D. Vonsée

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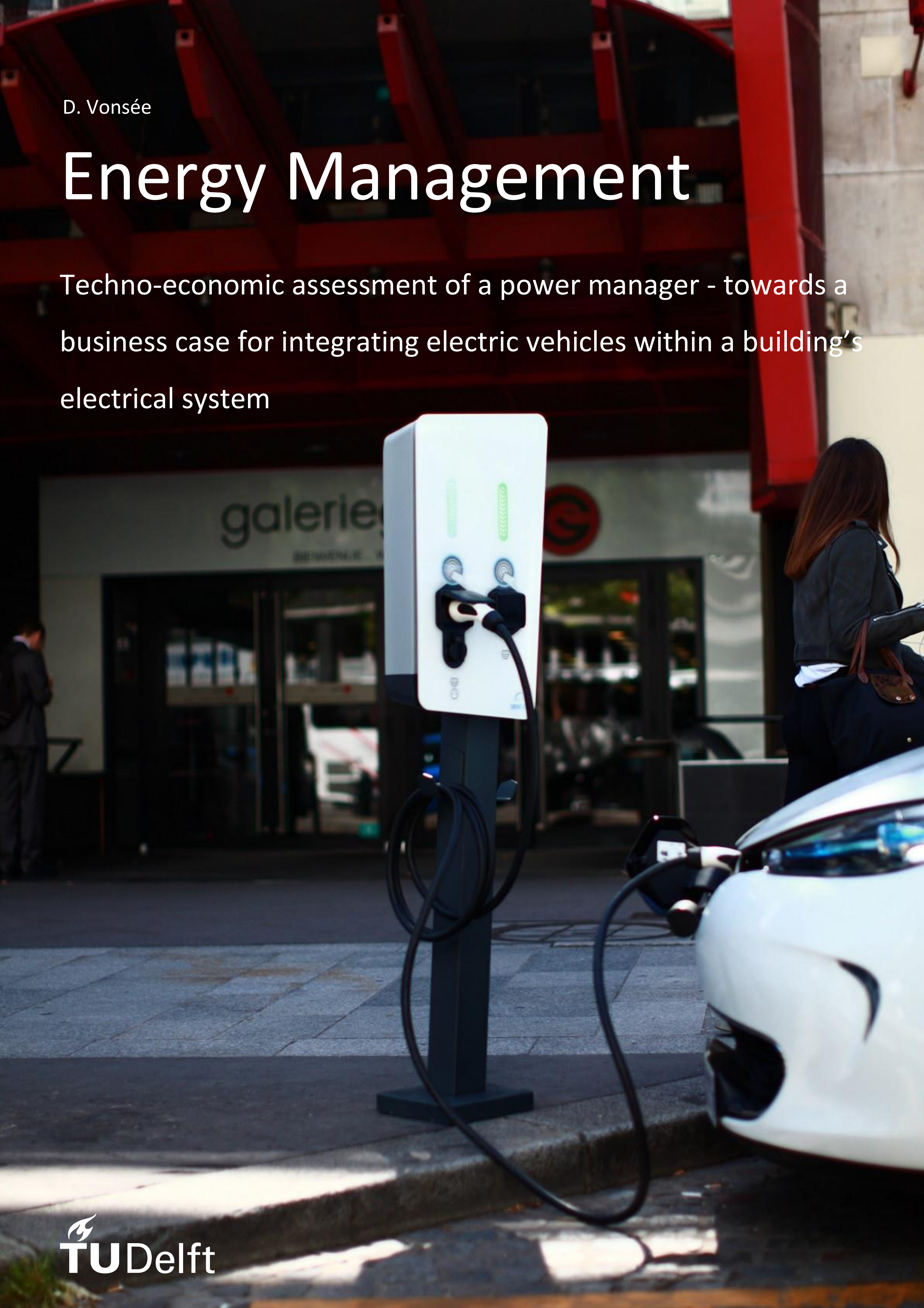
Techno-economic assessment of a power manager - towards a business case for integrating electric vehicles within a building's electrical system



TU Delft

Energy Management

Techno-economic assessment of a power manager – towards a business case for integrating electric vehicles within a building's electrical system

By

D. S. Vonsée

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“Balance is not something you find, it’s something you create”

– Jana Kingsford

Preface

With this dissertation, I hope not only to fulfill the requirements of my master in Sustainable Energy Technology but also to accelerate the development of a more reliable and efficient grid operation. I'm very proud and delighted to be able to present the findings of the conducted research and to contribute to the rapidly evolving innovations in the field of advanced energy management systems.

Eight months ago, I started searching for research topics that had an affiliation with technological innovation. This stemmed from my personal preference to work on the interface between technological inventions and market implementation. After having met professors from several research groups, I scheduled a meeting with Ad van Wijk. Ad's research group focuses on future energy systems, and especially the contribution of electric vehicles within these systems. The Car as Power Plant (CaPP) group overlooks the entire spectrum of technological feasibility, societal implementation, and business development. I showed up at the meeting with high expectancies, having in mind to join an already established research group. However, it turned out to be the exact opposite. I got to see a one-pager concerning a technological innovation invented by Honda in Japan. The aim of the research was to test the device and to create a business model for its implementation in the European market. I got inspired by the idea that the innovation has been brought forward with the aim to tackle grid outage problems in Japan. These outages were frequently caused by grid failures resulting from natural disasters. I soon realized this was the topic I preferred to work on for the upcoming eight months. The practical insights I gained over my thesis' lifetime at the Green Village and at Honda R&D Europe, made this research very special to me.

First, I would like to thank Ad van Wijk for being able to conduct research within his progressive and renowned Car as Power Plant research group. I had the opportunity to attend conferences at which Ad talked about his vision concerning future energy systems. I became aware of the importance of innovative grid supporting solutions, based on the attention he received as both a researcher and entrepreneur. Moreover, he helped me in structuring my research by making clear the overall concept of future energy systems. Additionally, I would like to address special thanks to my supervisors Carla Robledo and Jaco Reijerkerk. Carla's attentiveness and expertise in the field of 'vehicle to grid (V2G) systems', inspired me about innovations to include in my future plans and business proposal to Honda. She has been very accommodating in answering my questions and discussing challenges concerning my thesis. I would like to thank Jaco for making my research practically relevant, by combining desk-research with Honda's real-life cases and implementation of a business model. Additionally, he frequently involved me in fun projects; such as transporting a hydrogen fuel cell vehicle to Amsterdam and test projects at TU Delft's Green Village.

Finally, special thanks will be addressed to Honda's contact persons Martin Stadie and Jørgen Pluym, who have accommodated a visit to Honda's R&D test facility in Germany. Their information and knowledge have developed my understanding and improved the quality of my research. Also, I would like to thank Rishabh Ghotge for his insights and help regarding the simulation software. I really enjoyed working in such a dynamic field; in which I was able to think about innovative solutions that could be implemented in reality. It has been an exciting research period in which I got to experience many fascinating solutions that are going to change our energy system forever. Whatever the future might bring, I'm pleased to contribute to the important energy transition.

