Forest protection rate
		Shi et al. (2005)	Protected forest
		Spangenberg (2002)	Nature reserves and other protected or unused areas, humans harvesting a share of the yield from natural regulation, like small scale forest dwellers or hunters and gatherers.
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land protected to conserve biodiversity, landscapes and specific natural elements.
		Van Delden et al. (2007)	Preservation of nature and forests
Regeneration / Increasing / Positive Impact	Nature / Response	Foody (2003)	Area revegetated
		Stork et al. (1997)	Reproduction; Regeneration; Succession
		Van Brusselen and Schuck (2005)	Area of regeneration within even-aged stands and uneven-aged stands, classified by regeneration type.
Deadwood / Decreasing / Positive Impact	Nature / Response	Stork et al. (1997)	Standing and fallen dead wood. State of decay of dead wood.
		Van Brusselen and Schuck (2005)	Volume of standing deadwood and of lying deadwood on forest and other wooded land classified by forest type.

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Natural Environment / Increasing / Positive Impact	Nature / State	Gomez-Sal et al. (2003)	% area natural
		Hiscock et al. (2003)	The area contains examples of habitats/biotope types, habitat complexes, species, ecological processes or other natural characteristics that are typical and representative. The area has a high degree of naturalness and ecosystems, habitats and species are still in a very natural state as a result of the lack of human-induced disturbance or degradation.
		Huang et al. (2009)	Natural environment
		Li (2004)	Natural environment
		Parr et al. (2003)	Measures of environmental information
		Piorr (2003)	Naturalness
		Russell and Thomson (2009)	Unimpaired environment; Nature as an asset
		Sarda et al. (2005)	Natural area in the municipality
		Scipioni et al. (2009)	Nature balance
		Scipioni et al. (2008)	Environment
		Spangenberg (2002)	Environmental space use; Nature; Natural capital
		Termorshuizen et al. (2007)	The (planned) abiotic conditions are appropriate for the nature conservation targets.
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land, classified by “undisturbed by man”, by “semi-natural” or by “plantations”, each by forest type.
		Van Delden et al. (2007)	Natural Vegetation (monthly, 1 ha)
		Zellner et al. (2008)	Natural features; Distance to natural areas

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Nature Conservation / Increasing / Positive Impact	Nature / Response	Aguilar-Amuchastegui and Henebry (2006)	The change in the diversity of habitats as a result of human interventions is maintained within critical limits as defined by natural variation and/or regional conservation objectives.
		Foody (2003)	Conservation
		Hiscock et al. (2003)	Conservation of biological diversity; Improving marine conservation in the UK
		McGinley and Finegan (2003)	Stratification of the managed forest is carried out with the objective of determining areas for production, protection and conservation (INAFOR (2000a); INAFOR (2000b)).
		Lenz and Beuttler (2003)	Nature conservation
		Lopez-Ridaura et al. (2002)	Conservation of resources
		Olsen (2003)	Improving marine conservation in the UK
		Piorr (2003)	Nature conservation areas
		Silva et al. (2006)	Conservation
		Termorshuizen et al. (2007)	Targets of the higher administrative levels are used for choosing nature conservation targets in the planning area. The (planned) abiotic conditions are appropriate for the nature conservation targets.
		Van Delden et al. (2007)	Preservation of nature and forests
Changes in Natural Vegetation Type Groups / Decreasing / Positive Impact	Nature / State	Aguilar-Amuchastegui and Henebry (2006)	Wide dynamic range vegetation index
		Barrios et al. (2006)	Vegetation type

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Boer and Puigdefabregas (2005)	Vegetation covers
		Fischer and Lindenmayer (2007)	Following McIntyre & Hobbs (1999), a landscape is characterized by sharp boundaries between a minimal amount of remnant native vegetation (< 10%) and is surrounded by modified land; often seen in areas with intensive agriculture Variegated landscape. Following McIntyre & Hobbs (1999), a landscape is characterized by gradual boundaries between native vegetation and is surrounded by modified land (native vegetation cover typically c. 60–90%); often seen in areas with extensive livestock grazing.
		Foody (2003)	Native vegetation clearing
		Gomez-Sal et al. (2003)	% riparian environment covered by vegetation; Local mean no. of patches with different natural or semi-natural vegetation; Local mean no. of types of natural or semi-natural vegetation
		Jaeger et al. (2008)	Responds rapidly to change: the indicator responds rapidly to changed conditions. Spatial and temporal range: the indicator is applicable to a large spatial range and over a long time in the past and in the future.
		Kuo and Chiu (2006)	The extent of change in vegetation
		McGinley and Finegan (2003)	The extent of change in vegetation (CIFOR C&I Team, 1999)
		Parr et al. (2003)	Broad-scale environmental change
		Piorr (2003)	Change of broad, semi-natural and natural habitats / biotopes
		Shi et al. (2005)	Vegetation

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Silva et al. (2006)	Scrubland (caatinga); Other types of vegetation
		Stork et al. (1997)	In some cases the dominant process determining change in species composition may be local extinction. For example, in a system characterized by small patches of a particular vegetation type, the loss of a patch and the ensuing local extinction of a species dependent on that vegetation type result in a more broad-scale extinction (Lomolino, 1996).
		Van Delden et al. (2007)	Changes in natural vegetation type groups
Cultural & Natural Heritages under Protection/ Increasing / Positive Impact	Nature / Response	Andriantiatsa-holiniaina et al. (2005)	Totally or partially protected area of at least 1000 ha that are designated as national parks, natural monuments, nature reserves, wildlife sanctuaries, protected landscapes and seascapes, or scientific reserves with limited public access to secure land sustainability and environmental functions such as carbon and waste assimilation.
		Bohringer and Loschel (2006)	Protection of habitats and natural systems and biodiversity
		Foody (2003)	Terrestrial protected areas
		Gomez-Sal et al. (2003)	% catalogued as a protected natural area; Heritage: architecture, arts and crafts, infrastructures, knowledge, cultural landscape, etc.
		Hiscock et al. (2003)	Species for which the UK has international obligations or which are protected under UK legislation.
		Kuo and Chiu (2006)	Ratios of cultural heritages under protection; Contribution to traditional culture protection

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Lenz and Beuttler (2003)	Natural heritages under protection
		Li (2004)	Measures taken for environmental protection (all-year) (Measures)
		Olsen (2003)	Construction and maintenance of shoreline protection work.
		Russell and Thomson (2009)	Respecting and protecting the natural heritage and resources; Maintain the cultural inheritance and diversity
		Sarda et al. (2005)	Coastal protection index
		Spangenberg (2002)	Protected reserves
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land designated to protect infrastructure and managed natural resources against natural hazards
		Van Cauwenbergh et al. (2007)	Cultural, spiritual and aesthetic heritage value features are maintained or increased
		Yuan et al. (2003)	A measure of wetland protection and other activities in the Chongming Eco-county
Management of Ecosystems / Increasing / Positive Impact	Nature / Response	Aguilar-Amuchastegui and Henebry (2006)	Sustainable management
		Bohringer and Loschel (2006)	Management of natural resources
		Foody (2003)	Management of terrestrial areas
		Hiscock et al. (2003)	Integrated management
		Gomez-Sal et al. (2003)	No. of types of hill country management
		Jaeger et al. (2008)	Management of Ecosystems
		Ko (2005)	Environmental Policy and Management
		Li (2004)	The existence of regular environmental monitor (Yes/No)

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		McGinley and Finegan (2003)	Forest management will promote the conservation of biological diversity and its associated water and soil resources. Measures exist to control hunting, capture and collection of plant and animal species. The management of ecosystems is taken into account in the planning process. (CNCF, 1999). The changes produced in the ecosystem by forest management operations are evaluated. Results from monitoring and evaluation are used to improve the management system.
		Olsen (2003)	Within the user groups that will be most affected by the integrated coastal management program.
		Piorr (2003)	Landscape management
		Stork et al. (1997)	Management of ecosystem processes
		Termorshuizen et al. (2007)	The management of ecosystems (including physical development) is taken into account in the planning process. The (planned) management of ecosystems (including physical development) is consistent with the required habitat for the conservation targets.
		Van Brusselen and Schuck (2005)	An area of forest and other wooded land designated to prevent soil erosion, to preserve water resources, or to maintain other forest ecosystem functions
		Van Delden et al. (2007)	Land Management
Burning / Decreasing / Positive Impact	Nature / Pressure	Foody (2003)	Fire regimes
		Nader et al. (2008)	Burnt forest area
		Spilanis et al. (2009)	Burnt area per land use / total area

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
		Stork et al. (1997)	Burning is also common, especially in drier forests. This intervention involves changes to natural fire regimes, including the frequency, intensity or extent of the fires.
Logging / Decreasing / Positive Impact	Nature / Pressure	Andriantiatsa-holiniaina et al. (2005)	Logging
		Stork et al. (1997)	Selective logging is the most common form of intervention in tropical forests. In the context of C&I it includes all associated infrastructure such as skid trails, roads, river landings, etc.).
Ecosystem Sustainability / Increasing / Positive Impact	Nature / Response	Lenz and Beuttler (2003)	Sustainability of groundwater usage
		Prato (2005)	Ecosystem sustainability
		Olsen (2003)	Sustain fresh water inflows to estuaries.
		Van Delden et al. (2007)	Sustainable land use in the region
Loss of Ecological Functions or Services/ Decreasing / Positive Impact	Nature / Response	Fischer and Lindenmayer (2007)	Loss of habitat for a particular species
		Foody (2003)	Extent of aquatic habitats; Extent of native vegetation
		Hiscock et al. (2003)	Habitat restricted to a limited number of locations. A species that is sessile or of restricted mobility at any time of its life cycle is assessed as being rare.
		Jaeger et al. (2008)	Loss of ecological functions or services
		Piorr (2003)	Loss of biodiversity, decreases of environmental damages
		Russell and Thomson (2009)	Loss of landscape

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Stork et al. (1997)	Some human interventions cause a direct loss of species which act as mediators because the loss of these species can cause the loss of other species (e.g., loss of obligate pollinators).
		Troyer (2002)	Loss of ecological functions or services
Eco-justice / Increasing / Positive Impact	Nature / Response	Nader et al. (2008)	Complaints concerning environmental issues; Methods of complaining about environmental issues
		Russell and Thomson (2009)	Eco-justice
Environmental Health / Increasing / Positive Impact	Nature / State	Barrios et al. (2006)	Healthy looking, thick/bad plants
		Scipioni et al. (2008)	Environmental health
		Spangenberg (2002)	Environmental health problems
		Van Brusselen and Schuck (2005)	Forest Ecosystem Health
Environmental Impact / Decreasing / Positive Impact	Nature / Pressure	Goncalves et al. (2009)	Environmental impacts
		Ko (2005)	Central environmental impact
		Kuo and Chiu (2006)	Serious impacts to environmentally sensitive areas
		Lenz and Beuttler (2003)	Impact on landscape scenery
		Li (2004)	The existence of environmental impact assessment (EIA) procedure for every new tour project (Yes/No)
		Makropoulos et al. (2008)	Environmental impact
		Nader et al. (2008)	Projects undergoing environmental impact assessment
		Parr et al. (2003)	Climate Change Impact
		Piorr (2003)	Environmental impact

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
		Russell and Thomson (2009)	Global impacts of local action
Environmental Alienation / Decreasing / Positive Impact	Nature / Pressure	Hiscock et al. (2003)	A very sensitive habitat or species are one that is very easily adversely affected by external factors arising from human activities, and is expected to recover only over a very long period, or not at all. A sensitive habitat or species is one that is easily adversely affected by a human activity, and is expected to only recover over a long period.
		Huang et al. (2009)	Environmental alienation
		Parr et al. (2003)	Measures of environmental information
		Russell and Thomson (2009)	Live within environmental limits
		Scipioni et al. (2008)	Environmental alienation
Environmental Laws / Increasing / Positive Impact	Nature / Response	Andriantiatsa-holiniaina et al. (2005)	Environmental laws and enforcement
		Hiscock et al. (2003)	Species for which the UK has international obligations or which are protected under UK legislation.
		Ko (2005)	Environmental Policy and Management
		Nader et al. (2008)	Implementation of environmental laws at the municipal level
		Olsen (2003)	A law, decree or other high level administration decision creating an integrated coastal management program as a permanent feature of the governance structure.
		Scipioni et al. (2008)	Environmental laws
		Spangenberg (2002)	Sustainable forestry or fishing. Cultivation sets some framework conditions and uses the natural regulation mechanisms to produce the harvest.

