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Business model prototyping for electric mobility and solar power solutions

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Abstract

Which business models create maximum value for customers by leveraging the synergies between electric vehicles, installed batteries, photovoltaic systems, and the power grid? Both the solar power generation and the number of electric vehicles are massively increasing in the forthcoming years and thus they have to be respected as irreversible trends. Assuming that the combination of those technologies through a cooperative energy management approach allows entrepreneurs to make superior value propositions and to generate competitive advantages, a framework is proposed to figure out several business model prototypes. To quickly assess the dynamic behavior and the profitability of those prototypes in an innovation process the framework is complemented by a System Dynamics simulation model.

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Keywords: Sustainability; Solution thinking; System Dynamics

1. Introduction

Mobility and energy constitute elemental needs of private persons as well as companies. In the last century, these needs were met by two uncoupled industries: the automotive industry with its internal combustion engine vehicles and the energy industry as a supplier of electricity. Over time, both industries were increasingly put under pressure by legal requirements for a more environmental friendly way of value creation. Thus, in the last decade two disruptive technologies gained in importance: electric mobility [1] and solar power [2]. Enabling the customers to generate electricity by installing solar panels on their free areas enhances the attractiveness of purchasing an electric vehicle. Due to this coupling of technologies there is a merging of industries as shown in Figure 1. Nowadays, the energy suppliers as well as the car manufacturers are offering installed batteries, which maximize the self-consumption of the photovoltaic energy, and charging stations. In this way, former complementary players become competitors by expanding their industry boundaries in the same direction [3]. But who will be ahead of the game? Who is able to create the most valuable solutions for the mobility and energy needs of the customers?

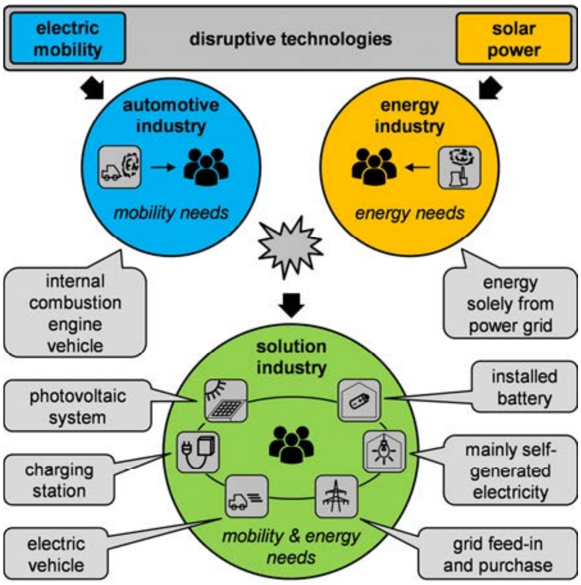

Fig. 1. Disruptive technologies cause a merging of industries

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Consider the entrepreneur Elon Musk, the co-founder of Tesla Motors and SolarCity. While the first company is a manufacturer of electric vehicles and installed batteries, the second company is an energy service provider with focus on the installation of photovoltaic systems. Through the synergies of the offerings of these two companies it is possible to offer integrated mobility and energy solutions. In this way, Elon Musk's companies are in competition with both the manufacturers of internal combustion engine vehicles and the suppliers of electricity. Obviously, a distinctive kind of solution thinking is a required prerequisite to be ahead.

Beyond, viable business models are necessary to capture value from new technologies [4]. Neither the physical behavior of cooperative energy management nor the business dynamics of complex value constellations are easy to assess. Thus, it is indispensable to prototype several options of solutions in a structured innovation process.

Focusing on the synergies between electric mobility and solar power this paper asks the following questions: Which building blocks and invariant inputs have to be considered to compose holistic solutions for mobility and energy? Which design opportunities exist to tailor these solutions for different customers? How can the fit between the technical system and the value constellation be analysed and ensured?

2. Business Model Prototyping with System Dynamics

Business model prototyping is a tool for elaborating and assessing new business model options during the business model innovation process. It makes abstract concepts tangible and facilitates the exploration of new ideas [5]. With regard to the overall business model design process it is classified in the design stage, as it is shown in the lower half of Figure 2.

