PRODUCT SERVICE SYSTEMS AND SUSTAINABLE MOBILITY: AN ELECTRIC VEHICLE INTRODUCTION CASE

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Abstract
A product service system (PSS) is a function-oriented business model aimed at providing sustainability of both consumption and production. A PSS is defined as a marketable set of products and services capable of jointly fulfilling user needs. In theory PSSs are normally shown realized with smart products. The first PSS were largely motivated by the need of traditional firms to cope with changing market forces and the recognition that services in combination with products could provide higher profits than products alone. Such need is there in the case of the introduction of electric vehicles (EVs). EVs have advantages over present internal combustion engine vehicles (ICEV) in terms of 'well-to-wheel' efficiencies, mitigation of local emissions and use of renewable energy sources. But they also have disadvantages in terms of on-board energy carrying capacity and non-existent charging infrastructure. EVs have the potential to be smart products with the help of aspects such as induction charging and vehicle-to-grid function. EVs are introduced at different locations with different business models with less success or less interest from the end user. This article proposes that EVs stand a better chance when marketed for their services and customized to fit user needs than when positioned as a replacement for ICEVs.

The research project tries to show that the development of PSSs could be well based on the technology assessment and design-oriented scenarios. A case for developing a methodology for the integration of EVs into the built environment, that of the Schiphol Airport

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area in the Netherlands, is illustrated in order to explore the possibilities and implications for developing electric vehicle service systems (EVSS).

**Keywords**

*Product service systems, Electric vehicle, Function-oriented and Sustainable mobility.*

**1 Introduction**

Mobility is growing continuously. This growth is coupled with our economic development and our vanity for travel. Mobility could be defined as creating an access to another place in time with physical displacement. This movement has made use of several forms, styles and energy sources over the last century. These actions have several types of reactions in terms of congestion and emissions in urban spaces. In order to reverse this phenomenon the new term ‘sustainable development’ was coined in the mid 80s. Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Bruntland, 1987). The important aspect for this research is the link between Sustainable development and mobility. What does sustainable mobility mean? Can we design, develop and measure sustainability in relation to mobility? Does sustainable mobility mean optimizing our use of resources to travel or our priorities to travel? Either way, one needs to look into demand and supply, i.e., travel needs and energy resources that are spent on them. The means to ‘optimize resources’ is related to infrastructure, modalities and energy supply. The means to ‘optimize priorities’ is related to a change in behaviour and it deals with the way our economic system works. The balance between the resources and mobility needs outlines theoretically the sustainability of a system.

In this paradigm, the role of designers is very important in order to strike the balance as well as solve common problems and common goals. This process is carried out with different actors, such as companies, institutions and end users, towards a common solution. Such attractive design solutions will satisfy the requirements of all stakeholders, which could be intended as Product Service Systems (PSS). The role of designers is very important despite the fact that there are not many clear-cut methodologies available in design disciplines. PSSs represent a very wide area of intervention for a designer. The definition of a standard set of methods and tools to use for designing a PSS is therefore impossible. However, designers should consider creating their own toolbox including methods and tools to be used in different contexts and for different PSS.
The innovation potential of a PSS requires a sound consideration of accurate design process, communicational, social and economic aspects.

A PSS is a social construction, based on “attraction forces” (such as goals, expected results and problem-solving criteria) that catalyze the participation of several partners. Its effectiveness is based on a shared vision of possible and desirable scenarios. The design activity within this process should therefore focus on the catalyzing factors that generate cohesion, which means that designers should have tools to: identify the actors, plot the possible scenarios, define the PSS requirements, sketch the logical and organizational structure and represent in appropriate management tools.

The following sections will refer to research experience during the Schiphol The Grounds 2030, a scenario for integration of electric mobility into the built environment, developed at Delft University of Technology among different faculty groups. The tools and methods applied during this project are not new; they are commonly used in different disciplines. The contribution of this paper, however, consists in application of such tools in the form a methodology with the aim of generating a methodology for the design process of a PSS.

2 EV systems
The present state of EVs is summarized by a feasibility study in social, economic, technological and policy terms with the help of an extensive technology assessment.