Indicator / Trend / Sustainability	**Theme / (PSR)**	**Authors**	**Description**
"Ecological Networks" / Increasing / Positive Impact	Nature / State	Jaeger et al. (2008)	"Ecological networks"
		Kuo and Chiu (2006)	Ratios of ecological coordinators increase
		Silva et al. (2006)	Ecological Units
		Termorshuizen et al. (2007)	"Ecological networks" is used as a spatial concept.
Plant Growth / Increasing / Positive Impact	Nature / Response	Stork et al. (1997)	Area of mature or "old-growth" forest.
		Van Delden et al. (2007)	Restricted factor for plant growth (yes/no); Represents the processes of biomass growth as well as the resource partitioning of crops and natural vegetation. It calculates plant structural properties (biomass, leaf area index, vegetation cover fraction) as well as their yields (Mulligan and Reaney, 2000).
Elimination of Over-Harvesting / Increasing / Positive Impact	Nature / Response	Aguilar-Amuchastegui and Henebry (2006)	Harvest intensity
		McGinley and Finegan (2003)	Measures exist for the protection of rare, threatened, and endangered tree species, as well as those whose harvesting is restricted or prohibited, and for the protection of the characteristics of their habitats.
		Olsen (2003)	Elimination of destructive fishing practices and over-harvesting. Halting or slowing undesired trends such as overfishing, sand and coral mining, eutrophication.
		Saifi and Drake (2008a)	Harvesting
		Spangenberg (2002)	Humans harvesting a share of the yield from natural regulation

Indicator / Trend / Sustainability	Theme / (PSR)	Authors	Description
Sustainable Use of Environmental Resources / Increasing / Positive Impact	Nature / Response	Aguilar-Amuchastegui and Henebry (2006)	Sustainable management
		Foody (2003)	Monitoring of environmental resources for sustainable development
		Hiscock et al. (2003)	Pressing for sustainability
		Spangenberg (2002)	Sustainable forestry or fishing. Cultivation sets some framework conditions and uses the natural regulation mechanisms to produce the harvest.

APPENDIX 4 - INDICATORS OF SUSTAINABLE TRANSPORTATION

Summary

Generally, the current paper is a literature review of the following topics:

1. History of Environmental economics is highlighting the views of classical and neoclassical Economists;
2. History and definitions for Sustainable Development by referring to the equity issues and transportation impacts on sustainability;
3. Introduction to Urban Transportation reviewing the factors influencing urban behavior, the comparison of traditional transportation planning with sustainable development orientations, urban activity and transportation Interaction, various models, first described the procedural steps by a decision maker, the linkage between transportation planning and stages of decision making, economic valuation methods etc.
4. Sustainability Indicators analyzing the objectives-led structure for strategy formulation, suggested indicators for different transport policy objectives, simple and comprehensive sustainable transportation indicators, defined 26 variables and the matrix of interrelations between each other, the society indicator (I_9) with respect to relatively global weight W_9 out of 10 general indicators.
5. Some suggestions are provided for the future work considering the case study (Greece).

A.4.1 History of Environmental Economics

According to Wonnacott and Wonnacott (1979):
“Economics is the study of how people make their living, how they acquire the food, shelter, clothing, and other material necessities and comforts of this world. It is a study of the problems they encounter, and of the ways in which these problems can be reduced. “

Economics is a social science concerned with how people, either independently or in groups, try to accommodate limited resources to their needs through the processes of production, distribution, substitution, consumption and exchange (Gilpin, 2000).

Inter-linkages between the economy and the natural environment are all-embracing; every economic action can have some effect on the environment, and every environmental variation can have an impact on the economy. By “the economy”, the authors refer to the population by economic means, institutions including firms and governments and the inter-linkages between means and institutions, such as markets. By “environment”, the authors mean the biosphere to quote from Nisbet (1991), the atmosphere, the geosphere and all flora and fauna. The authors' definition of the environment thus contains life forms, energy and material resources, the stratosphere and the troposphere. These components of the environment interact with each other. The effects of human activity on the environment, and the consequences of these influences on human well-being are important for Hanley et al. (2002).

The father of classical economics is considered Adam Smith (1723-1790). He entitled his great work, as *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776). John Stuart Mill (1806-1873) in his *Principles of Political Economy* (1848) defined economics as "the practical science of the production and distribution of wealth". Smith was the first of a group of classical economists. Other well-known classical economists were Thomas Malthus (1766-1834), David Ricardo (1772-1823) and John Stuart Mill (1806-1873). These classical economists were much concerned with "environmental questions", in that they were attracted in the consequences for the long-run development of the material standard of living off the fact that nature cannot provide humans with limitless amounts of good quality land from which to win the "necessities and comforts of this world" (Common, 1996).

As Malthus (1798) referred, the classic story was that while the living standards of the mass of the population might rise temporarily, the long-run tendency must always be for the wages of workers to be driven down to subsistence level. This occurs because Malthus assumed the availability of a fixed amount of land. Due to the growth of population, the operation of diminishing returns lessens the per-capita food supply. Population' intensification stops when the reduction brings the food supply down to subsistence level. Ricardo (1817) concentrated on a wide range of matters than Malthus and tried to offer a wide-ranging theory of how the whole economic system worked. Ricardo's analysis was also subtler than that of Malthus. However, the essential conclusion was basically the same as that of Malthus. It was that the economy was "inevitably on its way to meet poverty for most people" (Samuelson and Nordhaus, 1985). The source of the conclusion was also fundamentally the same as with Malthus – "the law of diminishing returns". Ricardo did not suppose that the total amount of land available was fixed. He did suppose that the available land varied in quality and that the best land would be carried into cultivation first. For Ricardo, the per-capita food supply cut down as population raised because the successive augmentation of labor were being applied to the poor status of land.

Marx (1818 – 1883) assumed the labor theory of value from the classical economists in his main economics work. Moreover he agreed with the classical economists' view of the future scenarios for the bulk of the residents. However, for Marx the poor outlook for the working classes derived not from the essential insufficiency of natural resources (land in the Malthus/Ricardo terminology) but from the existing system of economic association. This Marx saw as engaging the misuse of the workers by the owners of capital. He argued that the development of capitalism would lead to the increment of exploitation to the point where a workers' revolution would occur. Following the revolution capitalism would be replaced by socialism, and by the end of exploitation the material standards of the workers would dramatically improve.

As Common (1996) discussed that the labor theory of value was abandoned within the development of mainstream economics itself. A process of evolution from classical economics into neoclassical economics began, starting around 1870. This process involved, as well as the abandonment of the labor theory of value, an alteration in the predominant method of analysis and an alteration in the substantive issues which were the subject's major concerns.

As noted above, the classical economists thought that the labor costs of production determine prices. Neoclassical economics does not deny that prices are influenced by costs. It does reject that cost is the only determinant of price, and it does reject that labor costs are the only applicable costs of production. In neoclassical economics a commodity’s price is a measure of its scarcity, and the more scarce a commodity the higher its price. A commodity may require little labor in its production; yet command a high price either because a large amount of some other input is necessary in production, or because the demand for a commodity is huge.

The main responsibilities of the economists are initiating the process by which classical economics are supplanted by neoclassical economics. The neoclassical economists are Jevons (1835-1882), Menger (1840-1921) and Walras (1834-1910). Any one of them published his major work in the 1870s; for details and references see Blaug (1985) or Spiegel (1971). Jevons and Menger were particularly connected with the development of the analysis of the demand for commodities, i.e. with the development of the study of preferences over commodities often referred to as utility theory, and, in this context, with the introduction of the marginal method of analysis. Walras is mostly famous for initiating the formal study of the interdependencies between all of the individuals who comprise an economy, which study is now known as general equilibrium analysis (Common, 1996).

Alfred Marshall (1842-1944) in his Principles of Economics (1890) described economics as “the study of mankind in the ordinary business of life; it examines that part of individual and social action which is most closely connected with the attainment and with the use of the material requisites of well-being. Thus it is on the one side a study of wealth; and on the other, and more important side, a part of the study of man.... Economics is a study of men as they live and move and think in the ordinary business of life.”

Lionel Robbins (1898 - 1984) in his *An Essay on the Nature and Significance of Economic Science* (1932) described economics as “a science which studies human behavior as a relationship between ends and scarce means which have alternative uses”.

Nowadays, the science of economics is regarded as being concerned with the distribution of resources, priced or unpriced, between substantive individual and the social uses; the allocation of output among individuals and groups; the ways in which production and distribution change over time; the efficiencies and inefficiencies of economic systems and the implication of sustainable development (Gilpin, 2000).

A.4.2 History of Sustainable Development

Sustainable development is economic development that meets the requirements of the present without compromising the ability of future generations to meet their own needs. The concept has been widely embraced, but few have been able or willing to translate this noble concept into policies, which are dissimilar to those already prevailing. Most may agree that cutting down the world's forests, harvesting all the fish in the oceans, indifference to the loss of biodiversity on an increasing scale, runaway global warming, radioactive contamination, accumulated toxic wastes, and a world population that has exceeded the means of effectively feeding itself, would guide to a devastating future. However, most existing policies aim at preventing such disasters (Gilipin, 2000).

Within the field of environmental economics, it is now broadly known that the purpose of sustainable development is principally an equity, rather than an efficiency issue (Howarth and Norgaard, 1993). Many believe that economic efficiency is irrelevant to sustainable development, as reducing the quantity of natural resources used up per unit of human satisfaction will obviously assist to reduce demands on the environment. However, economic efficiency is not a satisfactory condition for sustainable development. Thus eliminating government policies or market failures which support incompetent use of environmental resources may improve the prospects for sustainable development, but will not guarantee it. Achieving sustainable development (SD) involves achieving equity both within generations (intergenerational equity) and across generations (intergenerational equity) (Hanley et al., 2002).

Equity is one of the most significant concepts in sustainable transportation development, but its meaning is quite conceptual. Equity can be merely described as “fairness or justice”, but it is difficult to evaluate; thus there has been little research on transportation equity (Ying and Shi, 2008). Many theories such as the different functions of social welfare, and Rawls’s typical theory of justice (Rawls, 1971) were developed to explain various equities in the economic world. Equity is closely linked to distribution, and the key problem of equity is how to distribute resources fairly, where distribution here includes both opportunities and benefits. According to Rawls’s theory of justice, equally talented and motivated people must have equal chances to achieve enviable positions. In other words, the distribution of opportunities is “fairer” than that of benefits. Litman classified transportation equity into horizontal and vertical types (Litman, 2003b and Litman, 2005). These concepts of equity refer to a reasonable allocation of benefits among various social groups or individuals, but do not consider the problem of distribution of opportunities.