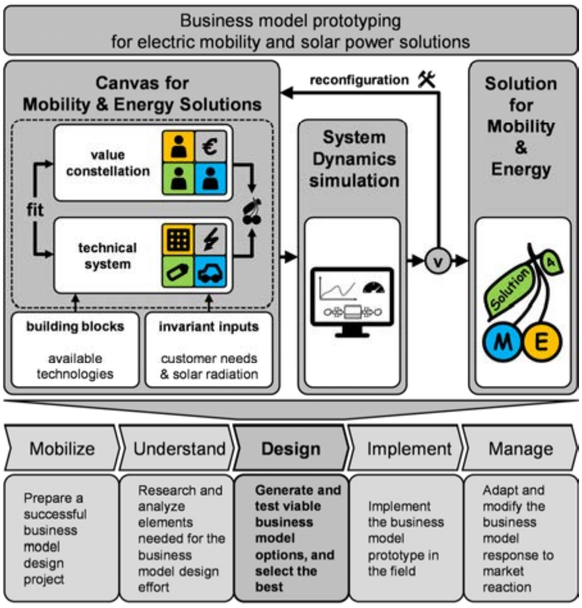

Fig. 2. Integration of business model prototyping for electric mobility and solar power solutions into the business model design process following [5]

Business model prototyping for electric mobility and solar power solutions comprises two phases which are passed through repeatedly in order to design the solution incrementally. First, the framework 'Canvas for Mobility and Energy Solutions' is used to analyze existing offerings regarding to both their technical and economic characteristics and to invent prototypes for innovative solutions by considering different possible design opportunities. It includes not only photovoltaic systems and installed batteries but also electric vehicles and thus complements the existing literature [6]. Second, the developed prototypes are subsequently simulated with the aid of System Dynamics, which has already been used in solution design [7], to get an instant feedback of how well the solution works. If necessary, the prototype will be accordingly reconfigured. The outcome is a well-matched solution for mobility and energy. This outcome is symbolized as two cherries obtaining their energy from a common leaf, the photovoltaic system, and finally from the sun. An overview is given in the upper half of Figure 2.

Section 3 gives an overview of the Canvas for Mobility and Energy Solutions and describes its elements in detail. Section 4 presents the generic structure of the Systems Dynamics model and illustrates the prototyping process on the basis of a specific example.

3. Canvas for Mobility and Energy Solutions

The Canvas for Mobility and Energy Solutions is a framework enabling the innovation team to get a shared mental model of a customer tailored solution for his mobility and energy needs. First, the canvas helps to clarify the technological building blocks which can be included in holistic solutions and the invariant inputs such as the customer needs and the solar power profile. Second, the canvas makes it possible to discuss the different options of configuring the technical system of the solution. Third, the canvas helps to make clear, which players are involved in the customer's solution, which value propositions they make, and which cash flows between them and the customers exist. These three points are explained in detail in the following subsections.

3.1. Building Blocks

The technical system is modelled as a combination of sources, sinks, storages, and valves. Figure 4 gives an overview of the considered building blocks for mobility and energy solutions.

The conventional building blocks are the power grid and the residential and industrial energy consumers. The power grid constitutes the interface to the energy provider. The residential and industrial energy consumers represent common devices and machines that need electricity to be operated. The building blocks of electric mobility are the electric vehicle, the traction battery and the charging station. As an entire electric vehicle is an energy storage and an energy consumer at the same time, the electric vehicle and the traction battery are regarded separately. The main characteristic of the electric vehicle is its consumption per kilometer.