D.S. (Daan) Vonsée

Delft, September 2018

Abbreviations

AC: Alternating Current

AMI: Advanced Metering Infrastructure

API: Application Programming Interface

APX-ENDEX: Amsterdam Power Exchange and European Energy Derivatives Exchange

BEV: Battery Electric Vehicle

BFE: Bundesamt für Energie

BIPV: Building-integrated photovoltaic

BMS: Battery Management System

BRP: Balancing Responsible Party

CaPP: Car as Power Plant

CASP: Capacity ancillary service program

CPP: Critical peak pricing

DC: Direct Current

DER: Decentralized Energy Resource

DLC: Direct load control

DoC: Depth of Charge

DSB: Demand-side bidding

DSO: Distribution System Operator

EDR: Emergency demand response

EMS: Energy Management System

EV: Electric Vehicle

EVSE: Electric Vehicle Supply Equipment

G2V: Grid to Vehicle

H2V: Home to Vehicle

HAN: Home Area Network

HEMs: Home Energy Management system

HESS: Home Energy Storage System

HEV: Hydrogen Electric Vehicle

IL: Interruptible load

ISO: Independent System Operator

LCOE: Levelized Cost of Energy

MPPT: Maximum Power Point Tracker

NEC: National Electrical Code

PaL: Prêt-à-Loger

PHEV: Plug-in-hybrid electric vehicle

PLC: Power Line Carrier

PX: Power Exchange

RES: Renewable Energy Source

RTO: Regional Transmission Organization

RTP: Real-time pricing

SAE: Society for Automotive Engineers

SoC: State of Charge

TOU: Time-of-Use

TSO: Transmission System Operator

V2B: Vehicle to Building

V2G: Vehicle to Grid

V2H: Vehicle to Home

VDC: Volts Direct Current

VMS: Vehicle Management System

VPP: Virtual Power Plant

Abstract

Due to the intermittent character of renewable electricity sources and increasing decentralized electricity production, grid operators are facing challenges in balancing electricity- demand and supply within grid operations. These characteristics make it challenging for operators to forecast in- and outflowing electricity in the grid. This often leads to disadvantageous frequency-, voltage-, and electricity fluctuations in the grid. The implementation of smart grid technologies allows the easier integration of sustainable electricity sources and to increase the grid's reliability. Additionally, more components can be integrated in the grid system that can provide grid regulating services. In the context of sustainability, it's interesting to stress the potential of grid services delivered by parked electric vehicles. The principle of a Car as Power Plant (CaPP), where vehicles can provide electricity back to the grid via Vehicle-To-Grid (V2G) technology, can potentially solve challenges that grid operators are currently facing. This can be designed in such a way that the operation becomes beneficial for all parties involved. This research implies a techno-economic assessment of a power manager device; which is a multifunctional device that includes an energy management system (EMS), allows for vehicles to charge and discharge and functions as a converter (from direct current to alternating current). The power manager enables electric vehicles to deliver ancillary services when operating in V2G mode.

This research stresses the economic- and environmental benefits of a power manager; once it's integrated in grid-connected commercial- and residential buildings. Emphasis is put on buildings in future energy systems, which are equipped with DC loads and contain features that make the building operate in a more sustainable manner than today. For this purpose, several cases have been modeled to address the cost benefits of a power manager within a buildings' electrical system. The cost optimization is conducted by means of the HOMER optimization software. Environmental- and financial benefits could be achieved in a behind-the-meter operation, in case electricity flows are managed smartly and ancillary services are delivered to the grid. Price arbitrage and peak shaving were among the most emphasized ancillary services. By integrating electric vehicles by means of a power manager, the batteries of parked electric vehicles could get an extra function, besides being primarily used for driving purposes. Several cases have been optimized by applying a dispatch strategy, considering different components in the microgrid (solar panels, DC electrical loads, battery electric vehicles). These dispatch algorithms were embedded in the power manager's energy management system.

This research has shown that, once the vehicles' battery capacity was aggregated for grid facilitating purposes in a behind-the-meter operation, parties could achieve financial- and environmental benefits. This could be realized by integrating permanently parked vehicles within commercial- and residential buildings' electrical systems by means of a power manager. When a power manager was added to a building's system without

integrated solar panels, annual cost savings of € 35 and € 60 could be achieved respectively for residential- and commercial buildings by accounting for price arbitrage services. Once a power manager device was added to a building's electrical system with integrated solar panels, the renewable energy fraction of the system increased from 53.9 to 57.4 for a residential building and from 68.0 to 70.8 in a commercial building. Altogether, price arbitrage practices primarily caused financial benefits, while peak shaving services resulted in an increase in the system's renewability. It's presumed that a power manager's economic- and environmental benefits could increase once a larger battery capacity is obtained by aggregating BEVs in a 'before-the-meter' operation. Favorable regulations and privacy matters need to be established and discussed to make a power manager device run at its full potential. Additionally, it's important to determine what party will be fulfilling the aggregating role, and therewith, takes the responsibility for demand response operations. For this, a potential business case is established for the implementation of a power manager in the Dutch market.

Contents

1. Introduction

Since electricity demand has risen from 440 Mtoe in 1973 to 1,737 Mtoe in 2015, we have to deal with electricity shortage- and climate problems to sustain the earth's future (International Energy Agency, 2017). Sustainable energy technologies are needed to meet electricity demand and deal with the climate challenges we're currently facing. To meet this growing electricity demand, people are continuously seeking ways to improve the electricity grid and its corresponding electricity distribution system. The increased number of decentralized electricity generation systems and share of renewable energy sources (RES) installed has changed the way in which electricity is produced- and supplied to the electricity grid. In addition, the intermittent nature of these RES, cause fluctuations in the grid's voltage and frequency. This requires grid operators to manage and regulate the grid in a more efficient way. This challenge can be approached from both a producer- and consumer perspective. From a demand side perspective, a dynamically changing electricity profile is presented throughout the day. This indicates the importance of smart demand-side response methodologies that allow the electricity grid to meet the consumers' flexible electricity need (Liang, 2013). Therefore, the implementation of a so-called 'smart grid' facilitates the current electricity system and make it suitable for future prospects. According to Daim et al, the smart grid can be defined as *"an electricity network that incorporates a suite of information, communication, and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users* (U. Daim, Wang, Cowan, & Shott, 2016, p. 3)*".* In so doing, the smart grid facilitates the needs of end users and helps reducing the environmental impact by coordinating energy- supply and demand. Moreover, forecasting methods are becoming increasingly important for grid operators to adapt to electricity fluctuations in the grid (Liang, 2013).

The electricity grid system mainly operates in a demand-driven way, by passively adapting to time-varying electricity needs. However, this causes many power inefficiencies, and therefore, emphasizes the need for a future power system in which demand and supply are dynamically intertwined with each other. Smart energy optimizing software can help to proactively regulate electricity supply and demand. Consequently, it can deal with excess- and shortage power in the grid system. An energy management system (EMS) is needed within a building to optimally allocate electricity sources and balance the delivered grid’s electricity and building consumption. According to Amoo & Ranalkar, an energy management system can be defined as *“a system dedicated for a load which enables the user to control, monitor and optimize his energy consumption. The main objective of the use of EMS is to enable the consumer to monitor and control the amount of energy consumed or to consume in a more efficient way* (Amoo & Ranalkar , 2016, p. 1)*”.* Moreover, an EMS uses a mathematically based optimization algorithm that dispatches the electricity supply; based on electricity demand and consumers’ preferences (Alskaif & van Sark , 2018). For this, it communicates with all loads and electricity sources by making use of a smart meter (Khoucha, Benbouzid, Amirat, & Kheloui, 2015). Forecasting, predictive charge-/discharge sequences and consumers’ electricity preferences can all be integrated into the EMS’ algorithm. With the integration of such a system, decentralized electricity sources, home batteries, EV’s/Plug-In Electric Vehicles (PHEV’s), loads and grids can be efficiently managed. The benefits obtained from an efficient electricity system cause the system to also become financially attractive (Alskaif & van Sark , 2018).

Residential- and commercial buildings account for 40% to the world’s total electricity consumption and for one-third of the global greenhouse gas emissions (UNEP, 2016). This states the importance of involving buildings intelligently within the smart grid system. By storing grid excess electricity in electric vehicles’ batteries during electricity surplus and supplying electricity back to the grid during times of shortage, vehicles and buildings can optimally be used to increase the overall system’s efficiency (U.S. Energy Information Administration, 2017). In future energy systems, efficiency benefits could be achieved when power is interchanged directly between appliances, batteries, and electricity sources within a building. Moreover, most of future’s buildings will operate on direct current (DC) distribution systems; which leads to fewer conversion losses (Boeke & Wendt , 2015) than the actual situation where buildings are namely AC and appliances mainly run on DC. When looking at the residential sector, the share of DC internal appliances has increased by 17% between 1990 and 2013. Referring to 1990’s standards, this number is expected to even further increase to 250% by the year of 2030 since improvements in electricity efficiency can be obtained (International Energy Agency , 2016). Also, the increase in demand for electric vehicles and plug-in hybrid electric vehicles, whose batteries work on DC, indicates the need for investments in DC distributed grid systems. In this case, less conversion losses will apply since electric vehicles can be directly charged with DC- instead of AC current (Sabry A. H., Hasan, Kadir, Radzi, & Shafie, 2017).

Vehicles could play a major role in contributing to avoid grid shortages in the future. This is because vehicles function as an electricity storage device. Therefore, grid-integrated services; such as vehicle-to-grid (V2G), vehicle-to-building (V2B) and home-to-vehicle (H2V), will provide the grid operator with extra possibilities to manage electricity fluctuations in the grid (Khoucha, Benbouzid, Amirat, & Kheloui, 2015). A V2G system can be defined as *"a system in which there is capability of controllable, bi-directional electrical energy flow between a vehicle and the electrical grid. The electrical energy flows from the grid to the vehicle in order to charge the battery. It flows in the other direction when the grid requires the energy* (Briones , et al., 2012, p. 5)*".* The potential for using vehicles as a source of electricity supply is highlighted by the fact that vehicles are, on average, parked for 95% of the day. Therefore, this is interesting to consider (van Themsche, 2016).