The range of electric vehicles (EVs) is limited when compared to conventional cars. The state of current battery technology, although it is constantly improving, is one of the reasons for the limited usage of EVs. Significant technological breakthroughs are needed in order to develop an EV with a comparable range and an affordable price. Safety, modularity and compatibility will be the key aspects in establishing dynamic and long-term solutions for EV charging infrastructures. It is of great importance for successful implementation that these user-related aspects are taken into account when assessing EV technologies. The biggest bottleneck for electrical infrastructure is achieving sufficient distribution capacity in the grid if EVs are concentrated in particular regions or locations and fast charged. The availability of full sized EVs for personal transport is still limited. However, with regard to market developments in the Netherlands, the numbers of hybrid EVs, professional market niches (e.g. on-site, public services, vans & small trucks), and electric bikes (pedelecs) and scooters are constantly growing. The environmental benefits of EVs are almost completely dependent on the type of energy production that is used to charge the battery. Changes in consumers’ behavior (e.g. using a second car, rental car or public transport) for longer trips
might need certain adaptations and changes specific to their mode choices in order to use EVs and related infrastructure. This situation could be avoided with the implementation of technological solutions such as fast charging, battery swapping and range extenders. The vehicle-to-grid (V2G) option for exchanging electricity back and forth to the grid is viable if the EV charging and energy distribution markets are matched. In the United States, V2G services are very profitable for users if this match is sold as spinning reserves and grid regulation. However, these high value energy markets are presently non-existent in the Netherlands. Changes are required in the current Netherlands energy market in order to make V2G services economically viable.

The higher purchasing price of an EV is a barrier for the buyer. As a result, there is a need for different business models, such as battery leasing, which will develop in the early years of EVs. A lot of uncertainty still exists, such as the high cost of electric cars and their second-hand value, and the long-term developments concerning legislation, taxes and subsidies. The transition to electric mobility will incorporate a reshuffling of the costs and benefits in the whole chain (Silvester et al., 2009). The benefits are sometimes difficult to express financially, such as the reduction of emissions, noise and independence from oil. The establishment of comprehensive infrastructures for vehicle charging is a prerequisite to the realization of electric mobility (Hatton et al., 2009). Stakeholders must work cooperatively to establish infrastructural systems capable of overcoming the socio-technical barriers that currently impede the implementation of electric mobility.

3 The Schiphol Case
This section presents the details of an integrated scenario development study for the introduction of electric vehicles at The Grounds location at Schiphol Airport in 2030. The scenario development study is part of a larger research project (named Diemigo) that has been executed by researchers at the Delft University of Technology and the Schiphol Group. The Diemigo project had two main objectives: to develop a preliminary methodology to select and design effective solutions for the implementation of large scale electric mobility and electric charging infrastructures in the built environment, and to develop and design a scenario specifically for The Grounds at Schiphol (including electric mobility solutions, charging interfaces, urban design implications, location choice and appropriate modifications to the electrical grid infrastructure). In this paper, only the results of the scenario development and design efforts for The Grounds are summarized. The detailed methodology is explained in the next section.
3.1 System Boundaries
The large-scale introduction of electric vehicles in our society is much more than a simple substitution of the internal combustion drive train by an electrical one. To really take advantage of all of the potential benefits, the transition towards electric mobility has to offer:

- The sustainability of urban areas, by means of the reduction of noise, CO2, NOx and dust emissions
- New possibilities for urban development, through the disappearance of restrictions caused by noise, etc.
- Efficient energy systems by linking the buffer capacity of EV batteries to the electricity grid and peak shaving
- Buffer of distributed renewable wind, solar and surplus energy of micro combined heat/power systems
- Attractive product-service business propositions, a shift from products towards services.

Synchronized actions from a broad array of stakeholders have to take place in order to establish a sustainable mobility system. In this project, a first attempt of a methodology is developed in order to cope with the complexity of these mutually dependent developments. This methodology, when fully developed, is meant to support the following stakeholders in urban mobility in taking the right decisions towards sustainability: regional authorities, urban developers, city planners, infrastructure and utilities companies, EV solution providers and fleet owners.