As Asheim (1991) defines: “Sustainable development is a requirement for our generation to manage the resource base such that the average quality of life we ensure ourselves can potentially be shared by all future generations”.

Early work in neoclassical growth theory which incorporated natural resource constraints on economic activity (Hartwick, 1977) implicitly modeled SD as non-declining consumption over time, and were concerned with intergenerational efficiency rather than equity. This literature led to the development of the Hartwick rule. However, given that individuals obtain utility directly from the environment, and not just from the consumption goods that are produced partly with natural resources, non-declining consumption has been substituted by non-declining utility as a target of policy in economic models (Pezzey, 1992). An optional way of taking into account SD has been focused on means rather than ends: since resources are necessary to produce utility, some constraint on the amount of resources passed forward to future generations might be an appropriate way of achieving SD (Hanley et al., 2002).

On nowadays questions concerning the correlation between economic activity and the natural environment have turned into much more important in public debate and political processes, principally within the framework of a concern for “sustainable development”. This sets equity issues at the forefront, in two ways. First, there is the question of intergenerational equity. Does current economic activity impact on the natural environment in such a way as to undermine its ability to support future economic activity? Are we now acting so as to bequeath to future generations an impoverished natural environment and lower living standards? Second, there is the fact of the current inequity. While some of the existing human populations have very high living standards, many exist in miserable poverty. The fact and the question are related. The prevailing orthodoxy on poverty mitigation is that the only effective clarification is economic increase. However, if the answer to the question is positive, the solution may not be accessible. Growing the level of economic activity now and in the near future may mean that generations in the further future are made poorly. The goal of sustainable development is to alleviate current poverty without creating future poverty (Common, 1996).

President Theodore Roosevelt in 1908 declared, “The nation behaves well if it treats its natural resources as assets which it must turn over to the next generation increased and not impaired in value”. President Roosevelt thus gave a note echoed by others, from time to time, all over history.

In 1980, the World Conservation Union (WCU), the UN Environment Program, and the World Wide Fund for Nature (WWF) launched the World Conservation Strategy (WCS). It showed that conserving the living resources in which that development depends, and the integration of development and conservation policies can only sustain development. It recommended every country to set up its own national conservation strategy. The principal successor to the WCS has been the document, Caring for the Earth: A Strategy for Sustainable Living, published by the same bodies in 1991. It included a wide range of recommendations for legal, institutional and administrative reform (Gilpin, 2000).

In 1987, the World Commission of Environment and Development (the Brundtland Commission), in the Common Future, its report to the Governing Council of UNEP, described sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Gilpin, 2000). Sustainable development considers both the living and non-living resource base with regard for conservation and the advantages and disadvantages of alternative courses of action for future generations. It permits the exploitation of depletable resources in an efficient manner with an eye to the substitution of other resources in due course. Sustainable development called for much more emphasis on conserving the natural resource base on which all development depends; and a greater regard for equity within society and between rich and poor nations, with a planning horizon that extends further than the present generations alive today. It needs an amalgamation of economic, social and environmental concerns in decision-making at both government and Corporation level (Gilpin, 2000).

Subsequently, the World Bank (Serageldin, 1996) advanced a more positive concept:

"Sustainability is to leave future generations as many opportunities as we ourselves have had, if not more . . . leaving future generations more capital per capita than we have had, although the composition of the capital we leave to the next generation will be different in terms of its constituent parts than the capital we have used in our generation."

Sustainability is occasionally defined narrowly, for example, by focusing on resource depletion and air pollution problems, on the grounds that these represent the greatest long-term ecological risk and are prone to being neglected by conventional planning (Committee for a study on Transportation and a Sustainable Environment, 1997). But sustainability is increasingly defined more broadly to include the issues in Figure A.4.1. Although Figure 1 implies that each issue fits into a specific category, in practice they often overlap. For example, pollution is an environmental concern, which also affects human health (a social concern), and fishing and tourism industries (economic concerns). Sustainable planning reflects the realization that impacts and objectives often interact, so solutions must reflect integrated analysis (Litman and Burwell, 2006).

Transportation facilities and activities have significant sustainability impacts, including those listed in Table A.4.1.

Figure A.4.1: Sustainability Issues

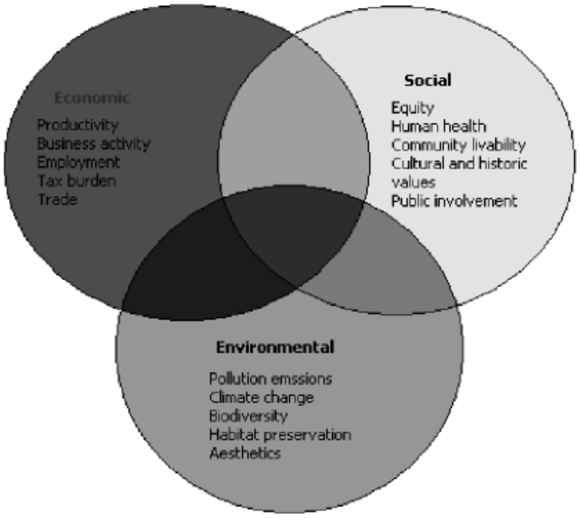


Table A.4.1: Transportation impacts of sustainability

Economic	*Social*	*Environmental*
Traffic congestion	Inequity of impacts	Air and water pollution
Mobility barriers	Mobility disadvantaged	Habitat loss
Accident damages	Human health impacts	Hydrologic impacts
Facility costs	Community interaction	Depletion of non-renewable resources.
Consumer costs	Community livability	
Depletion of non-renewable resources.	Aesthetics	

Taking into consideration food, clothing, accommodation and transportation impacts on sustainability, it is virtually unfeasible to predict the requirements of people some eight generations ahead. Beyond rational hesitation, that in 1800 it would have not been virtually viable to forecast the desires of people in the year 2000. Likewise in 2000, it is virtually unworkable to imagine the needs of people in the year 2200. Cities may be underground, climates rigorously controlled, food genetically designed, all productively recycled wastes, transport to revolutionize (Gilpin, 2000).

A.4.3 Introduction to Urban Transportation

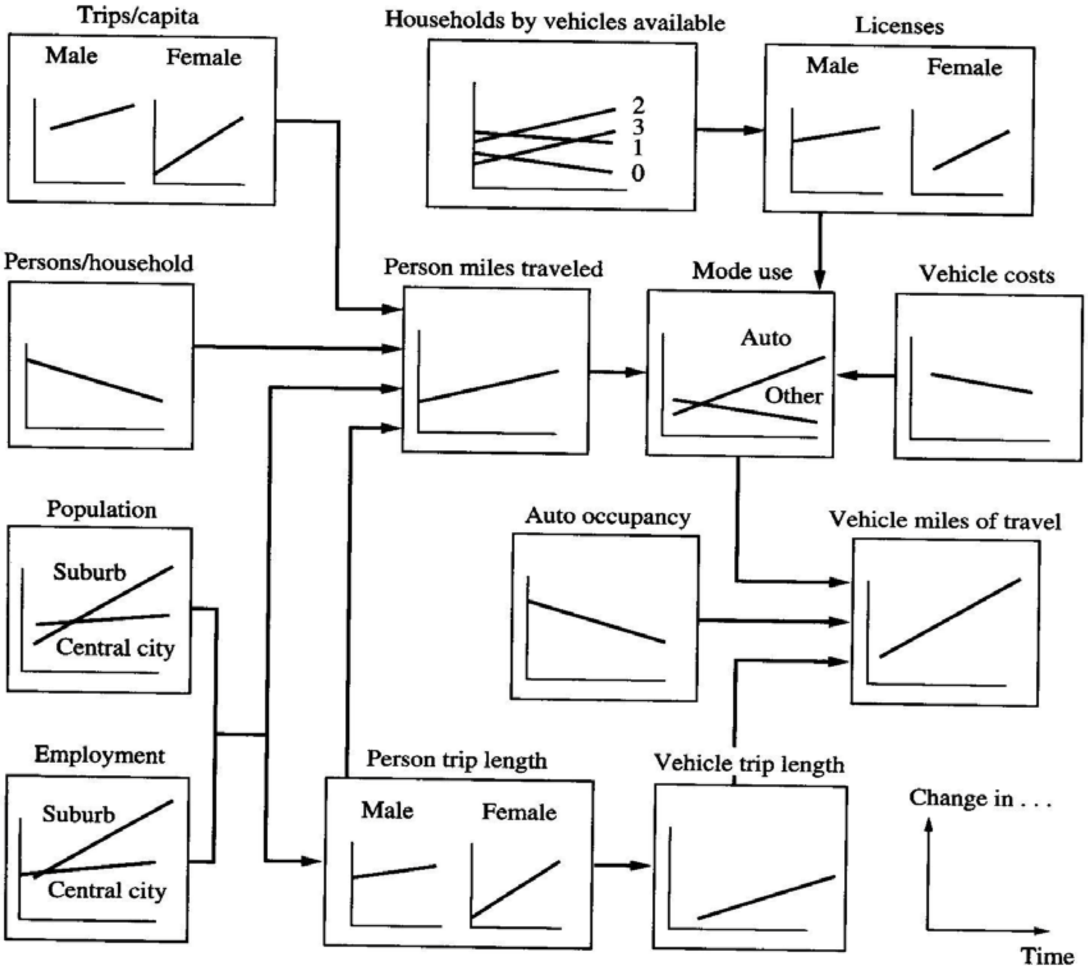
Transport has a main impact on the spatial and economic development of cities and regions. The good look of particular places depends on the relative accessibility, and this in turn depends on the quality and the quantity of the transport infrastructure. Generally, many believe that these interrelations are well established, but as Banister (1995) argues, the available methods for the analysis of the links between transport and urban development are not sufficient, particularly in the context of the altering nature of cities and the globalization of the world economy. It has been some 40 years since Mitchell and Rapkin published their seminal study, Urban Traffic - A Function of Land Use (Mitchell and Rapkin, 1954) where the links between land use and transport were first analyzed in depth. It was disputed that if activities related to certain land uses could be calculated, then quantitative estimates of the levels of traffic associated with those land uses could be made. The levels of traffic in the urban area were directly related to the land uses (Banister, 1995).

It was noticed that many of the research, such as the Sustainable Transport in Europe and Links and Liaisons with the Americas (STELLA) project introduced by Black et al. (2005) and Haynes et al. (2005), has been conducted in the context of developing countries. Although these works provide significant insight, whether the experiences are effective in Chinese cities depends more on the special features of the cities. To clarify the spatial features of the traffic problem and to make an objective diagnosis, Zhang and Gao (2008) took Beijing as an example and analyzed the traffic behaviors and satisfaction or dissatisfaction of Beijing residents on a micro-scale. The authors identified the spatial differentiation of the traffic environment across the pace and social groups, and discussed the policy implications of the results.

According to the arguments of Banister (1995) and Zhang and Gao (2008), the existing methods for the analysis of the interaction between transport and Urban development are not sufficient yet. Furthermore, there is impressive and growing literature on sustainable development, systems sustainability and management tools, there are a number of unresolved definitional, methodological and stakeholder issues in this literature (Litman, 2007; Litman and Burwell, 2006; Kennedy et al., 2005; Jeon and Amekudzi, 2005; Mebratu, 1998; Pezzoli, 1997). One of the unresolved issues is the development of frameworks that can incorporate the priorities of different stakeholder when adopting policies that promote sustainable development at broader (i.e., global, continental, national, and regional) levels of decision-making (Amekudzi et al., 2008).