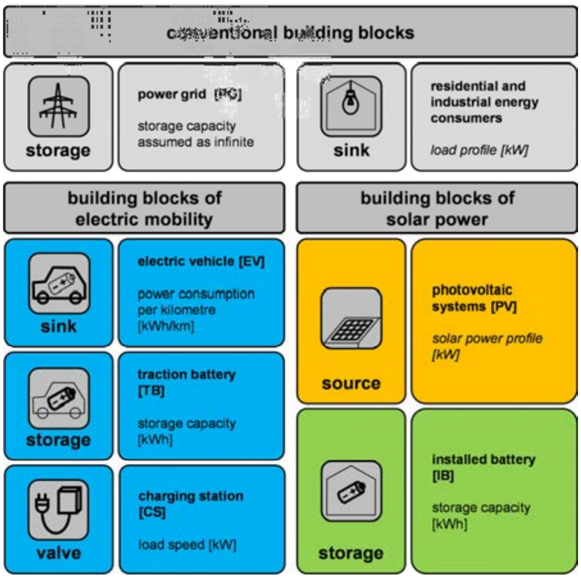

Fig. 3. Building blocks of solutions for mobility and energy

The traction battery is mainly determined by its storage capacity. Moreover, charging stations enable a controllable charging of electric vehicles which advances the interplay between the customer's system and the power grid. It is determined by its load speed. The building blocks of solar power are divided into the photovoltaic system and the installed battery that has to be considered as an addition. The source is entirely depicted by the solar power profile, whereas the installed battery is characterized by its capacity.

3.2. Invariant Inputs

So far, the static building blocks of the solution have been defined. In the following, the dynamic invariant inputs are considered. As the roof area, pitch, and orientation are assumed as invariants, the solar power profile is invariant, too. Furthermore, given the premise that a mobility and energy solution must not be inferior to conventional internal combustion engine vehicles and electricity supply, the mobility and energy needs are defined as invariants which must be completely satisfied. This means that customers do not accept any restrictions due to the technological shift. Thus, on the whole there are four invariant profiles considered which are illustrated in Figure 5.

First, the solar power profile provides information about how much energy the photovoltaic system is able to generate. It depends on the time of day and the time of year. Second, there is the load profile of the industrial and residential energy consumption which mainly depends on the time of the day, weekday, and time of the year. Third and fourth, the mobility needs of private persons and companies determine on the one hand the consumption of the electric vehicle and on the other hand whether the traction battery is connected to the charging station or not. They depend on the time of day and weekday. These building blocks and invariant inputs constitute the common base to design the technical system.

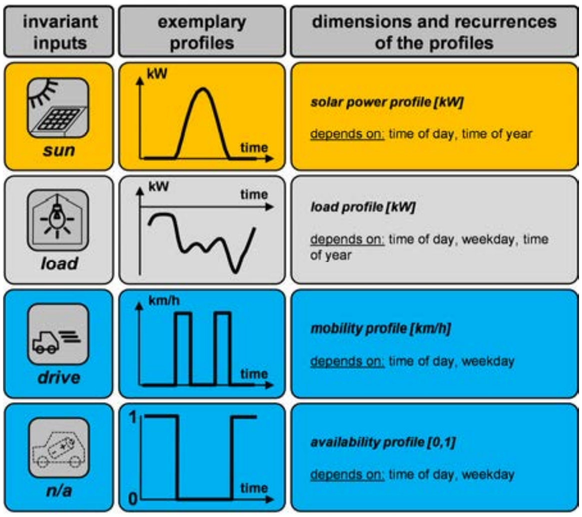

Fig. 4. Invariant inputs of solutions for mobility and energy

3.3. Designing the Technical System

The technical system is characterized by the inter-dependencies between the building blocks in consideration of the invariant inputs. All possible current flows between sources, sinks, and storages are depicted in Figure 6.

The traction current flows between the traction battery and the electric vehicle (a). The coverage of the electricity demand can be ensured by the power grid (m), the photovoltaic system (n), the installed battery (k), and the traction battery (l). The opportunity of absorbing energy in the case of an over production and the feed in of energy in the case of an energy demand of the energy provider can be realized through the controlled charging respectively discharging of the traction battery (d, e) and the installed battery (j, g). Furthermore, energy can be exchanged between the traction battery and the installed battery (b, i) and the photovoltaic system can charge the installed battery (h) and feed the power grid (f).