The major methodological challenges of the project will be elaborated here, leading to a description of the applied methodological framework.

**Electric transportation as a system innovation**

The introduction of electric vehicles and transportation into society involves innovation at different levels and sub-systems of the mobility system. System innovation goes beyond existing organizations and radically changes the relationship between companies, organizations and individuals. System innovation can be defined as a combination of technological, organizational and cultural changes that results in a totally new fulfilment of needs. Transitions and system innovations are seen as social learning processes. Currently, the public debate is focused on the performance characteristics of existing and future electric vehicles and in what way they fulfil customer and user requirements (e.g. driving range, speed, safety, costs, ease of use, and environmental impact).
Although customer needs fulfilment of the vehicle is essential for the adoption of EVs by users, it is not the only factor that needs to be taken into account. EVs imply innovation at several levels of the mobility system; for user adoption, it is also necessary to develop an effective electrical and urban infrastructure that supports the driver in making efficient use of an EV. For example, traditional fuel-based transportation is based on the wide availability of fuelling stations, optimally located at highways and within cities. The location of these fuelling stations is in part determined by the existing urban infrastructure (e.g. roads, intermodal hubs, and urban area functions) and related mobility patterns. With respect to EVs, the necessary electric and urban infrastructure is only partially available. Although most EVs can be charged with normal household sockets, charging solutions at business areas, large parking lots, flats, or crowded inner city streets have only received limited attention. Moreover, in order to be able to supply sufficient electricity to charge multiple EVs at a certain location within a certain time, the electrical infrastructure (grid) needs to be able to cope with this (peak) demand intelligently. This suggests that the transition to electric mobility in the next decades also requires changes and innovations at the level of urban and electrical infrastructures. The challenge is not only to design and improve efficient electric vehicles and mobility concepts, but also to design and implement urban and electrical infrastructure solutions that enable the transition to electric mobility.

**Adoption and diffusion of E-mobility**

Currently, the central question for regional authorities, local governments, cities and infrastructure and utility companies is how to accommodate and support the introduction of EVs into society. Primarily, this discussion is based on a ‘technology push’ approach; EVs offer all kinds of new possibilities, they seem to have benefits for the environment, and infrastructural solutions have to be developed to support this in the best way possible. Although this is not incorrect, it tends to miss the point that the adoption of electric transportation is highly dependent on the evolution of mobility needs in the future. These mobility needs are partially determined by urban developments and the related geographic distribution of urban functions, as well as the consumer/user trends of the future. The challenge is to align the technical possibilities of EVs and the related infrastructure solutions in a better way with future mobility needs. In this project a user-driven approach will be applied. This will require:

- Deep insight in user needs for mobility to identify new mobility solutions or to improve the adoption of existing solutions.
• Designing artefacts and creating visual representations in order to get quick feedback from users and producers.
• Designing artefacts to allow for experimentation and simulation, so that quick feedback for improvement can be obtained.

Making decisions in an uncertain world
The past years have witnessed the introduction of numerous and very different electric vehicle concepts and electric charging infrastructures (e.g. charging poles, and battery swapping stations). Also, at the level of the components of electric vehicles, technological developments are rapidly occurring (new battery types, electric drive trains, power management systems, hybrid vehicles and range extenders). Only very recently has the standardization of components and designs begun, but no definite dominant designs have emerged and new concepts are still being developed. Also, the availability of electric vehicles is still limited, except for several types of hybrid electric vehicles. This places regional developers, local governments, infrastructure and utilities companies, and fleet owners in a difficult situation. Since the direction of the development and adoption path of EVs is still highly uncertain, making investments in the right infrastructure solutions in the long term is complex. As investments in infrastructural solutions tend to be high and returns accrue only in the long term, this creates high investment risks for these actors. The strategic challenge at this stage is not to invest in single, highly specialized infrastructural solutions (because it is still highly uncertain whether these solutions will become dominant), but to develop and invest in solutions that allow and can accommodate many different technological options. This option-approach circumvents the risk of premature lock-ins in sub-optimal infrastructure and EV solutions.