Everybody moves whether it be work, play, shop or do business. All raw materials must be transmitted from the land to a place of manufacture or usage, and all goods must be transferred from the plant to the market place and from the workers to the buyers. Transport is the means by which these activities occur. The transport task is to meet the aforementioned needs (O’Flaherty, 1997). The interactions shown in Figure A.4.2 can assist to give an explanation to urban travel. These interactions can also be used to predict what the future might hold for urban transportation, assuming one knows the characteristics of the future population and that the underlying behavioral interactions do not alter (Meyer and Miller, 2001).

Figure A.4.2: Factors Influencing Urban Behavior over Time



The relations between transport and urban development are not well familiar, even in a physical sense. In addition to the physical interaction (e.g. density), there are significant economic issues (e.g. rent levels and land prices), social issues (e.g. equity and distributional factors) and environmental issues (e.g. quality of life). In each case, transport has an essential pressure, which is well accepted on the universal stage, but both the methodologies for analysis and the empirical evidence are limited at a more detailed stage (Banister, 1995).

Transport occupies a core location in the fabric of a current urbanized nation. To realize the last statement, it is helpful to regard as how today's land transport system, and particularly its road system, were developed over time. In most countries, this has been a story of evolutionary variation with new transport developments are substituting the old in reply to supposed societal and economic requests. The lifestyle of the population has also altered as a consequence of improvements in the way of life and in transport means. It can be definitely stated that interactive variations will continue and that it will be the task of the transport planner and the traffic engineer to cope with them (O'Flaherty, 1997).

Generally, solutions to transport problems can have major pressures upon human lives. These influences are reflected in the constraints which society currently places on the development and evaluation of road proposals. Usually, the constraints must be logically based, economically sound, socially reliable, environmentally sensitive, politically acceptable and inquiry proof. Meeting these needs has resulted in the development in moderately up to date times of a new professional area, transport engineering. As O'Flaherty (1997) mentions that transport engineering applies technology and scientific principles to the planning, functional design, operation and management of facilities for any mode of transport in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods.

Meyer and Miller (2001) described a comparison of transportation planning characteristics as practiced over the past 20 years and the characteristics of a future planning process more concerned with sustainability (shown in Table A.4.2).

Table A.4.2: Traditional Transportation Planning Compared to Sustainable Development Orientation

Characteristic	**Traditional Process**	**Sustainable Development Oriented**
Scale	• Regional and network level	• Local, state, national, and global perspective
Underlying "science"	• Traffic-flow theory • Network analysis • Travel behavior	• Ecology • Systems theory
The focus of planning and investment	• Accommodate travel demand • Promote economic development • Enhance system safety • Catch up to sprawl	• Efficient use/management of existing infrastructure • Provide transportation capacity where appropriate (from the ecological perspective) • Redevelopment of development sites • Reduce demand for single-occupant vehicles • Reduce material consumption and throughput

Characteristic	Traditional Process	Sustainable Development Oriented
Government economic policies	• Promote new development on new land • Economic policy focuses on productivity • Do not include secondary and cumulative impacts in policy analysis	• Promote reuse and infix development • Economic policy is fully integrated with environmental policy • Secondary and cumulative impacts are part of the policy decision analysis
Time frame	• 15-20 years planning • 4-8 years for decision-maker interest (elections)	• Short (1 to 4 years) • Medium (4 to 12 years) • · Long (12 to — years)
The focus of technical analysis	• Trip-making and system characteristics between origins and destinations • Air-quality conformity • Benefits defined in economic terms	• Relationships between transportation, ecosystem, land use, economic development, and community social health • Secondary and cumulative impacts
The role of technology	• Promote individual mobility • Meet government-mandated performance thresholds to minimize negative impacts • Improve system operations	• Travel substitution and more options • Benign technology • Total life-cycle perspective to determine the true costs • ·More efficient use of the existing system
Land use	• Considered as a given based on zoning that accommodates autos • Land use and transportation planning separated	• Integral part of the solutions set for providing mobility and sustainable community development • Infrastructure funding tied to sound land use planning • · Increased density and preservation of open space and natural resources

Characteristic	**Traditional Process**	**Sustainable Development Oriented**
Pricing	• Subsidies to transportation users • True "costs" to society not reflected in price to travel	• Societal cost pricing including environmental cost accounting • Value, that is, transportation priced as utility
Types of issues	• Congestion • Mobility and accessibility • Environmental impact at macro-scale • Economic development • Little concern for secondary and cumulative impacts • Social equity (increasingly)	• Global warming and greenhouse gases • Biodiversity and economic development • Community quality of life • Energy consumption • Social equity
Types of strategies	• System expansion/safety • Efficiency improvements • Traffic management • Demand management (from the perspective of system operating more smoothly) • Intelligent transportation systems	• Maintenance of the existing system • Traffic calming and urban design • Multimodal / intermodal • Transportation-land-use integration • Demand management (from the perspective of reducing demand) /no motorized transportation • Education

To achieve sustainable transportation (Sustainable Transportation Panel, 2007) humans must:

A. Reduce Carbon in the Atmosphere and Conserve Energy;

B. Coordinate Land-Use and Transportation in Support of Sustainability Objectives;

C. Achieve "Better Than Before" Outcomes for Our Communities and the Natural Environment as We Improve the Transportation System;

D. Apply Innovative, Sustainable Practices in the Development and Delivery of Transportation Projects and Services;

E. Adopt the Triple Bottom Line as a Way of Advancing and as a Yardstick for Evaluating the Sustainability of Surface Transportation System Policies and Performance.

The linkage between land use and transportation (Figure A.4.3) is a fundamental relationship in the study of transportation.

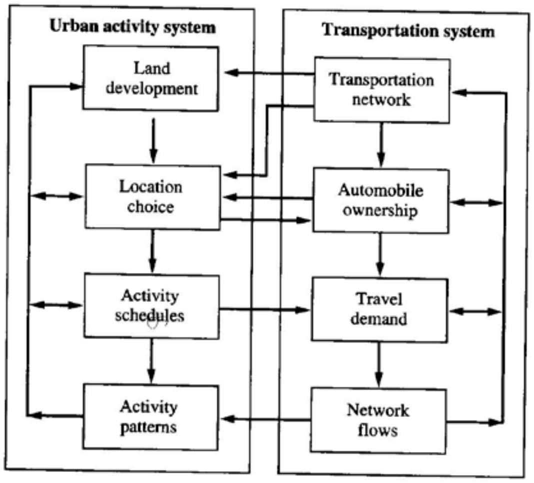
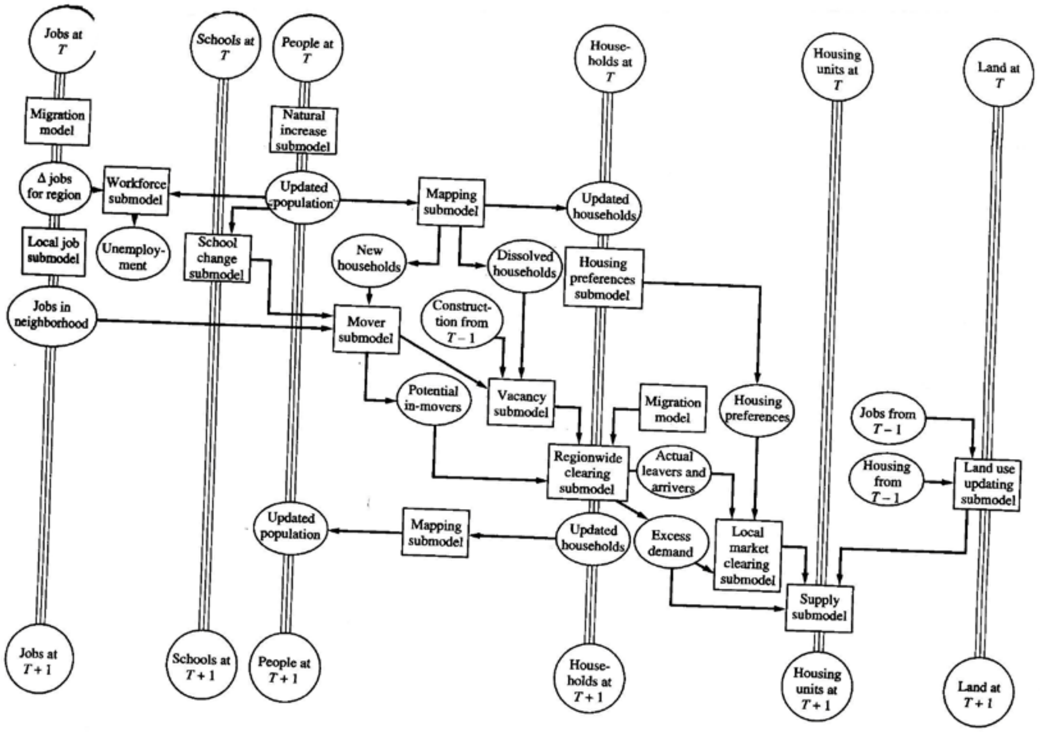


Figure A.4.3: Urban Activity and Transportation Interaction

The land development patterns influence business and household location decisions. The subsequent land uses (e.g., shops, schools, recreational facilities, and employment sites) influence the activity schedules of daily trip making, which influences overall activity patterns. The activity schedules create new travel demands and, consequently, a need for transportation services, whether in the form of new infrastructure or more efficient operation of existing facilities. The demand for transportation in conjunction with land-use patterns can influence auto ownership. For example, in a suburb without transit service, auto ownership is likely to be quite high. Improvements to transportation networks make the land more accessible for additional development to occur. Increased accessibility and improved land values, in turn, influence the location decisions of individuals and firms, once again spurring new land development and starting this cycle again, until an equilibrium is reached or until some other external factor intervenes (Meyer and Miller, 2001).

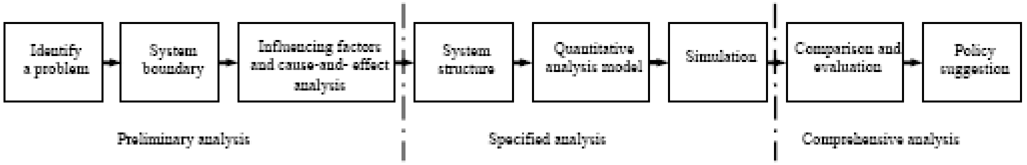
Meyer and Miller (2001) show how the various actors interact within the model, depicted on Figure A.4.4. Boxes point to the diverse sub-models in which the actors' decisions are actually simulated, ovals symbolize key pieces of information used and/or generated by these sub-models and cycles signify the key descriptors of the system state (distribution of jobs, households, housing etc.) as they exist at any point in time.