Given this generic structure, an amount of design opportunities for the physical system have to be explored to find the most valuable solution for customers. First, the included building blocks and their linkages can be varied. For example, the customer does not necessarily need an installed battery to fulfil his needs in the most cost-effective way. Second, the parameters of the physical elements can also be varied. The capacity of the installed battery, the capacity of the traction battery of the electric vehicle, the maximum loading speed of the charging station, and the traction current consumption play a significant role for the overall solution. Third, the charging strategies have to be elaborated accurately. For instance, the electric vehicle does not necessarily be loaded right when it has arrived. If it is available for a longer period of time, one can align the charging current with the need for negative balancing power of the grid operator. Designing the technical system makes it possible to determine when it is necessary to exchange electricity with the energy provider.

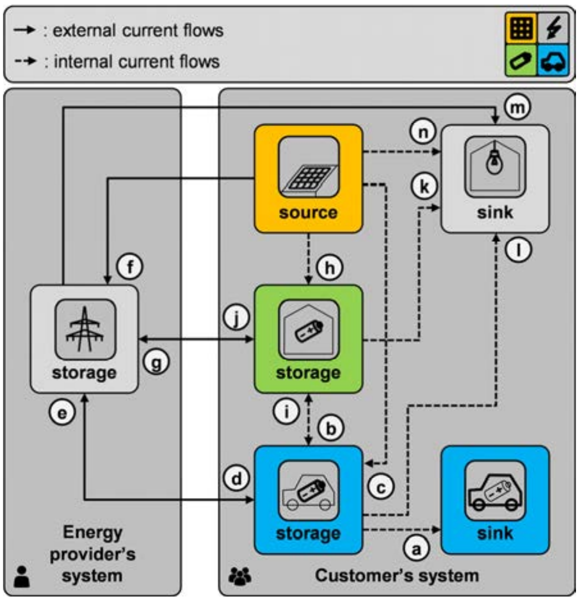

Fig. 5. Technical system of solutions for mobility and energy

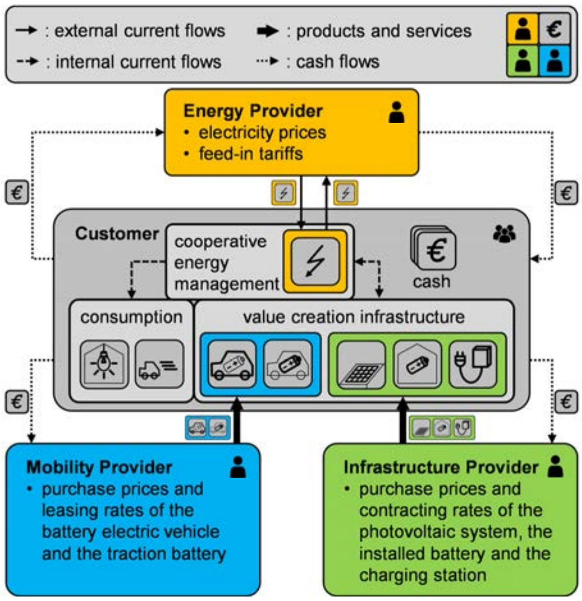

Fig. 6. Value constellation of solutions for mobility and energy

3.4. Designing the Value Constellation

A solution for energy and mobility is strongly characterized by the fit between the technical system of the solution and its corresponding economic system. Thus, the value constellation complements the technical system with the economic view. It focuses on 'the value-creating system itself, within which different economic actors […] work together to co-produce value' [8]. In this case, the following actors have to be considered: The mobility provider provides the battery electric vehicle and its traction battery. Additional, he might offer some financial services for the electric vehicle or the traction battery. The infrastructure provider provides the photovoltaic system, the installed battery, and the charging station. He might also offer some services such as the installation and maintenance of the several products. The energy provider supplies energy and absorbs surplus solar power generated by the customers. The counterpart is the customer who has mobility and energy needs. Thus, on the one hand, he is a consumer of energy. On the other hand, he is a creator of value due to his infrastructure which enables the generation and storage of electric energy. It is assumed that the customer does not only want to fulfil his mobility and energy needs, but that he also wants to create value with his infrastructure. This constellation is shown in Figure 7.