1.1 Theoretical framework

The applicable theories that were used throughout this research are being made explicit in this section. All theories are related to the following research topics:

- Smart grids and DC microgrids
- Ancillary services with vehicle integration
- Value adding dispatch strategy

Defining the smart grid

The use of a smart grid can lead to financial benefits when costs are reduced by efficiently dispatching generators and by scheduling load demand. Hereby, the grid operator can meet electricity demand in a stable, resilient, and reliable way, by effectively managing electricity flows within the grid (International Energy Agency, 2011).

The infrastructure of the smart grid itself won't be enough to achieve financial benefits and electricity savings. Sabry et al., states that with the introduction of the smart grid; and considering its possibility for fast electricity exchange between grid components, the potential of a fully DC grid should be emphasized. Losses when converting to alternating current (AC) can be reduced when the grid entirely operates on DC, since roof-integrated solar panels, batteries and an increasing number of home appliances operate on direct current (Sabry A. , Hasan, Kadir, Radzi, & Shafie, 2017). Therefore, it's important to turn smart grids into DC operating grid systems. According to literature studies, DC grids can be significantly important for the future's energy sector and power systems. Especially, because a DC distribution brings along improvements in availability and causes a reduction of the system's complexity (Ott, Boeke, & Weiss, 2013). According to Schavemaker et al., *"nowadays, the trend is to integrate more and more decentralized generation (DG) into the system, by connecting small-scale generators at the lower voltage levels* (Schavemaker & van der Sluis , 2008, p. 223)*".* This trend will turn the current vertically operated power systems into horizontal ones, which makes the smart grid's coordinating characteristics even more important.

Dispatch strategies programmed in EMSs are mostly based on delivering ancillary services, such as load shifting, peak shaving, and electricity consumption scheduling. Therefore, they can be used to optimally deal with electricity fluctuations in the grid (Boynuegri, Yagcitekin, Baysal, Karakas, & Uzonoglu, 2013). Figure 1 shows an example of the operation of an EMS within a house, therefore called Home Energy Management System (HEMS). The building is grid-connected and includes a PV system, load and battery pack.

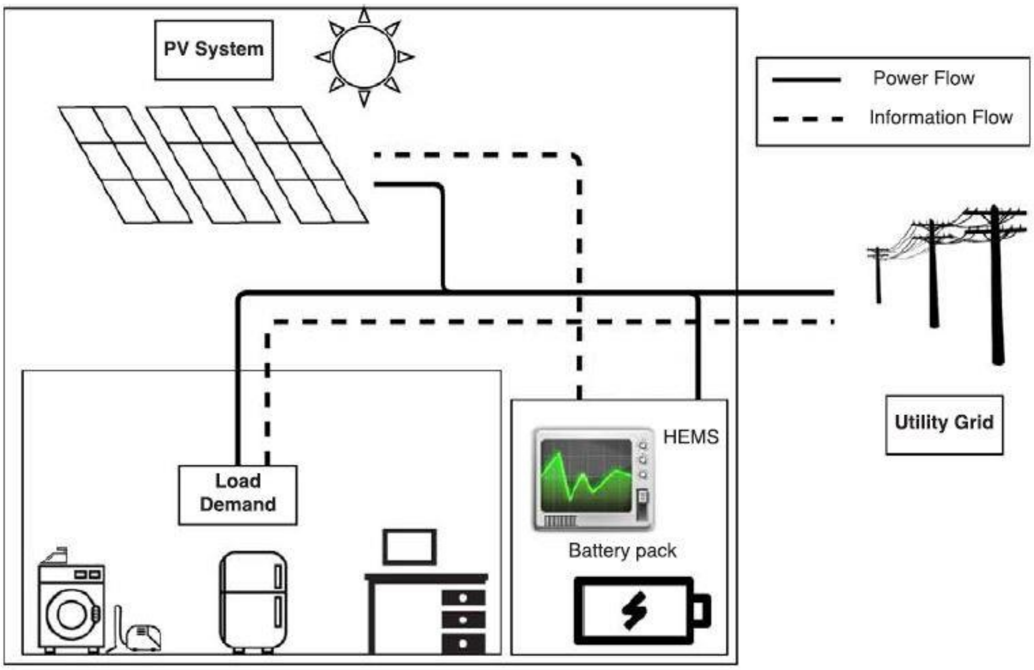

Figure 1: Schematic overview of a building integrated grid system; including an EMS. Adopted from (Alskaif & van Sark , 2018, p. 268).

As can be seen in Figure 1, the EMS is the control of the power and information flows within the building.

Ancillary services with vehicle integration

Electric vehicles and plug-in-hybrid electric vehicles can be integrated in an electricity network, by allowing for vehicle to grid, grid to vehicle (G2V) and vehicle to home (V2H) services.

When the electricity is directed back to the home or grid, the system can be seen as either a V2H or V2G system, respectively. The increasing number of EV’s and PHEV’s can also be successfully integrated into grid operations, especially when functioning in stationary mode (Ehsani, Gao, Gay, & Emadi, 2005). Therefore, it’s interesting to stress the potential of the integration of EV’s or PHEV’s in grid-connected buildings, both from an economic and electricity point of view (Tomic & Kempton, 2007) (Kempton & Letendre, 1997). Moreover, vehicles can deliver ancillary grid services during times of energy- oversupply or shortage in the grid. Additionally, vehicles can facilitate power transmission support in the power exchange process from the buyer to supplier. As a result, the grid becomes more reliable and trustworthy when operating in a sufficient way (Guille, 2009).

Figure 2 gives a schematic overview of the power flows within an electric vehicle, the vehicle's electricity exchange with the grid and how all this is integrated in the electrical system. The aggregator, system operator and end-users play a significant role in the electricity system and need to be included in the operations to add value by means of vehicle integration. The aggregator acts as a player between the end-user and the distribution system operator (DSO), by communicating a vehicle fleet to the DSO. In so doing, the aggregator collects individual EV data, considers the battery's state of charge (SoC) and provides the system operator with a data interface (Sortomme, 2012) (Singh, Kumar , & I.Kar, 2012). In turn, the system operator signals the aggregator; which controls the charge-/discharging pattern of vehicles (IEEE, 2012). The potential of integrating all actors is of great importance for the operation of the system. Hereby, financial benefits and cost structures for network operators and end-consumers must be considered.

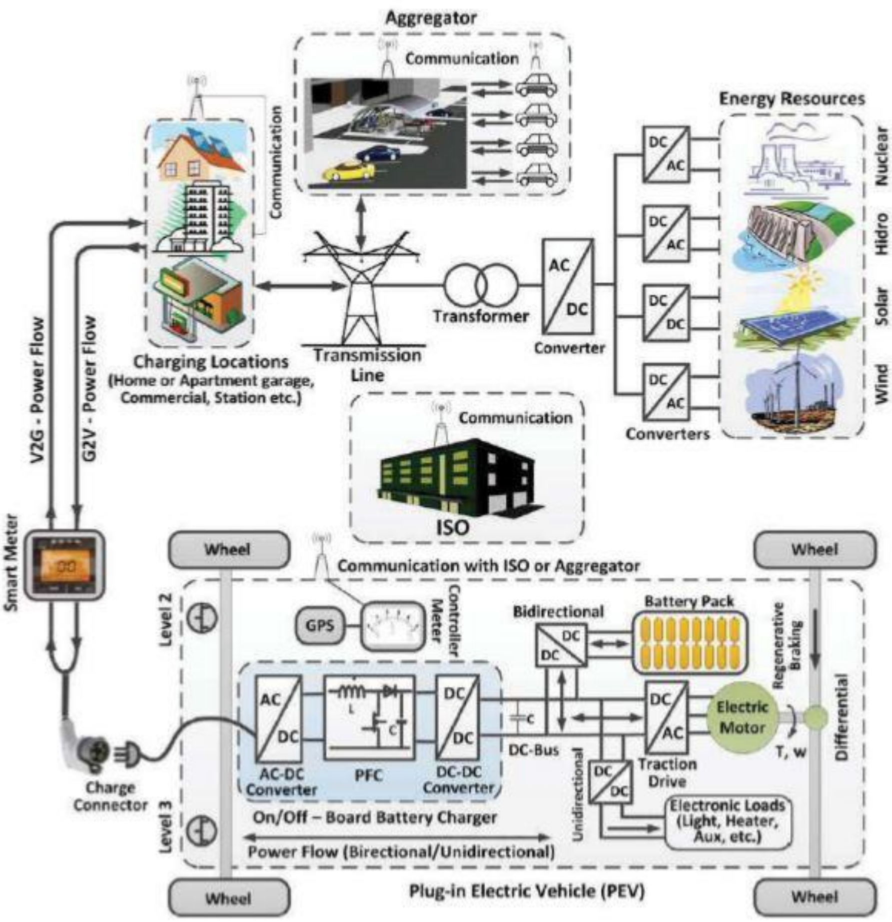

Figure 2: Components and actors within a V2G system operation. Adopted from (Yilmaz & Krein, 2013, p. 5675).