Figure A.4.4: Information Flow in the Community Analysis Model



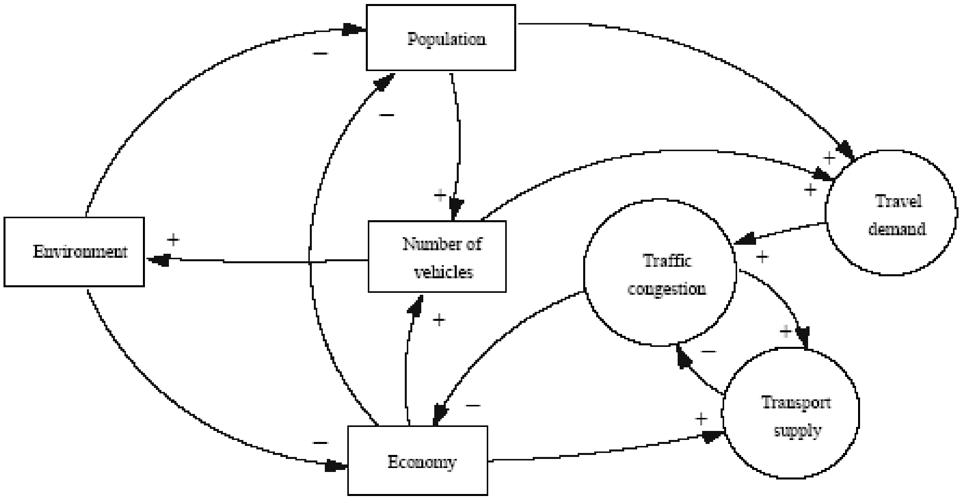
The process of applying a SD approach can be separated into three phases: preliminary analysis, specified analysis, and comprehensive analysis (Wang, 1998). In the preliminary analysis, with the understanding of the system characteristics deepened, it is required to discover the boundary of the system and describe the internal and external variables, especially the feedback casual loops of the variables. In the specified analysis, based on the results of preliminary analysis, the system structure is constructed and coefficients and equations are specified to conduct a simulation process quantitatively. In the most comprehensive analysis, the simulation results of different scenarios are estimated and compared, and relevant conclusions and policy suggestions are summarized. The flowchart of developing a SD model is shown in Figure A.4.5 (Want et al., 2008).

Figure A.4.5: Flowchart of System Dynamics Modeling



In general, an urban transportation system is a complex system influenced by economy, population, environment, and transportation sectors. The model of this system consists of seven sub-models including population sub-model, economy sub-model, number of vehicles sub-model, environment sub-model, travel demand sub-model, transport supply sub-model, and traffic congestion sub-model. Figure A.4.6 shows the relationships between sub-models. In this figure, arrows denote the cause-and-effect relationships, plus and minus signs denote the positive and negative effects, respectively (Wang et al., 2008).

Figure A.4.6: Relationships Among Sub-Models



The set of procedural steps followed by a decision maker in this rational model included (Dror, 1968):

1. Understand the context for decision making by identifying and weighing societal values and goals.
2. Establish operational objectives for the specific problem area under consideration.
3. Identify all possible alternatives.
4. Evaluate all the consequences of each alternative.
5. Select the alternative whose probable consequences maximizes the likelihood of achieving the specified goals.

This process (illustrated in Figure A.4.8) with minor differences, has served as a basis of the majority of transportation planning efforts for decades.

Another model depicted on Figure A.4.7 shows detailed emergy diagram of Beijing Economy (Jiang et al., 2009).

Figure A.4.7 Detailed Emergy Diagram of Beijing Economy

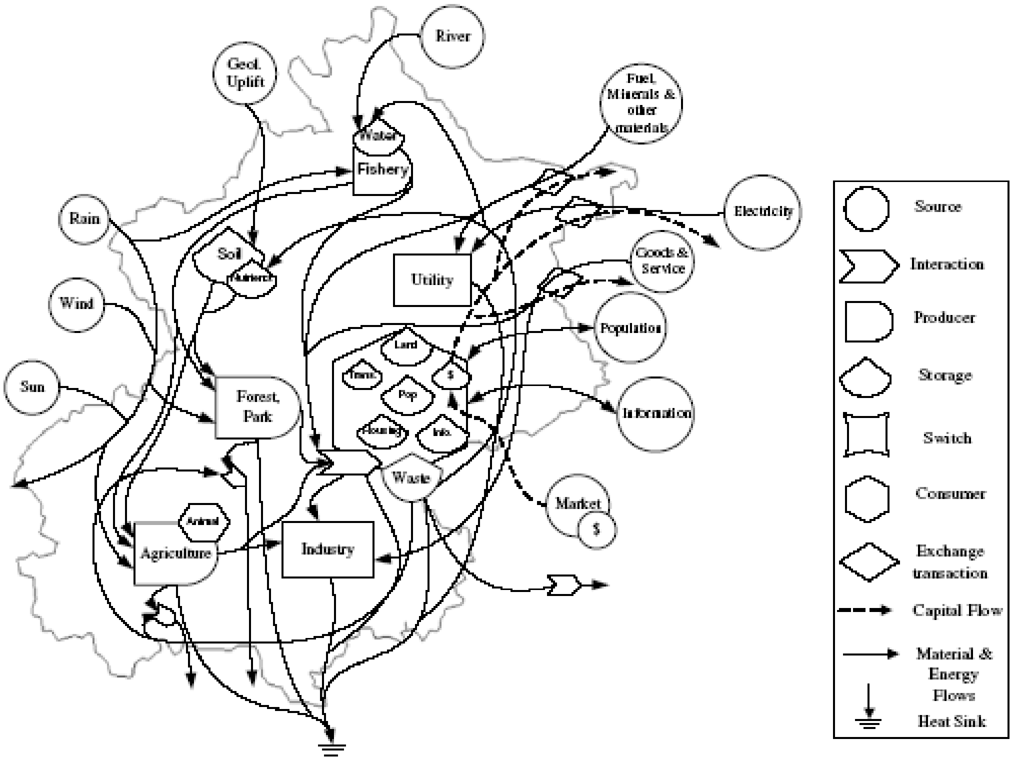
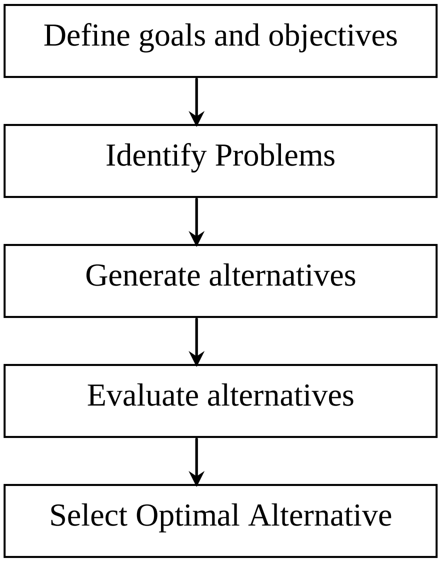
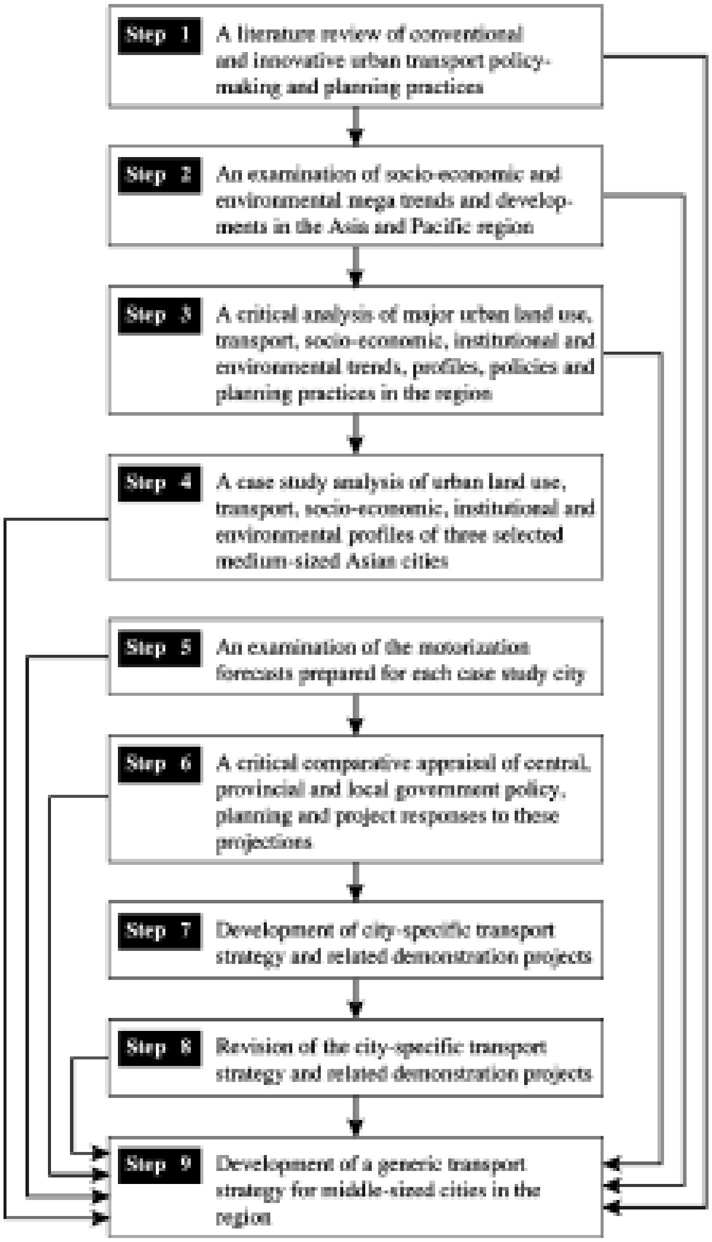


Figure A.4.8: The Rational Approach toward Transportation Planning



A nine stage analytical process (Figure A.4.9) describing the research methodology of Dimitrou (2006) somehow follows the set of procedural steps (Figure A.4.8) defined by Dror (1968).

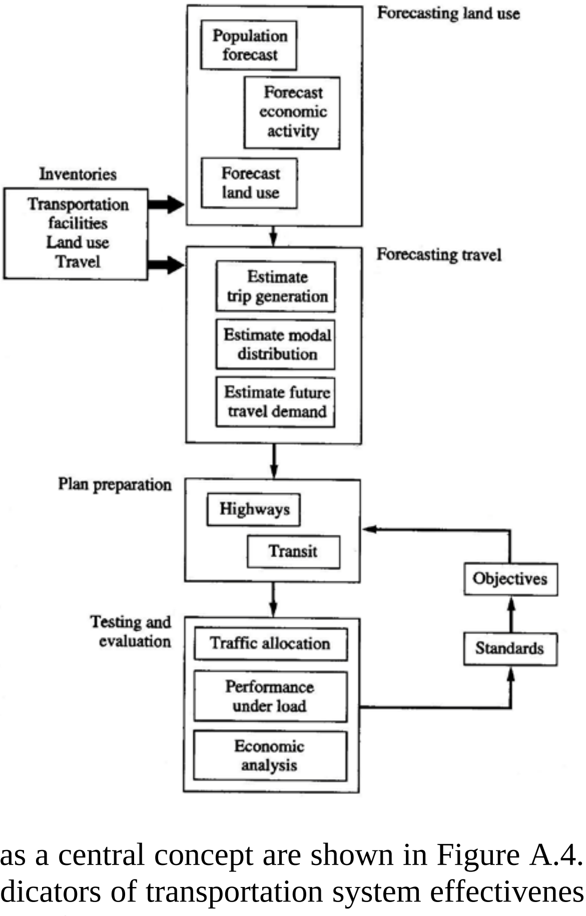
Figure A.4.9: The Research Methodology



Another work presented by Jonsson (2008) was carried out as a part of the EU Fifth Framework project PROSPECTS. The main output of PROSPECTS consists of three guidebooks, a Decision Makers' Guidebook (May et al., 2003), a Methodological Guidebook (Minken et al., 2003) and a Policy Guidebook (PROSPECTS, 2003). See also Vold (2005) and May et al. (2005). PROSPECTS were aimed to provide cities in Europe with guidance on how to plan their transportation and land use systems for sustainability. It was recognized from the outset that it is necessary to analyze these two systems in an integrated approach as they are very much dependent on one another. The PROSPECTS approach to planning for sustainability encompasses the whole planning process, from defining the objective of monitoring and assessing the outcome of decisions. A logical structure identifying the key steps in the process is an essential part of the approach. The study presented in this paper focuses on a part of the structure, mainly on modeling tools and appraisal methods.