Considering this value constellation, the following design opportunities for the economic system have to be considered. There is the possibility of a dynamic adjustment of the electricity prices and the feed-in tariffs. Given the case that the grid operator needs negative balancing power he might charge installed batteries and electric vehicles for free. Moreover, several products and services can be coupled to one single market offering. Thus, long-term relationships have to be considered to exploit the full potential of the value creation for customers.

4. System Dynamics Simulation

This section elucidates some basics of the System Dynamics methodology and illustrates its applicability for business model prototyping for mobility and energy solutions.

4.1. System Dynamics Basics

In the following, a short introduction is given to the diagramming notation of System Dynamics models. According to [9], stocks are represented by rectangles suggesting a container holding the contents of the stock. Inflows are represented by pipes pointing into the stock whereas outflows are represented by pipes pointing out of the stock. Valves control the flows. Clouds represent the sources and sinks for the flows and thus they constitute stocks outside the model boundaries. Clouds are assumed to have infinitive capacity and can never constrain the flows they support. Furthermore, there are parameters which do not change in time and dynamic variables that do change. Thin arrows symbolize the dependencies of the several variables.

Besides these generic elements, most software tools provide table functions in which temporal progressions of dynamic variables and flows can be deposited. These basic elements of a System Dynamics model are exemplary illustrated in Figure 3 in the simulation software AnyLogic®.

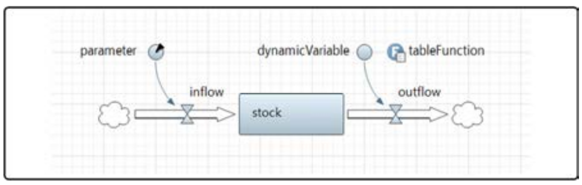

Fig. 7. Stock and flow diagramming notation in AnyLogic®

The System Dynamic simulation presented in the following section is assumed as an adequate methodology for the business model prototyping of solutions for mobility and energy. First, due to the fact that installed batteries and traction batteries are characterized by the accumulation of energy, the generic elements of the System Dynamics methodology fit very well to the physical structure of the observed system. Second, System Dynamics can not only model current flows of physical systems, but also cash flows and their accumulation in economic system [9]. Thus, System Dynamics can cover both the value architecture with the cooperative energy management and the revenue mechanisms of the mobility and energy products and services.

4.2. Building the Simulation Model

In this paper, the focus is on a 24 hours simulation of one single day to demonstrate the general applicability of System Dynamics to business model prototyping for mobility and energy solutions. After providing a generic System Dynamics model which covers the whole solution space described by the Canvas for Mobility and Energy Solutions, one specific business model prototype will be simulated to test the model.

The System Dynamics model presented in the following combines the technical system and the economic system. Figure 8 shows the generic structure of the generic System Dynamics model. The charging strategies are modelled with if-then-else statements in the equations of the current flows and the several profiles such as the load and mobility profiles are deposited in table functions. The model is built in the multimethod simulation software AnyLogic® 7.2.1.

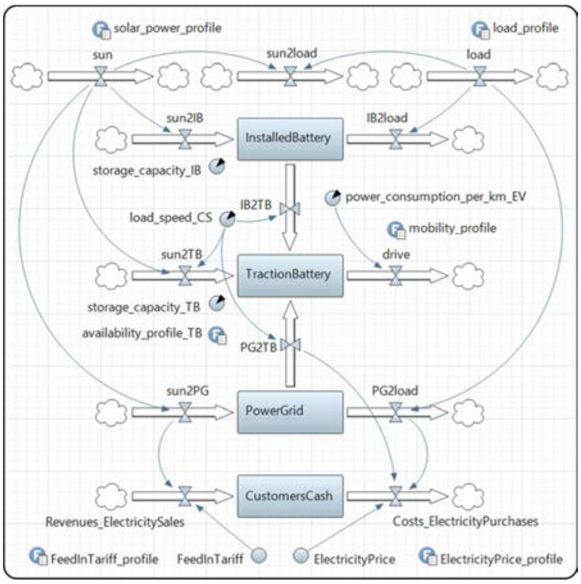

Fig. 8. System Dynamics model of a solution for mobility and energy

4.3. Testing the Simulation Model

To test the model it is necessary to specify the proposed generic model. Thus, some assumptions concerning the specific configuration of the physical system and the revenue mechanisms of the economic systems are made.