3.2 Methodological approach
The methodology for identifying, selecting, and developing the right combination of EV concepts, urban and electric infrastructure solutions has to facilitate the three strategic challenges as explained in the previous section: (1) It has to be able to address interdependent elements and sub-systems of the mobility system, (2) It should align future mobility and user needs with technological solutions, and (3) It should be able to identify the infrastructure and mobility solutions that can accommodate a wide variety of EV options in the future.

The applied methodology is structured according to the following phases: analysis, scenario development, concept development, design prototyping and evaluation (see Figure 1).
Figure 1: Methodology of research project Diemigo
Analysis

Within this phase a technology assessment is made of electric mobility in the Netherlands, mapping both developments in Hybrid Electric Vehicles (HEVs) and full Electric Vehicles (EVs). It covers not only technological developments relevant for electric mobility at a system level, but also policy developments by the government and developments in niche markets, pilots and experiments in society. In addition, it identifies social, environmental and economic aspects of the large-scale introduction and adoption of electric mobility in the Netherlands.

The findings of the technology assessment will be validated during a workshop with important stakeholders. The main goal of this workshop is to: (1) collect the expectations and opinions of these actors regarding relevant social aspects, barriers and drivers related to electric mobility up to the year 2030, and (2) to work on vision development for future electric mobility and to elaborate it for different types of built environments.

Based on the results of the Technology Assessment and workshop, all of the key factors that are relevant for the transition towards electric mobility will be identified. Ranking and clustering the key factors according to importance and uncertainty will lead to the formulation of the driving forces. These driving forces will form the input for the scenario development phase.

During the analysis, specific research will be executed on the climate and the sustainable energy potential of the selected area. The possibilities of local decentralized energy production for powering electric mobility at the Elzenhof The Grounds location will be investigated. Furthermore, the analysis of the urban context has to provide the most suited functionalities for the chosen location.

Scenario development

Scenario building is especially useful in circumstances in which it is important to take a long-term view of the technological developments and related strategies of the actors involved. It is also useful when there are a limited number of key factors influencing appropriate strategies, but also a high level of uncertainty about these influences. Scenario building tries to build plausible views of different possible futures for relevant actors based on groupings of certain key environmental influences and drivers of change. The result is a limited number of logically consistent yet different scenarios that can be considered alongside each other.

There are two main benefits to scenario building. First, actors can examine the strategic options against the scenarios and carry out a ‘what-if’ analysis. Scenarios can be used to determine the robustness of different strategies. Second, the implications of scenarios can
be used to challenge pre-assumptions about the environment and technological development in which industry actors operate. This is especially important when change is unpredictable and industry actors are concerned with short-term interests, goals and results (Johnson and Scholes, 1997).

Practice shows that scenarios have been applied in an increasing number of disciplines and sectors. Several overviews of the diversity of applications have been carried out (van Notten et al., 2003). Scenarios can be classified according to aspects such as project goal, scenario content and process design. Manzini makes the distinction between Policy-oriented scenarios (POS) and Design-oriented scenarios (DOS) (Manzini, 2008). Policy-oriented scenarios usually deal with the macro-scale of the socio-technical systems and present a variety of possible futures and facilitate political decisions. Design-oriented scenarios are conceived as tools to be used in design processes. These scenarios should propose a variety of comparable visions that have to be clearly motivated and enriched with visible and (potentially) feasible proposals. A Design-Oriented scenario is supposed to create inspiration for designers whether in industry, government, universities or NGOs, to design urban plans, products, services and social arrangements that might take steps towards the realization of these scenarios (Green, 2001). A DOS should contain the following elements:

- Various proposals developed as concrete plans, products and/or services.
- A global ‘vision’ picturing the effect of the implementation of the ‘proposals’ and their possible impact.
- The essential characteristics explaining the main effects and benefits that the DOS is expected to have in terms of sustainability, economics and user acceptance.
- A storyboard, describing ‘a day in the life…’ of the mobility user in 2030.

An assessment of the essential characteristics – sustainability, economics and user acceptance – will lead to the selection of the most promising scenario. This scenario will form the context for the concept development. To quantify the effects of the different scenarios, such as the impact on urban development in terms of the number of EVs and the pressure on the available space and facilities, an instrument referred to as the ‘Urban Indicator’ will be developed and applied.