Value adding dispatch strategy

Different types of energy management systems have been addressed by literature. All of them aim to optimize the electricity system. However, the question is what is considered as being the optimal dispatch strategy. Therefore, a dispatch strategy is based on site-specific preferences and the purpose of the research. In Kumar's paper, the objective is to design a hybrid electricity system that optimizes the net present value of the project, whereas in Boynuegri's paper, the emphasis is put on giving priority to renewable electricity generation while meeting the primary electricity demand (Pavan Kumar & Bhimasingu, 2015) (Boynuegri, Yagcitekin, Baysal, Karakas, & Uzonoglu, 2013). Consequently, there are different ways to create value with a dispatch algorithm.

Figure 3 illustrates the process of value creation; in which integrated analysis, thinking and reporting are the underlying frameworks for developing a value creating algorithm. Integrated reporting stresses the importance of user involvement in the optimal dispatch strategy design, so that value can be created both internally and externally. In addition, integrated thinking and integrated analysis add to the circulating process of redefining decisions that have been made at an early stage. Consequently, this circular process stage leads to better decisions, actions and optimized resource allocation. In this way, value can be added from both an environmental- and economic perspective (3Consulting Media Center , 2017). However, long-term improvements can't be exclusively achieved by calculations and assumptions at an early stage. Moreover, it requires the assessment of values and decisions; which we think are important in the future (Mulder, 2007).

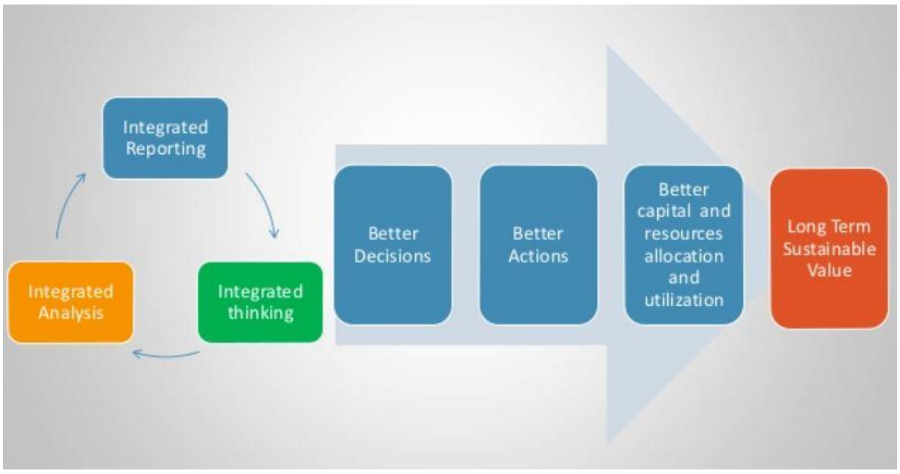

Figure 3: Process of value creation. Adopted from (3Consulting Media Center , 2017).

For instance, users can integrate their vehicle in the electrical system by means of a bi-directional charger, together with an integrated energy management system. Users become more aware of their electricity pattern and times of peak electricity consumption, by analyzing the entire operation in a smartphone application or by receiving electricity data in the form of a report. Additionally, differences in electricity consumption behavior can be seen by means of decreased-/increased electricity bills and the overall renewable electricity usage by the system. Based on this information, people can successfully adapt their electricity behavior to meet their objectives. Consequently, the integration of users within the system can lead to better decisions, actions and capital-/resource allocation. Moreover, the system can become even more efficient when people are able to program their times of electricity consumption within the established dispatch strategy. In so doing, the algorithm considers personal electricity behavior and manages the entire operation in a more efficient way. This can create long-term sustainable value.

1.2 Thesis scope

In this report, economic- and environmental aspects of integrating vehicles and solar panels within a residential and commercial building by means of a power manager device, is investigated. A power manager is a device that facilitates bi-directional charging and is equipped with energy management software. Additionally, it functions as a converter to integrate all DC and AC appliances and electricity supply systems. It can efficiently distribute electricity flows within a grid-connected building system. Additionally, the device enables end-users to use their vehicles for delivering ancillary services to the grid. For this purpose, Honda has developed a power manager that can efficiently integrate vehicles within a building's electricity system and manage electricity accordingly (shown in Figure 4). Therefore, the characteristics of the Honda power manager are used in this work as a sample device that stresses the capabilities of potential prospective devices. Since the device is still in a developing stage, it's interesting to investigate the economic- and environmental potential of the Honda power manager according to the Dutch grid infrastructure.

Figure 4: Honda power manager. Adopted from (Chademo, 2018).

This research focuses on a small office building and a residential building as a base case, which are located at the TU Delft's Green Village research area. This location is chosen since the intention of Honda is to install one of their power managers at this location to test and verify the device. In so doing, the technical- and operational capabilities will be evaluated. Herewith, this report focused on its capabilities in two different environments, namely residential- and small commercial buildings to identify the optimum business case for such a device. In the simulated models, several components, such as electric vehicles and solar panels were considered in either the presence or absence of the power manager. Also, different types of ancillary services that can be delivered to the grid by means of the power manager were evaluated.

The residential cases analyzed were mainly based on data and sizes acquired from the Prêt-à-Loger (PaL) house; which is located in the Green Village research area at TU Delft, the Netherlands (see Figure 5). The house has been designed and built by a group of TU Delft students for the purpose of the Solar Decathlon Europe competition held in 2014. The PaL building is chosen for simulation purposes since the house is designed in such a way that it operates in a sustainable manner. To suffice these sustainable requirements, the house is equipped with a layer, which thermally insulates the building. In addition, it's equipped with a central heating system, an air source heat pump, and a building integrated photovoltaic system. The house is used primarily for living- and research purposes and has a 148 m^2 gross area. Furthermore, the house is entirely electrified and has a bi-directional electricity connection with the electricity grid. It's assumed that one vehicle is integrated in the residential building's model.

Figure 5: Aerial picture of the Prêt-à-Loger building. Adopted from (EvH fotografie, 2018).

The influence of the power manager is tested on a commercial building as well. The reference office for the commercial building is located at TU Delft's Green Village as well (see Figure 6). This office consists of flexible work spots and sustainable in- and outdoor materials to optimize the building's electricity efficiency. Laminated wood from a European forest is used for the construction of the building. Additionally, the façade is covered with a thermally sustainable type of wood, which is treated with linseed oil. Also, the office facilitates rooms for research purposes and functions as a hub for innovative ideas. The building's area amounts 252 m^2 and provides workplaces for 20-25 employees. In addition, the building was recently equipped with an on-roof solar installation, which entirely covers the roof. The office is completely electrified and is assumed to have only DC appliances (Sustainer Homes , 2018) (the Green Village , 2018). Since there's no real electricity data yet, estimation for its solar production and electricity use has been made. It's assumed that three vehicles are integrated in the residential building's electricity system.

Figure 6: Office lab at TU Delft's Green Village. Adopted from (Sustainer Homes , 2018).

Altogether, the most financially- and environmentally attractive times for (dis)charging the vehicles' battery can be indicated from simulated results. Consequently, the battery's lifetime can be declared from the results based on the battery's total electricity throughput.

1.3 Relevance of research

Different ways of implementing energy management systems in buildings have been extensively stressed in research; ranging from smart management designs to the operational part of bi-directional charging-/discharging of electric vehicles. First of all, more emphasis is put on personalizing consumers' electricity behavior by proactively arranging electricity consumption within a grid-connected residential building. In addition, algorithms based on peak shaving, load shifting and optimal scheduling are applied to optimally arrange the interaction with the grid (Tejani, Al-Kuwari, & Potdar, 2011) (Li, Chung, Xiao, Hong, & Boutaba, 2011) (Virag & Bogdan, 2011). These algorithms exclusively consider the option to take electricity from the grid, without making use of sustainable decentralized energy resources (DERs). Especially when looking at future energy systems, it's significantly important to include renewable electricity production in both commercial- and residential buildings.