The considered technical system and its charging strategies are illustrated in Figure 9. In the simulation there is neither a supply from the traction battery to the power grid nor there is a supply from the traction battery to the residential or industrial consumers. The installed battery is not either able to supply the power grid. The charging strategies of the solution are represented by the white/black dots displaying the priorities of the outgoing/ingoing flows.

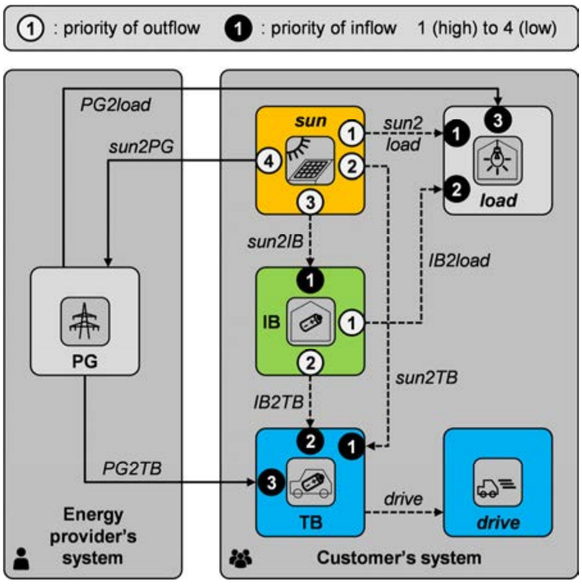

Fig. 9. Modelled technical system and charging strategies

As one day is considered, only the business relationship to the energy provider is modelled. The feed-in tariff is set as constant for the whole day, whereas the electricity price depends on the day time.

The simulation results are shown in Figure 10. The following insights can be derived from these results and should be discussed in a business model prototyping process: In the daytime solar power has to be fed in the grid and in the night time electricity has to be obtained from the grid (a) which leads to the cash flows depicted in (c) and finally to the decrease of the customer's cash throughout the day (d). That is why alternative configurations of the solution with different parametrizations, charging strategies, and structures should be prototyped to find a solution that mitigates that decrease of the customer's cash. On the one hand, an enlargement of the capacity of the installed battery should be considered to maximize the self-consumption of electricity. On the other hand, charging strategies should be tested through which the traction battery is charged at night to benefit from the lower electricity prices during the nighttime (e). Moreover, the charge status of the traction battery is constantly high (b). This shows that the capacity of the traction battery is bigger as it is required to fulfill the mobility needs which unveils the opportunity of cost savings by reducing the capacity of the traction battery.