Concept development
During the concept development phase, different options for urban plans, mobility concepts and electric infrastructures are developed in parallel. One of the important instruments to be used in fostering the richness of the options generated is the morphological chart.

“A morphological chart is a visual way to capture the necessary product functionality and explore alternative means and combinations of achieving that functionality. For each element of product function, there may be a number of possible solutions. The chart enables these solutions to be expressed and provides a structure for considering alternative combinations” (IFM 2009).

**Design prototyping**

Potentially demonstrable elements of the scenarios in the near future or solutions that can already be applied are important in order to show the potential of the transition towards electric mobility for Schiphol Airport City. These spin-offs will motivate the various stakeholders, whose support is needed for the long-term transition process.

Visual representations of the urban development, the mobility concepts, the e-infrastructure and the e-charging solutions will be important deliverables of the project. Due to the limited time available for the whole project, real physical prototyping is not an option.

**Evaluation**

This phase will not be included in the project. As part of the follow-up research within the DIEMIGO project, the Schiphol The Grounds project will serve as a case to develop an evaluation framework for:

- The ecological aspects (ecological quality, emissions, and use of natural resources).
- The social aspects (perceived characteristics, acceptance of urban design, mobility concepts, and product/service propositions).
- The economic aspects (return-on-investment and new business opportunities).

**3.2 The Grounds 2030**

The Grounds 2030 scenario describes a world in which rapid technologic development and minimalistic design principles play a key role. It marks a sea change in consumer behaviour, as people exhibit a clear preference for value-based products and attention to detail. Members of the society described in this scenario have a long-term perspective, which is manifested by their interest in education, collaboration, and innovation.
Schiphol The Grounds is a centrally located and green business-science park that focuses on innovative and sustainable products and services. Because of its prime location, The Grounds is also used as a transfer point; departing travellers park their electric vehicles (EVs) in the long-term parking facilities and visitors to the Netherlands pick up their tailor-made e-rentals, which enable them to move throughout the country in style and comfort. The park also serves the airport’s airside needs, providing a portion of the facilities that enable its characteristically smooth operation. This cooperation between airside and landside functions has led to innovation in the field of transportation. Several pioneering forms of e-mobility and supporting infrastructural networks have been integrated into Schiphol’s real estate, resulting in innovative, comfortable, silent, and green urban environments. Schiphol’s electric vehicle fleet is charged with solar power at The Grounds airside location. Renewable energy sources also power the landside vehicles that traverse the area. Schiphol’s workers use several modes of public and private transport, which come in a variety of shapes and sizes. Many employees use ultra-light electric vehicles as an extension of public transport for the final kilometres to their destination. These vehicles can be easily folded for charging and storage and they fit conveniently into the trunk of a car or the luggage compartment of a train. Employees and travellers alike are encouraged to make use of the e-robe, a personal rapid transit system that brings passengers from one end of Schiphol to the other within the privacy of their own cabin. It takes just minutes to travel from the customs area in the airport to The Grounds via e-robe.

Before landing at Schiphol, airline passengers may order custom-made e-rentals based on their preferred travelling style and the predicted weather conditions. The build-a-vehicle e-rentals are modular vehicles that are assembled on demand, according to a variety of user-specified options such as the number of wheels, battery size, or the driver’s preferred posture. Schiphol provides inductive charging lanes, which may be utilized by EV drivers who have no time to recharge their vehicles while they are parked. In these lanes, dynamic contactless energy transfer charges the EV’s batteries while the vehicle is on the move.

The inner street of The Grounds houses hotels, offices, e-robe stops, and vehicle storage facilities. The park also has a metro stop, which is located between Schiphol Plaza and Amsterdam Zuid-as. Travellers that wish to store their vehicles during their trip may choose to park their EVs in Schiphol’s Park&Charge long-term parking garage located at The Grounds. Users drop off their EVs at the entrance to the parking garage. The vehicles will
then be conveyed into the garage and automatically stored. They are returned fully charged at the entrance to the garage upon the traveller’s return.