Secondly, research has focused on the design of dispatch models for optimizing the operation of loads and electricity sources within residential buildings. In so doing, they have included an electricity input supplied by renewable electricity sources and discussed cases in which they stressed the allocation of electricity sources within a grid-connected system; including home batteries, photovoltaic systems and loads. However, since they didn't include a sensitivity analysis in their research approach, it's hard to select the optimal method for dispatching energy- supply and demand. Therefore, it's important to consider this in further research. Also, many articles make use of mathematical optimization models to stress the impact of DERs on grid instability. Hereby, the potential of including demand-side response methods and pricing schemes in the model are considered. Consequently, the algorithms are being used to dispatch electricity production optimally to meet the household's electricity demand (Wang, Sun, Zhou, & Dai, 2012) (Alskaif & van Sark , 2018). Since these articles build further upon the cost aspects of a home energy management system's implementation, it gives a good overview of financial benefits for households. However, all of them lack the essential integration of EV's and PHEV's in the HEMS, which are factors that could potentially reduce electricity costs even more. This emphasizes the need for a cost-model that includes vehicles within a building's electrical system.

Thirdly, extensive research has been conducted in the field of electricity usage prediction within a microgrid electricity system. Microgrids can provide a good infrastructure for electricity flows within buildings, since the penetration of renewable electricity sources and the possibility for electricity exchange are being facilitated. In research conducted by Xiaolong *et al.*, day ahead dispatch methods have been used to forecast electricity usage and reduce electricity costs. Energy- and cost reductions were achieved by applying this model to commercial buildings, which makes forecasting and consumer behavior an interesting aspect to put emphasis on. This enables the grid operator to manage fluctuations in the grid (Xiaolong, et al., 2017). However, since this research includes only forecasting methods, it's less suitable to adopt in cases where real-time modeling is applied. Especially, since electricity can be stored in EV's and PHEV's, vehicles can function as a source of electricity supply and means of storage. This increases the vehicle's value within a smart grid system.

Finally, experiments have been conducted with the integration of vehicles in V2G, V2H and H2V operation, to optimally regulate electricity flows within a building and smartly contribute to the stabilization of the grid (Rotering & Ilic, 2011). In addition, smart algorithms have been designed for the integration of EV's/PHEV's in a grid-connected house; including an in-home battery, attached PV panels and loads, to optimally dispatch the electricity usage by allocating electricity sources (Khoucha, Benbouzid, Amirat, & Kheloui, 2015). Even though this is promising research, financial benefits haven't been considered. This makes it less likely that barriers and risks; faced by consumers, are taken away by adopting an energy management system.

Altogether, conducted research contributed sufficiently to the development of EMSs and the inclusion of V2H, V2G and H2V services within smart grids (Zeman, Bauer, & Chandra Mouli, 2016). Nevertheless, the conducted research often lacked the inclusion of costs in the model. In addition, it's not yet clarified whether an EMS gives consumers any financial benefits on a daily operation. Therefore, it's important to use an algorithm within the EMS that prioritizes the use of sustainable electricity and reduces the grid supply to a bare minimum so to reduce costs. Also, there seems to be an interesting potential for a system's cost reduction by integrating a vehicle fleet in a grid-connected system, since vehicles are being parked for 95% of the time. Therefore, electric vehicles can function as an electricity supplier and adaptive electricity storage. Results by Zeman et al. show the fruitful potential of integrating vehicles in an electricity system with a grid connection and solar panels (Zeman, Bauer, & Chandra Mouli, 2016). Since the integration of several vehicles showed its bi-directional charging potential, it's interesting to model such an operation together with the inclusion of the operation's economic aspects in this report. In so doing, an EMS's financial benefits can be stressed.

In this research, the emphasis is put on the integration of electric vehicle within grid-connected commercial- and residential buildings including an EMS system, building's load, PV panels and electric vehicles. The vehicles' battery capacity has been used to supply a building's electricity need and reduce grid fluctuations. The potential electricity savings and financial benefits, acquired from integrating electric vehicles, were stressed by including electricity prices and stressing a case with- and without a power manager.

1.4 Research question

By considering the before mentioned research contributions and shortcomings, this thesis seeks to answer the following research question:

"How can a power manager device contribute to environmental- and cost benefits in commercial- and residential buildings, by using electric vehicles' battery capacity to deliver price arbitrage and peak shaving services?"

To objectively answer this question, it's important to firstly stress the operation of a power manager within a grid-connected building. Secondly, the best combination of electricity sources and loads is stressed, after which the electricity efficiency and operation costs could be optimized. Thirdly, possibilities for the inclusion of bi-directional charging-/discharging services within the EMS' algorithm should be defined. Finally, the financial benefits and electricity savings could be determined. The main question is divided into the following 4 sub-questions:

Q1: How can a power manager operate effectively within a grid system by considering its contribution to the system's overall electricity efficiency?

Q2: What is the potential of including V2G, V2H and V2B services within the building's electrical system, when putting emphasis on a financially attractive operation for consumers and grid operators?

Q3: What dispatch strategy can best be used to optimize the operation of the proposed energy management system; including PV panels, loads, vehicle (s) with bi-directional charging ability and the grid?

Q4: What financial and environmental benefits can be achieved by integrating a power manager within commercial- and residential buildings?

The way in which these questions are answered is described in the method section of the report.

1.5 Research Approach

A techno-economic research assessment can be conducted in different ways. The multidisciplinary character of this research entails a research method in which several forms of data analysis and conducted research are proposed. Therefore, the main structure of the research report is based on the functionalistic research approach, as described and defined by Bhattacherjee (Bhattacherjee, 2012). An overview of this structure is shown in Figure 7.

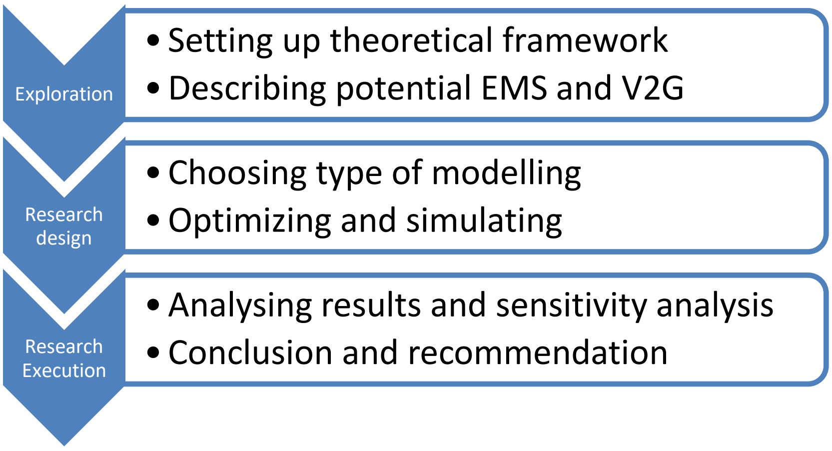

Figure 7: Overview of research approach based on Bhattacherjee's Functionalistic Research Process.

Exploration

The answer to sub-question 1 is formulated in the exploration phase, by using a literature review approach. In this approach, several theories and research outcomes were combined and used to stress the optimal operation of an EMS within a building. Additionally, books, company data and online sources were consulted for this purpose. Emphasis has been put on the most electricity efficient and cost-optimal operation of an EMS. Additionally, the answer to sub-question 2, concerning the functioning of bi-directional charging- discharging, has been expressed by using a literature review approach. Results of conducted case-studies have been consulted to indicate best practices, besides online sources and books. Subsequently, these could be adopted and applied in this research.

Research design

The research design amplifies all steps taken to successfully answer the main research questions. In this work, two grid-connected microgrid cases are analysed, namely a residential and commercial case. For these cases, the power manager's simulated dispatch strategy is described in a model considering the cases' overall cost- and environmental effects. The model was optimized by means of the HOMER optimizations software. The power manager's dispatch strategy is established based on the principles of the Trias Energetica model.

The Trias Energetica's 5 steps framework (as shown in Figure 8) especially focuses on the built environment and its carbon neutral design. The framework indicates that electricity use should be reduced in the first-place. Secondly, it's important that sustainable electricity sources are utilized. Thirdly, fossil energy sources should be used efficiently, only in case there is no option to avoid them. In the case of a building's operation, this can be interpreted as the process of taking electricity from the grid. Moreover, only 12 percent of the Dutch grid's electricity is currently produced by sustainable electricity sources and should therefore be avoided as much as possible (CertiQ, 2016).