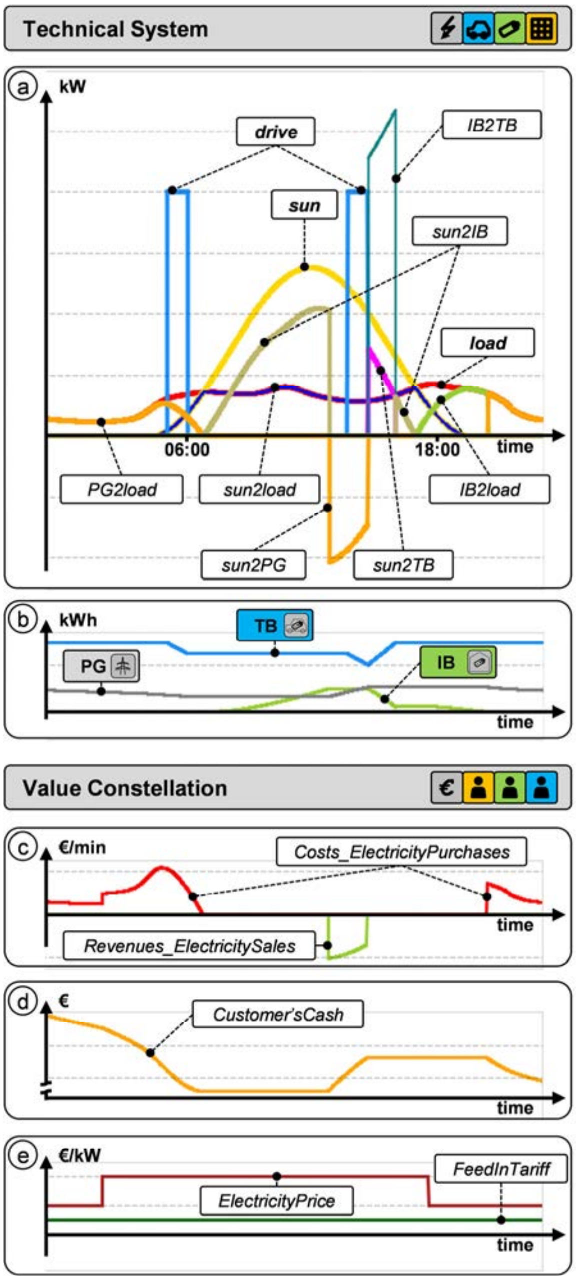

Fig. 10. (a) Current flows; (b) Charge levels of storages; (c) Cash flows; (d) Customer's cash; (e) Electricity price and feed-in tariff

5. Conclusion and Outlook

5.1. Conclusion

With the Business Model Canvas for Mobility and Energy Solutions this paper provides an illustrative framework for the business model innovation process for mobility and energy solutions. The valuable insights derived from the simulation underpin that System Dynamics is an adequate methodology to prototype this kind of business models. The findings of this paper help entrepreneurs to understand the dynamics of their business models and to assess the created value for customers.

5.2. Outlook

Simulating one exemplary day is a first step to assure the usefulness of System Dynamics to coping with complexity of such kind of solutions. The dynamics of long-term service contracts and the consideration of the variability of the photovoltaic profile over the year which are relevant for a total cost of ownership calculation will be part of future research. In this way, the value proposition can be evaluated over the whole lifecycle of the solution. Creating value is only one side of the coin. The other side is capturing value. Thus, the profitability of these business models for the different providers has to be considered, too. For this purpose, an agent-based simulation clarifying the emergent behavior caused by the interdependencies of a multiple of these solutions might be useful. Future research should focus on the following questions: Which combinations of products and services reduce the total cost of ownership focusing a time horizons of multiple years? How does the opportunity of loading the car at other places, e.g. at work, affects the design of home solutions? Which effects has the increasing degree of self-sufficiency on the energy industry?

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References

[1] Christensen CM. The innovator's dilemma. Boston: Harvard Business School Press. 1997.
[2] Frankel D, Ostrowski K, Pinner D. The disruptive potential of solar power. McKinsey Quarterly, April 2014.
[3] Bohnsack R, Pinkse J, Kolk A. Business models for sustainable technologies: exploring business model evolution in the case of electric vehicles. Research Policy 43.2 2014: 284-300.
[4] Chesbrough H, Rosenbloom RS. The role of the business model in capturing value from innovation: evidence from Xerox Corporations's technology spin-off companies. Industrial and Corporate Change 11.3 2002: 529-555.
[5] Osterwalder A, Pigneur Y. Business model generation. Hoboken: John Wiley. 2010.
[6] Hoppmann J, Volland J, Schmidt TS, Hoffmann VH. The economic viability of battery storage for residential solar photovoltaic systems – A review and a simulation model. Renewable and Sustainable Energy Reviews 39 2014: 1101-1118.
[7] Lee S, Geum Y, Lee H, Park Y. Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom line (TBL)-based system dynamics approach. Journal of Cleaner Production 32 2012: 173-182.
[8] Normann R, Ramírez R. From value chain to value constellation: designing interactive strategy. Harvard Business Review 71.4 1993: 65-77
[9] Sterman JD. Business dynamics. Boston: McGraw-Hill. 2000.