At parking facilities, it is now standard to charge vehicle batteries by means of static contactless energy transfer. The Park&Charge garage fulfils a vehicle-to-grid function: the batteries of parked EVs will temporarily become a part of Schiphol’s sustainable energy system. The EV’s batteries are connected to the grid by means of a bidirectional charging device. These batteries are charged from the grid when there is plenty of sustainable electricity available and discharged to supply the grid at times of peak energy demand. In this way, the sustainable energy system provides economic benefit to the owners of the garage, as well as to those of the EVs. This innovative bidirectional charging system is also connected to various types of locally generated sustainable energy. Schiphol is a prime example of decentralized energy production and the use of a micro-grid attached to the national energy grid network.

A high penetration of electric mobility in the built environment generates little environmental impact and results in full integration into green urban areas. Through the development of The Grounds business-science park and mobility transfer hub, Schiphol plays a key role in the roadmap to green mobility. With the implementation of new transport technologies, unique services, and advanced sustainable energy production and management systems, Schiphol builds on the values of a progressive society to offer an innovative and inspiring environment for work and travel.

4 Discussion
An urban plan was developed, resulting in a combination of a business-science park and a mobility transfer hub. The principles of ‘decentralized concentration’ were chosen for the development of the area. The urban structure around Schiphol will be a collection of several concentrated centres, one of which is The Grounds. This principle is a challenging way of combining optimal use of the space with a high quality of living/working. Within this decentralized concentration, initially the requirements for the short-cycles city approach are drawn and then the urban design. Within the concentrated areas walking, (e-) bicycling and ultra-light EVs will be the primary mobility modes.

The ultra-light EV is a small foldable, one-person electric powered vehicle used to form a link in chain mobility. It is suitable for short and medium range and in combination with other modes, such as with the E-car 2030 or public transport.
Between the concentrated areas, combinations of public and private transport will be the dominant modes. Three concepts were defined in this study. The E-car 2030 is a space efficient four-wheel EV for two persons meant for airside and landside personal mobility, which is optimized for automated parking and inductive charging. User-specific settings can be stored and uploaded in every available E-car. The e-rope is a special suspended vehicle that is based on a combination of both individual and collective components. It offers a frequent and comfortable bidirectional transport mode. The infrastructure needed for the e-rope is lighter and less rigid than a rail oriented solution. The Build-an-EV is a customizable vehicle to match individual needs and wishes. The concept is meant to serve different purposes with the help of standard components (two, three or four wheels; covered or open; variable ratio of person versus luggage space; etc.).

Part of the urban design is the Park&Charge Garage solution. This automated parking system makes it possible to store electric vehicles in high densities and charge them simultaneously. By situating these garages and the offices/hotels on the outer edge, the centre of the territory can be kept as an open green public space. The actual transfer point is situated on the southwest corner of the territory. A Metro station, an e-rope stop, an E-car 2030 exchange point, the Park&Charge Garage entrance and the service station for tailor-made e-rentals are concentrated at this location to provide Schiphol employees, visitors and passengers with seamless connections. Additionally, the ‘closing of cycles’ on the level of The Grounds is an important element. The urban plan provides possibilities for local agriculture, production of biomass and wastewater treatment.

With the integral urban design for The Grounds location it has been demonstrated that sheltering and servicing of 9400 electric cars in a green, comfortable and silent business-science park of only 30 ha is feasible.

5 Conclusions
It was not possible for the evaluation to be carried out within the time frame of this research. The methodology applied was successful in bringing different disciplines together and creating with solutions. From a methodological point of view, there were some glitches during the process. The initial problem was to formulate a clear theoretical framework that could be converted into requirements. This occurred with the existence of different groups and the ambition for a solution based approach. Due to the time pressure, less stakeholder involvement was achieved than originally intended.
Solution based PSSs are important for stakeholder satisfaction and to achieve intended sustainable framework of solutions and products. Synergy between different actors is also very important in order to achieve intended solutions that satisfy all participating actors. Design has been a powerful means to generate synergy between the different disciplines. More cases have to be carried out in order to further develop the methodology for the large-scale implementation of electric mobility in the built environment.

References