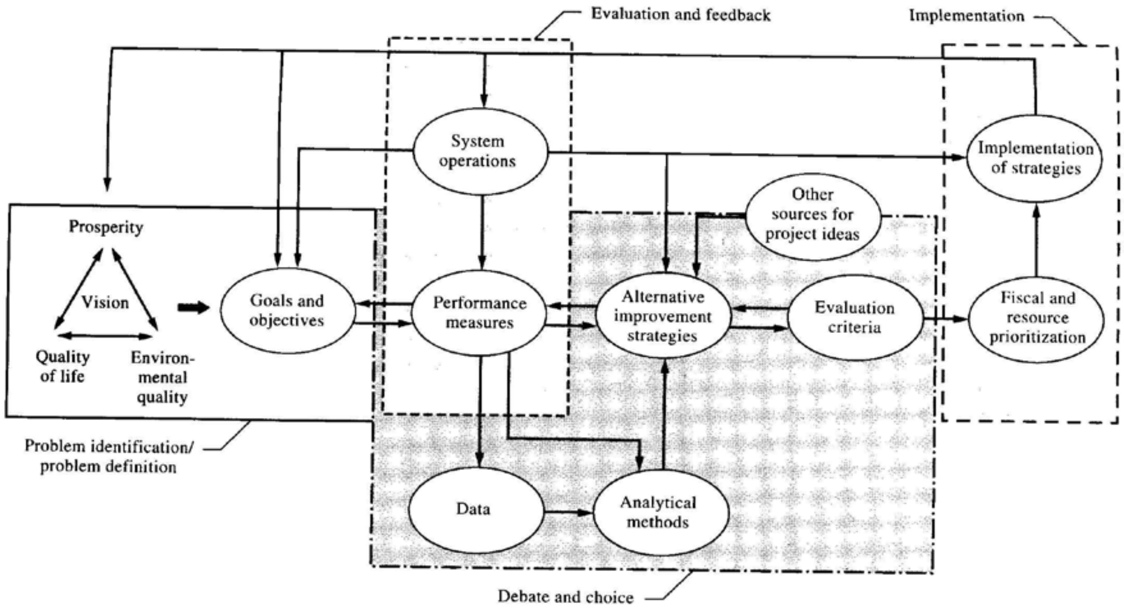
One more example of this process is provided by the 1962 transportation plan SN for Chicago (Cambridge Chicago Area Transportation Study, 1962). The transportation planning process was described as consisting of “fact gathering, forecasting and plan making” (Figure A.4.10). The stated objective of planning was to provide a transport system for the Chicago metropolitan area that reduced “travel frictions within the constraints of safety, economy, and the desirable development of land use.”

Figure A.4.10: The planning process for Chicago’s 1962 Transportation Plans



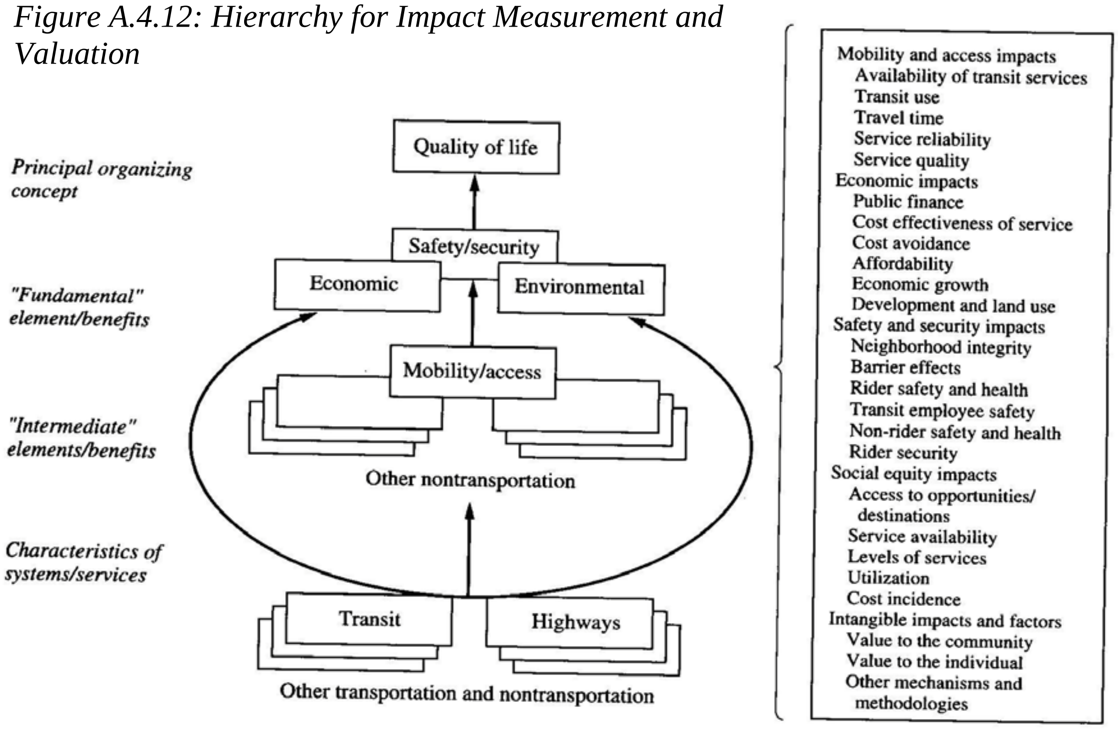
Performance measures as a central concept are shown in Figure A.4.11. Performance measures, defined as indicators of transportation system effectiveness and efficiency, focus on the information of greatest concern to decision makers. This information could reflect concerns for system delays, travel-time reliability, average speed, and accident rates, all measures relating to system operations. Performance measures should also reflect the ultimate outcomes of the transportation system. Performance measures not only define data requirements and influence the development of analytical methods, but they become a critical way of providing feedback to the decision-making process of being the results of previous decisions. The use of performance measures, however, becomes problematic if there is no agreement on the goals that are to be achieved. Many types of solutions can be considered in trying to meet the performance targets, and unless they are placed in the context of overall goals achieved, there is strong possibility that conflicts over which strategies to implement could lead to decision-making impasse.

Figure A.4.11: Linkage Between Transportation Planning and Stages of Decision-Making



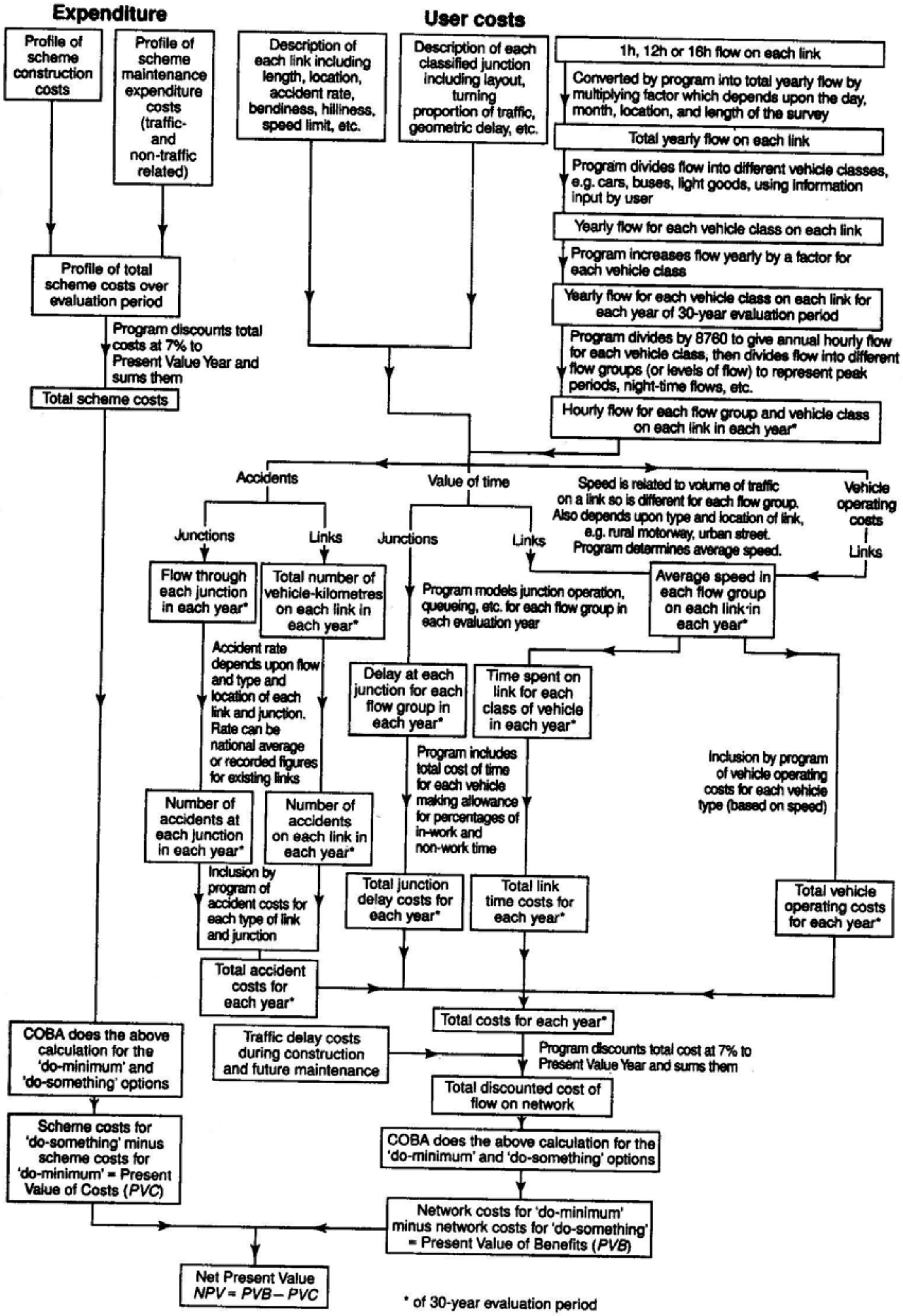
Each described model needs to be evaluated. Figure A.4.12 shows a hierarchy of benefits and costs commonly considered as part of a transportation planning process. The hierarchy is related to the evaluation of transit investments, but certainly it could be used to evaluate any form of transportation system change.

Figure A.4.12: Hierarchy for Impact Measurement and Valuation



Economic evaluations can be carried out in many ways. That which is commonly used in Britain, particularly for trunk roads, involves the use of a computer program known as COBA (Figure A.4.13) to determine the present values of the benefits and costs associated with each option under consideration (O'Flaherty, 1997).

Figure A.4.13: Overview of the COBA Method of Economic Evaluation



A.4.4 Sustainability Indicators

The sustainability objective has been described as being the search of development that meets the desires of the present without compromising the capacity of future generations to meet their own desires (Brundtland, 1987). It can therefore be thought of in transport terms as a higher-level objective, which considers the trade-off between efficiency and accessibility on the one hand, and the environment and safety on the other. A strategy which achieves improvements in efficiency and accessibility without degrading the environment or increasing the accident toll is clearly more sustainable (O'Flaherty, 1997).