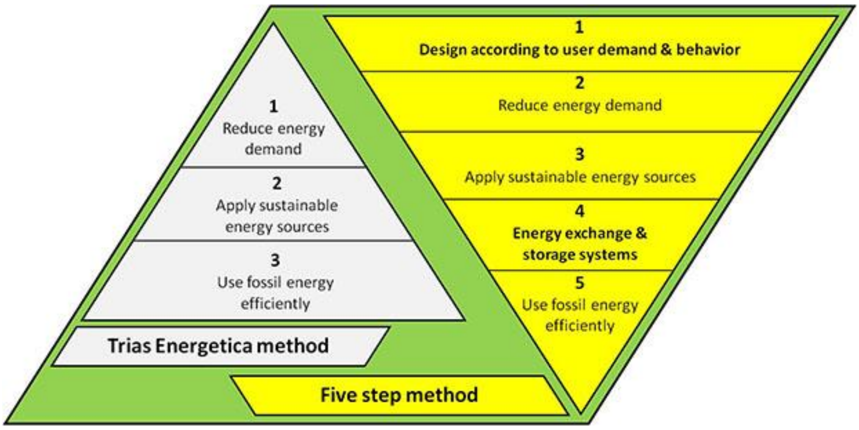

Figure 8: Trias Energetica for a sustainable building design. Adopted from (Gvozdenovic, Maassen, Zeiler , & Besselink , 2015).

An optimal dispatch strategy has been designed by having a close look at the consumers' behavior and living circumstances. Preferably, renewable electricity sources are used directly to meet primary electricity demand. A potential electricity oversupply will namely be stored or exchanged with the grid (Rijksdienst voor ondernemend Nederland , 2015). Several cost-optimization simulations have been conducted to determine the most economically favorable dispatch strategy within the Trias Energetica framework. Ultimately, decisions for selected data, model assumptions and the optimization model were argued.

Research execution

The analysis of the model's results is essential to answer sub-question 4, from which conclusions can be formulated. In this section, Sankey diagrams were obtained from the simulated results to visualize the power manager's influence on the buildings' annual electricity flows. Additionally, the extent to which a power manager allows for peak shaving and price arbitrage services is graphically reviewed. In the case of peak shaving, the amount of load shaved by the vehicle's battery is expressed in percentages. The occurrence of price arbitrage is clarified by graphically differentiating the grid's electricity supply during peak- and off-peak hours. After stressing the results of the residential- and commercial base cases, a sensitivity analysis has been conducted to stress the influence of varying- load, solar capacity and feed-in tariffs on the base case operation.

From this, conclusions and recommendations could be described. Finally, a business model is proposed to Honda describing ways to maximize a building’s economic- and environmental benefits by means of a power manager.

1.6 Structure of the report

In Chapter 2 of the report, background- and current status information is given about electricity efficient grid operations and operating actors within the electricity market. Additionally, the importance of DC systems is addressed and explained as part of future energy systems. For this purpose, the need for- and operation of energy management systems was highlighted. Chapter 3 describes the simulated model and the research approach. Emphasis is put on the simulated cases and input values for the HOMER optimization software. Results are shown and discussed accordingly in Chapter 4, after which recommendations are given to Honda in Chapter 5. Also, a potential business model has been developed in which special attention is paid to the integration of a power manager within a building’s electrical system. Final conclusions are presented in Chapter 6.

2. EMS and EVs within smart grids: background and current status

2.1 Grid operation

Smart grids become increasingly important. Especially in this era, in which the number of decentralized electricity resources keeps rising and the need for electricity becomes more flexible. Moreover, due to the intermittent character of renewable electricity sources, it's important to have an electricity infrastructure that's able to regulate energy- supply and demand during times of energy- surplus and shortage. The smart grid facilitates the distribution and flexible electricity exchange between (de)centralized electricity generation units and electricity consumers. As can be seen in Figure 9, generation, transmission, distribution & consumption are among the main aspects of a smart grid operation. The connection between the grid and most of the renewable electricity generators is established by means of power electronic interfaces. This gives the electricity output a different behavior in comparison with a synchronous generator, for instance. By making use of such electronic interfaces, the electrical output of renewable electricity sources can be regulated based on a certain power input. Therefore, this power electronic surface functions as a DC to AC converter and optimizes the electricity yield by making use of a power point tracker. Such a power point tracker is frequently being used in PV systems. The voltage to the transmission line can be increased by connecting large power plants to the transmission network with step-up converters. The control system of generation plants regulates the grid's voltage and frequency fluctuations (Schavemaker & van der Sluis , 2008) (Trilliant , 2017).

High voltage transmission is required to prevent significant ohmic losses in transportation cables. Most of the bulk electricity is transported over a large distance to local distribution networks before the electricity is delivered to the end-user. In the case of a vertically operating power system, the distribution network is highly dependent on the electricity flow coming from the transmission network. Moreover, the operation of a vertically operating power system can be computed beforehand more or less, since electricity will be generated and supplied to the distribution & generation network. Nowadays, an intelligent electricity network is required, since electricity is increasingly produced in a decentralized manner. This can be considered as being a horizontally operating system. When a horizontally operating power system will be sufficed, a more autonomous network can be developed; in which decentralized electricity sources can supply electricity demand on a local scale. Therefore, the system can be disconnected from the entire grid system and functions in a decentralized- and more controllable manner. A connection with the transmission line is still required to secure a backup electricity supply in case of a local power outage or electricity shortage, even though this might work efficiently from an electricity distribution point of view. The fact that both systems operate under slightly different frequencies and voltages makes this evolution challenging. As a result, the system control gets considerably complicated. Additionally, a leading system needs to be designated that will be followed by the other system. This can lead to prioritizing problems within the system (Schavemaker & van der Sluis , 2008).

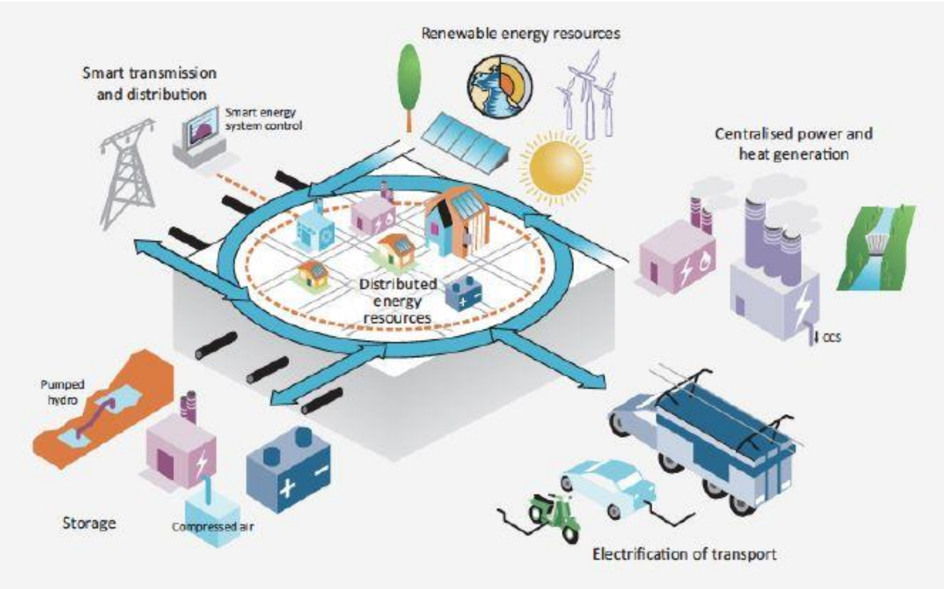

Figure 9: System overview of a smart grid operation. Adopted from (Obinna, 2017).

The distribution and consumption part concern the energy- delivering and exchange between residential- and commercial buildings. This part of the power system can be considered as a microgrid operation, in which decentralized electricity production and storage can take place. According to Zeineldin *et al.*, a better quality and a more reliable power system can be achieved, when a microgrid operation of distributed generators is performed (Zeineldin, El-Saadany, & Salama, 2015). In addition, cost and electricity savings can be realized by making use of fast switching electronic devices in DC microgrid operations. As a result, technical barriers can be overcome and a reliable system can be realized (Wunder , Ott, Szpek, Boeke, & Weiss, 2014).

Microgrid operation

Electricity consumption in buildings accounts for 40% of the world's total electricity consumption. A big impact can be achieved by making buildings more electricity efficient. One way is to make use of DC instead of AC power architecture. Using AC and DC appliances within a smart grid lowers the system's total electricity efficiency. This can increase the efficiency of total electricity use by 5% and the solar electricity input by 7%. In addition, higher investment- and maintenance costs apply. Moreover, using an AC-DC operating grid, with converters and rectifiers, causes more electricity losses. This is highly unfavorable (Weiss , 2011).