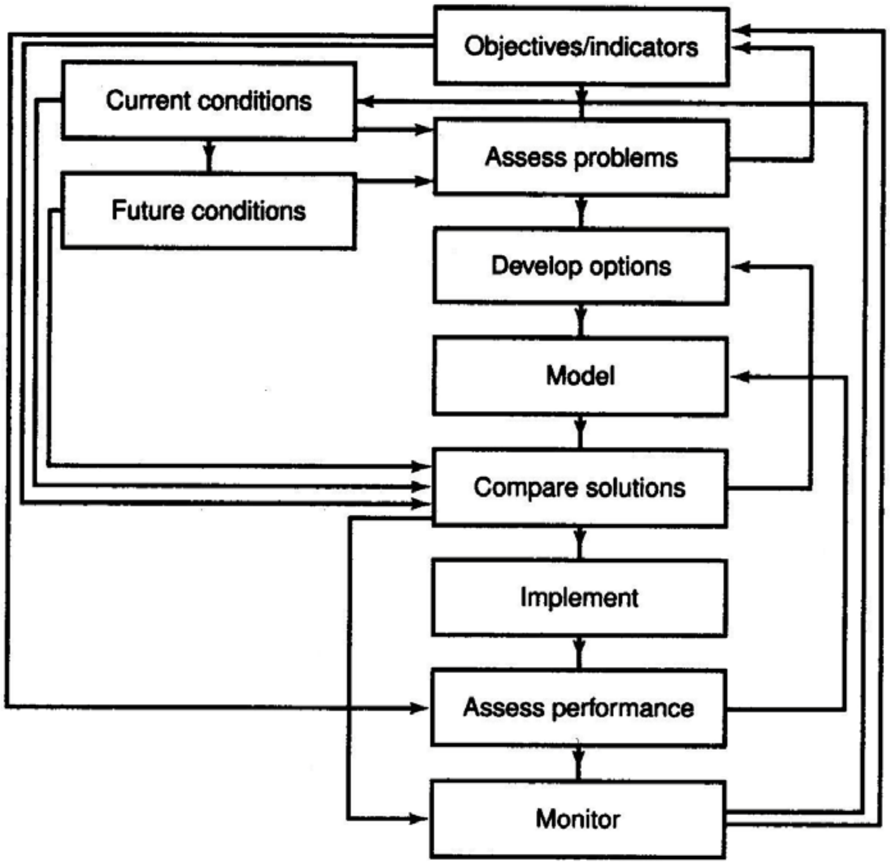
However, the definition of sustainability also includes considerations of the impact on the wider global environment and on the environment for future generations. Issues to be considered under this heading include the reduction of carbon dioxide emissions, which are a major contributor to the process of global warming (Department of the Environment, Climate Change, 1994), is controlling the rate of consumption of fossil fuels, which are non-renewable, and is limited also the use of other non-renewable resources used in the construction of transport infrastructure and vehicles.

O'Flaherty (1997) argues that the level of the strategy for an individual urban area, that there would be no significant impact on the global environment, and hence that this wider objective can be discounted. The flaw in this argument is that global consumption of fuel and emission of carbon dioxide is the result of a myriad of such local decisions, and need to be treated at this level. It was for this reason that the Rio Summit agreed to impose targets on all industrialized nations; the UK government has since reflected this in its own policy documents (Department of the Environment, Climate Change, 1994) and (Department of the Environment, Sustainable Development, 1994).

Hanley et al. (2002) set out certain approaches to operationalizing SD (these approaches are called "rules"). Once the possible rules for achieving SD have been identified, it is possible to discuss a range of indicators which might show whether an economy was becoming more or less sustainable. A variety of indicators are thus discussed, along with data requirements for implementing these indicators.

Figure A.4.9 presents a structure for strategy formulation in which objectives are the starting point. They are used initially to identify problems, both now and in the future, indications that the objectives are not being met. Possible solutions are then identified, not as desirable measures in their own right, but as ways of overcoming the problems which have been identified. The potential solutions are then compared, often means of a predictive model of the transport system, by appraising them against the objectives which they are designed to meet. As measures are implemented, their impact is assessed, through before and after studies, again in terms of achievement against objectives. On a regular basis, too, conditions are monitored and current conditions and problems reassessed, in terms of the overall objectives.

Figure A.4.14: An Objectives-Led Structure for Strategy Formulation



As noted by O'Flaherty (1997), the problem-oriented approach to transport planning starts by identifying problems and developing solutions for them. The objective-led approach defines problems in terms of specified objectives. Both methods converge at the stage of problem identification and then use these as a basis for identifying solutions and strategies (Figure A.4.14). In either case it is essential to be comprehensive in the list of types of problem. This may be difficult to achieve with the problem-oriented planning approach in which there is no pre-defined set of objectives to prompt the question "how do we know the existence of problem".

With the objective-led approach the situation is simple. Once quantified objectives have been defined and defensible targets and thresholds specified, it is a straightforward process to use these for problem identification. This approach was advocated in a study for the UK Department of Transport (Coombe, 1985). Table A.4.3 is taken from the report of Coombe (1985). It lists the objectives in the left-hand column, and uses them to define thresholds, beyond which problems occur, in the right-hand column. Table 4 suggests a set of possible indicators which could be used for each of these objectives with the exception of practicability (O'Flaherty, 1997).

Table A.4.3: Objectives and Problem Indicators for Urban Road Appraisal

Issue group	**Issue headings**
Efficiency	Delay · private vehicles · commercial vehicles · public transport · cyclists · pedestrians
Safety	Road accidents
Human environment	Occupiers/users of facilities · noise · vibration · visual impacts Pedestrians · noise · pedestrian delay · air pollution · visual impacts · severance · fear and intimidation

Table A.4.4: Suggested Indicators for Different Transport Policy Objectives

Objective	**Indicators**
Economic efficiency	Delays for vehicles (by type) at junctions Delays for pedestrians at road crossings Time and money costs of journeys actually undertaken Variability in journey time (by type of journey) Costs of operating different transport services
Environmental protection	Noise levels Vibration Levels of different local pollutants (CO, HCs, NO_X, particles) Visual intrusion Townscape quality (subjective) Fear and intimidation Severance (subjective)
Safety	Personal injury accidents by user type per unit exposure (for links, junctions, networks) Insecurity (subjective)

Objective	**Indicators**
Accessibility	Activities (by type) within a given time and money cost for a specified origin and mode Weighted average time and money cost to all activities of a given type from a specified origin by a specified mode
Sustainability	Environmental, safety and accessibility indicators as above CO_2 emissions for the area as a whole Fuel consumption in the area as a whole
Economic regeneration	Environmental and accessibility indicators as above, by area and economic sector
Finance	Operating costs and revenues for different modes Costs and revenues for parking and other facilities Tax revenue from vehicle use
Equity	Indicators as above, considered separately for different impact groups (see Figure A.4.9)
Practicability	Useful Checklist

As noted by Segnestam (2002), indicators can be a more useful analytical tool than the data from which they are derived. They assist in the assessment of conditions and trends, facilitate informed discussion among diverse groups within the community because indicators are often easier to understand that the statistics that underlie them, and provide input into the policy process. Indicators help communities identify important tradeoffs they may face in all sorts of decisions that affect sustainability, including land use, transportation infrastructure and fiscal policies, to name a few (Olewiler, 2006).

Sustainability is usually evaluated using a set of measurable indicators to track trends, compare areas and activities, evaluate particular policies and planning options, and set performance targets (Litman, 2003a; CST, 2001). Which indicators are selected can significantly influence the analysis results. A particular policy or programme may rank high when evaluated using one set of indicators, but low when ranked by another set. There is a tension between convenience and comprehensiveness when selecting indicators. A smaller set of indicators using easily available data is more convenient to use but may overlook important impacts. A larger set can be comprehended, but may have unreasonable data collection costs. It is important to avoid confusing goals and objectives when selecting indicators. *Goals* are what society ultimately wants. *Objectives* are things that help achieve goals, but are not ends in themselves. Decision makers sometimes focus on easy-to-measure impacts and objectives, while overlooking more-difficult-to-measure impacts and goals (Litman and Burwell, 2006).

Simple sustainability indicators (Litman and Burwell, 2006):
To facilitate sustainable transportation analysis, some evaluations use a relatively simple set of indicators using relatively easily available data. Below are examples:

- transportation fossil fuel consumption and CO2 emissions: less is better
- vehicle pollution emissions: less is better
- per capita motor vehicle mileage: less is better
- mode split: higher transit ridership is better
- traffic crash injuries and deaths: less is better
- transport land consumption: less is better
- roadway aesthetic conditions (people tend to be more inclined to care for the environments that they consider beautiful and meaningful).

However, overly simple indicators may fail to provide effective planning guidance. They may overlook some important impacts (such as community livability and equity), and they tend to favour solutions that address one or two specific objectives (such as alternative fuel vehicles), while undervaluing solutions that provide modest but multiple benefits (such as mobility management strategies and more accessible land use).

Comprehensive sustainable transportation indicators (Litman and Burwell, 2006).
Comprehensive sustainable transport indicators take into account a wide range of impacts. This should include indicators that reflect the full range of sustainability goals and objectives as indicated in Table A.4.5.

Table A.4.5: Sustainable Transportation Indicators

Objectives	***Indicator***	***Direction***	***Data***
Economic			
Accessibility – commuting	Average commute travel time	Less is better	3
Accessibility – land use mix	The number of job opportunities and commercial services within 30-minute travel distance of residents	More is better	1
Accessibility – smart growth	Implementation of policy and planning practices that lead to more accessible, clustered, mixed, multimodal development	More is better	1
Transport diversity	Mode split: portion of travel made by walking, cycling, rideshare, public transit and telework	More is better	2
Affordability	A portion of household expenditures devoted to transport by 20% lowest-income households	Less is better	2

Objectives	***Indicator***	***Direction***	***Data***
Facility costs	Per capita expenditures on roads, traffic services and parking facilities	Less is better	3
Freight efficiency	Speed and affordability of freight and commercial transport	More is better	1
Planning	The degree to which transport institutions reflect least-cost planning and investment practices	More is better	1
Social			
Safety	Per capita crash disabilities and fatalities	Less is better	3
Health and fitness	Percentage of population that regularly walks and cycles	More is better	1
Community livability	The degree to which transport activities increases community livability (local environmental quality)	More is better	1
Equity– fairness	The degree to which prices reflect full costs unless a subsidy is specifically justified	More is better	1
Equity – non-drivers	Quality of accessibility and transportation services for non-drivers	More is better	1
Equity – disabilities	Quality of transport facilities and services for people with disabilities (e.g., wheelchair users, people with visual impairments)	More is better	2
Non-motorized transport planning	The degree to which impacts on non-motorized transport is considered in transportation modeling and planning	More is better	1
Citizen involvement	Public involvement in the transportation planning process	More is better	1
*Environmen*t			
Climate change emissions	Per capita fossil fuel consumption, and emissions of CO2 and other climate change emissions	Less is better	3

Objectives	***Indicator***	***Direction***	***Data***
Other air pollution	Per capita emissions of 'conventional' air pollutants (CO, VOC, NOx, particulates, etc.)	Less is better	3
Noise pollution	A portion of population exposed to high levels of traffic noise	Less is better	2
Water pollution	Per capita vehicle fluid losses	Less is better	1
Land use impacts	Per capita land devoted to transportation facilities	Less is better	1
Habitat protection	Preservation of wildlife habitat (wetlands, forests, etc.)	More is better	1
Resource efficiency	Non-renewable resource consumption in the production and use of vehicles and transport facilities	Less is better	2

Data availability: 1: limited, may require special data collection; 2: often available but not standardized; 3: usually available in standardized form.

Ulengin et al. (2009) defined 26 variables (Table A.4.6) with their definitions, obtained from World development Indicators (2006).

Table A.4.6: Variables and Their Definitions

1. Air pollutants: Air pollutants include carbon dioxide, sulfur, and nitrogen emissions. The state of a country's technology and pollution controls is an important determinant of particulate matter concentrations.	**14. Rural population:** The rural population is calculated as the difference between the total population and the urban population.
2. Emission limits for vehicles: The emission limits are determined by government policies to control the air pollutant emissions of vehicles.	**15. Speed limits:** Speed limits are determined by government policies.
3. Economic Well-Being: Gross domestic product (GDP) and gross national income (GNP) as well as their per-capita values are well-known indicators of the economic well-being of a country.	**16. Transportation mode-air:** Passengers carried by airlines and goods shipped by airfreight are used as indicators of the air transportation mode.

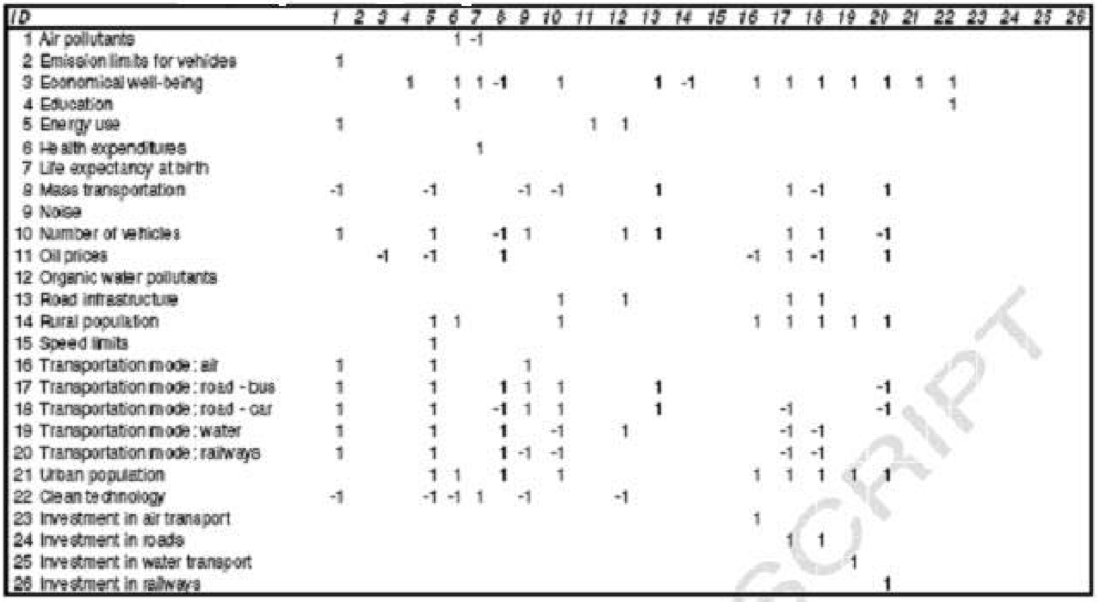
4. Education: Literacy and school enrollment levels of a country are indicators of education level. The gross enrollment ratio is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education considered.	**17. Transportation mode-road – car:** Passengers carried by car, goods hauled over roads, and lengths of paved road are used as indicators.
5. Energy use: Energy use refers to the use of primary energy before transformation to other end-use fuels, which is equal to domestic production plus imports and changes in reserves, minus exports and fuel supplied to ships and aircraft engaged in international transport.	**18. Transportation mode-road – bus:** Passengers carried by bus, and lengths of paved road are used as indicators.
6. Health expenditure: Total health expenditure is the sum of public and private health expenditure. Health expenditure per capita can be used as an additional indicator.	**19. Transportation mode-water:** Port traffic, passengers carried by water, and goods shipped by water are used as indicators of the water transportation mode.
7. Life expectancy at birth: Life expectancy at birth is the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.	**20. Transportation mode-rail:** Length of rail lines, passengers carried by rail, and goods shipped by rail are used as indicators of the rail transportation mode.
8. Mass transportation: Mass transportation includes bus and rail transportation of passengers (especially in urban areas).	**21. Clean Technology:** Biofuel production is an important indicator of the use of clean technology of transportation systems.
9. Noise: Noise generated by transportation vehicles, measured in decibels.	**22. Urban population:** Urban population is the mid-year population of areas defined as urban in each country and reported to the United Nations.
10. Number of Vehicles: The number of road vehicles, including cars, buses, trucks, etc.	**23. Investment in air transport:** Investments made by both government and the private sector for maintenance and infrastructure expansion for air transportation.

11. Oil prices: The pump price for diesel fuel is used as an indicator of oil price.	**24. Investment in roads:** Investments made by both government and the private sector for maintenance and infrastructure expansion of road transportation.
12. Organic water pollutants: Emissions of organic water pollutants are measured in terms of biochemical oxygen demand, which refers to the amount of oxygen that bacteria in water will consume in breaking down waste.	**25. Investment in water transport:** Investments made by both government and the private sector for maintenance and infrastructure expansion of water transportation.
13. Road infrastructure: The total road network includes motorways, highways, main or national roads, secondary or regional roads, and all other roads in a country.	**26. Investment in railways:** Investments made by both government and the private sector in maintenance and infrastructure expansion of railway transportation.

*Obtained from World Development Indicators (2006)

The resulting pairwise comparison matrix is given in Table A.4.7.

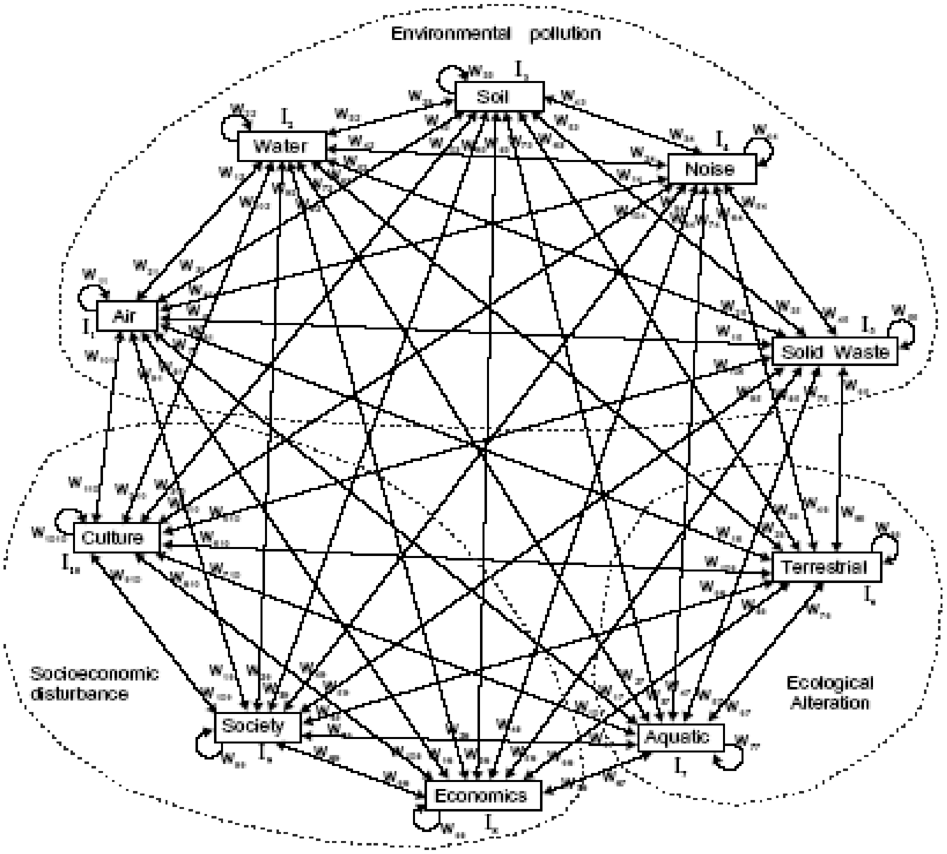
Table A.4.7: Relationship Matrix of Variables



ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1 Air pollutants						1	-1																			
2 Emission limits for vehicles	1																									
3 Economical well-being				1		1	1	-1		1			1	-1		1	1	1	1	1	1	1				
4 Education						1																1				
5 Energy use	1										1	1														
6 Health expenditures							1																			
7 Life expectancy at birth																										
8 Mass transportation	-1				-1				-1	-1			1				1	-1		1						
9 Noise																										
10 Number of vehicles	1				1			-1	1			1	1				1	1		-1						
11 Oil prices			-1		-1			1								-1	1	-1		1						
12 Organic water pollutants																										
13 Road infrastructure										1		1					1	1								
14 Rural population					1	1				1						1	1	1	1	1						
15 Speed limits					1																					
16 Transportation mode : air	1				1				1																	
17 Transportation mode : road - bus	1				1			1	1	1			1							-1						
18 Transportation mode : road - car	1				1			-1	1	1			1				-1			-1						
19 Transportation mode : water	1				1			1		-1		1					-1	-1								
20 Transportation mode : railways	1				1			1	-1	-1							-1	-1								
21 Urban population					1	1		1		1						1	1	1	1	1						
22 Clean technology	-1				-1	-1	1		-1			-1														
23 Investment in air transport																1										
24 Investment in roads																	1	1								
25 Investment in water transport																			1							
26 Investment in railways																				1						

Liu and Lai (2009) defined 5 indicators of the environmental pollution: air (I_1), water (I_2), soil (I_3), noise (I_4) and solid waste (I_5); the ecological alteration contains two indicators: terrestrial (I_6) and aquatic (I_7); the socioeconomic disturbance includes three indicators: economics (I_8), society (I_9) and culture (I_{10}). As Liu and Lai (2009) mentioned the transportation inaccessibility refers to the society indicator (I_9) with respect to relatively global weight W_9. The authors identify the dependencies among all components of just cited 10 indicators. In Figure A.415, an arch from indicators I_i to I_j denotes that I_j is influenced by I_i; its attachment w_{ij}, an influence weight, represents the degree of influence which I_i exerts on I_j.

Figure A.4.15: Influence Network



A.4.5 Conclusion

Summary:

Generally, the current paper is a literature review of the following topics:

1. History of Environmental economics is highlighting the views of classical and neoclassical Economists;
2. History and definitions for Sustainable Development by referring to the equity issues and transportation impacts on sustainability;
3. Introduction to Urban Transportation reviewing the factors influencing urban behavior, the comparison of traditional transportation planning with sustainable development orientations, urban activity and transportation Interaction, various models, first described the procedural steps by a decision maker, the linkage between transportation planning and stages of decision making, economic valuation methods etc.
4. Indicators of Sustainability analyzing the objectives-led structure for strategy formulation, suggested indicators for different transport policy objectives, simple and comprehensive sustainable transportation indicators, defined 26 variables and the matrix of interrelations between each other, the society indicator (I_9) with respect to relatively global weight W_9 out of 10 general indicators.
5. Some suggestions are provided for the future work considering the case study (Greece).

Future Work

One of the problematic issues is Transportation Traffic, especially, in the city of Athens, Greece. The necessity of sustainability indicators for transportation is required. The section of sustainability indicators outlines some already classified indicators. The first core task will be to identify indicators for the transportation sustainability with the case of Greece. Secondly, suitable variables for the current study will be chosen out of 26 variables taken from the paper of Unlengin et al. (2009). Thirdly, the weights will be given to each indicator considering the interlinks or interactions between each indicator (Liu and Lai, 2009). Later on, the intersection of variables and indicators with their own weights will be analyzed. The new interlinked matrix for the variables will be constructed. Finally, the relationships between variables based on proper proposed hypothesis will be settled down.

This approach was suggested but not performed due to lack of existing statistical data like indicators for the transportation sustainability with the case of Greece.