This power system can be made more efficient by implementing one central AC/DC converter, which is placed between the AC power network and the smart grid. This idea is schematically sketched in Figure 10.

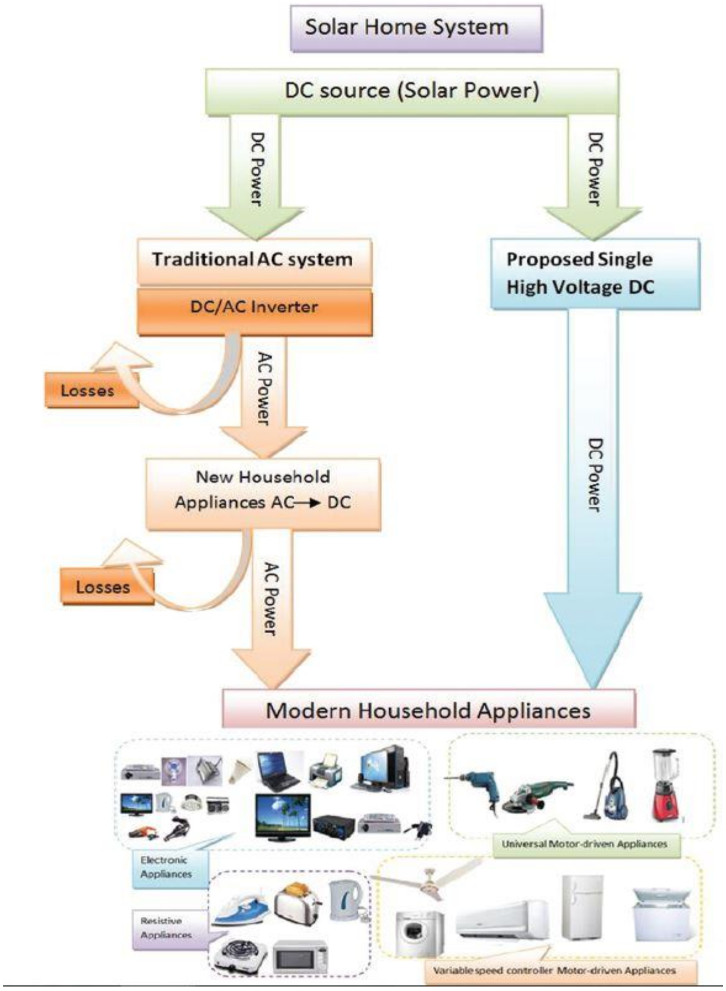

Figure 10: Overview of a traditional AC grid versus a DC grid system. Adopted from (Sabry A. H., Hasan, Kadir, Radzi, & Shafie, 2017, p. 4163).

Yet more research is needed in the field of power semiconductors and subsystems to make this model operate in a reliable way. Power semiconductors can control the electricity use and make appliances run at maximal efficiency. This decreases the emission of greenhouse gasses and reduces the operational costs. Therefore, these devices are considerably important (Weiss , 2011).

Design of DC operating grid system

A rectifier system can be used as an interface within the conventional grid, when a building with solar panels is connected to a 380 VDC grid. Therefore, all appliances, storage components and solar panels can become DC operated. This can result in 55% higher electricity efficiencies. This holds true for cases in which all appliances operate at full capacity. Additionally, the PV system efficiency can also be increased by 7% (Ott, Boeke, & Weiss, 2013).

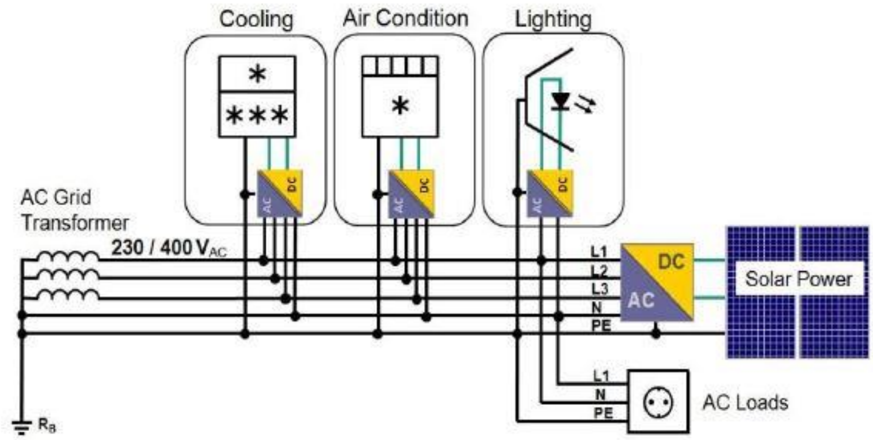

Figure 11: AC-grid system operation with a 3-phase connection. Adopted from (Ott, Boeke, & Weiss, 2013, p. 1).

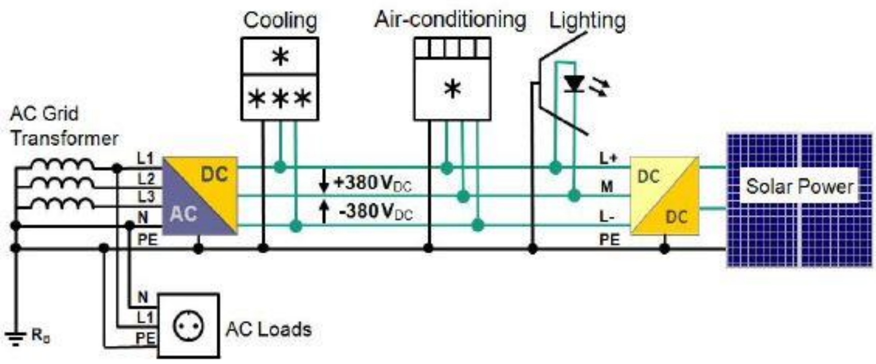

Figure 12: DC-grid system operating under 380 VDC with a 2-phase connection. Adopted from (Ott, Boeke, & Weiss, 2013, p. `1).

From the comparison between Figure 11 and Figure 12, it can be observed that fewer converters and rectifiers are needed when systems operate fully on DC. In this case, a converter is placed between the grid and the building's micro-grid. No conversion losses occur within the grid system because the electricity can be produced at a local scale. Additionally, the DC operation of a storage unit, home appliances, and a connected vehicle are matched. This system design will achieve a better distribution efficiency by considerably reducing the complexity of the system. A central rectifier and grid controller are needed to convert AC to DC and to regulate the grid's voltage (Ott, Boeke, & Weiss, 2013).

Actors within the electricity network

TSO

The central grid operator, commonly known as transmission system operator (TSO), is chiefly responsible for keeping the transmission system working correctly. A TSO possesses an own network, which mostly covers a larger geographical area. Therefore, their task is to exploit the transmission network and take care of the network's maintenance services. This makes a TSO possess an intermediate position between several control zones. Moreover, a TSO enables the generation of power and guarantees its supply to the 'distribution and consumption' part of the network. Investments are needed for this end. In so doing, the TSO facilitates the market by adjusting the grid's frequency and voltage in such a way that it suffices the required standards. The stabilization of the grid's frequency around 50 Hz ensures the system's reliability by taking out risks. In addition, a TSO controls the transmission system by mapping real-time power flows to functionally execute congestion management. Transmission system operators also establish connections with neighboring countries to interchange electricity by means of cross-border transactions. In so doing, the electricity capacity of the entire system can be insured (de Vos, 2015) (Entsoe, 2015).

DSO

The DSO is responsible for guiding and developing the distribution network. In so doing, it monitors and controls electricity meters on a regular basis and secures the network operation. Additionally, the DSO installs new grid connections to make the system run in a more reliable- and efficient way. The DSO has a public role by regulating the use of electricity and stimulating the use of decentral electricity generation. Altogether, the DSO's responsibility concerns the transport of electricity at the lower voltage level (de Vos, 2015) (Entsoe, 2015).

There are many requirements for transmission, generation and coordination processes. Therefore, it's important for each process to run at its maximal capacity and efficiency to assure electricity supply. In addition to 'physical' capacity requirements, the before mentioned processes also deal with financial aspects. A schematic overview of the electricity market operation is shown in Figure 13 (Ela, et al., 2014).

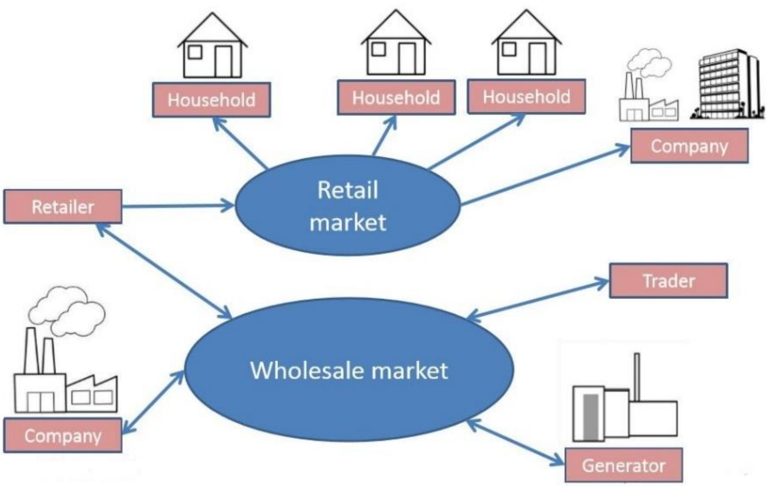

Figure 13: Schematic overview of the electricity market's energy- and money flows. Adopted from (de Vos, 2015, p. 46).

Electricity is sold to a retailer in the so-called wholesale electricity market. The actors that are involved in this market are, among others; generators, suppliers, traders and big consumers, such as commercial instances and industries. The market organizer offers an electricity trading service between actors within this platform. Retailers buy electricity from the market operator (APX-ENDEX) on the power exchange market (PX) and sell the electricity to households and companies in the retail market. Finally, the balancing responsible party (BRP) balances the electricity portfolio, by considering day-ahead electricity supply predictions. Moreover, the BPR publishes and nominates the day-ahead and intra-day trading and sends the applicable information to the TSO. Costs for potential imbalances are issued by the TSO and paid by the BRP. A well-functioning market is based on established bilateral agreements between actors. It's important that the TSO and DSO give consumers access to all electricity markets and make them cooperate herein. Therefore, consistency is required between the retail market and wholesale market to facilitate fair trade. In addition, it's important that aggregation of electricity sources occurs in an efficient way.

Electricity producing companies send offers to the wholesale market, while electricity consumers submit bids. The operator of the market (APX-ENDEX) clears the market price by using a market clearing method in which it includes and considers market bids and offers. Mostly, the market will be cleared 24 hours before the actual operation of the market. The APX needs to ensure the transparent supply of information from all actors operating in the wholesale market, so they can facilitate fair and sustainable bilateral agreements between the parties to which they apply. The market electricity price will be cleared based on an automatically functioning algorithm (Galiana & Conejo, 2008).

The price of electricity for a consumer is on average 0.20 €/kWh. This price is composed of 5 cents power costs, 11 cents electricity tax and 4 cents value added tax (VAT). The electricity tax is established by the government to stimulate reduction in electricity consumption. Consumers also pay a fixed cost for electricity consumption on top of the variable costs. This accounts for the connection to the electricity grid and the rent of the electricity meter. A consumer can choose for either a single- or double electricity tariff. In the case of a single tariff, the consumer pays one tariff regardless the time of electricity consumption. In the case of a double tariff, the consumer pays a lower tariff during off-peak hours and a higher tariff during peak-hours. Peak hours are in between 07:00 and 23:00 during weekdays. Off-peak hours apply from 23:00 to 07:00 on weekdays and during the entire weekend. The most beneficial tariff is based on the electricity consumption pattern of a building and is therefore case dependent (Miliecentraal , 2018). Residentials and commercials with a maximum of 3×80 Ampère grid connection are indicated as small electricity consumers by the electricity law. Residentials and commercials with a bigger grid connection are considered as being big electricity consumers. Other electricity prices apply for big- and small electricity consumers (Consuwijzer , 2018).

Aggregator

The role of an aggregator becomes increasingly important in future energy systems since it seeks to provide active demand services by aggregating the flexibility of consumers. In addition, the aggregator regulates the system's involved risks. In so doing, the aggregator fulfills a mediating role between power system actors; including consumers, electricity producers and other actors within the electricity markets (Ela, et al., 2014) (Entsoe, 2015). The aggregator's role in aggregating electric vehicles is schematically presented in Figure 14. As can be seen, the aggregator operates between the distribution- and consumption phase and aggregates a group of electric vehicles. This concept is not only applicable to electric vehicles. Locally produced and stored electricity by consumers can also be aggregated.

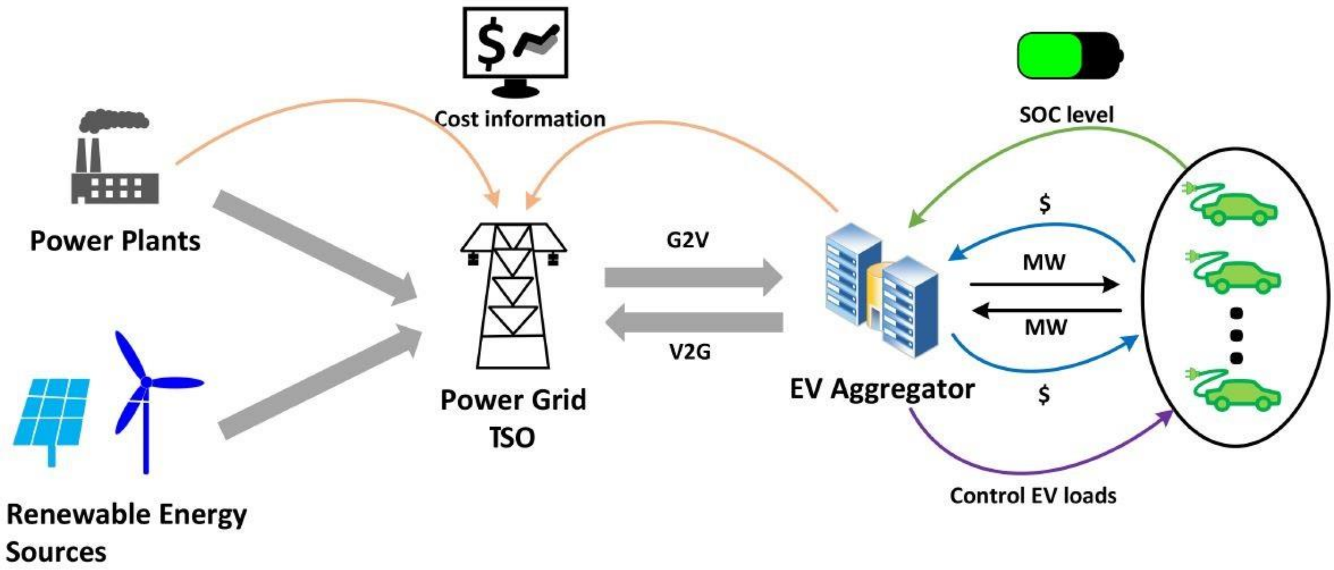

Figure 14: Role of aggregator within electricity system. Adopted from (An, Kyung-Bin Song, & Hur, 2017)

Government

The government also plays an important role within the electricity network in terms of consumer risk reduction. In so doing, it takes on regulations to stimulate decentralized electricity production within the electricity sector. This is mainly interesting for the increased number of consumers that became producers by means of installed solar panels on their rooftops. Consumers that also produce electricity are commonly known as prosumers. The Dutch government introduced the so-called *salderingswet* in 2004 to stimulate these sustainable developments. This law insured prosumers a fixed electricity purchase- and sell tariff, regardless the moment of production or usage. Moreover, excess solar electricity could be fed to the grid or handled for self-usage against the same tariff. However, this law will be interchanged for a feed-in tariff regulation by 2020 since the older system can't be persisted by the government anymore. This is due to the decreasing solar panel costs over the years. In the new regulation, prosumers will be paid a feed-in price according to the amount of electricity that is fed back to the grid. This grid-sell price will presumably be around 0.14 €/kWh, but the exact price is still unknown. The government aims to assure consumers approximately a 7-year return on investment time (PWC, 2016).

2.2 Ancillary services with vehicle integration

An increased pressure is exerted on the grid due to the increase of electricity generation by renewable sources. For this reason, it's important to investigate ancillary service possibilities that can be delivered by electric vehicles. Hereby, grid pressures can be reduced at a certain period of time. As broadly discussed and verified in literature, vehicles can contribute to this operation by mitigating pressure in microgrids using virtual power plants (VPPs) (Tushar, Assi, & Maier, 2014) (Abegaz & Mahajan, 2014). A VPP indicates a cluster of decentralized electricity generation units that can be controlled from one central point in the system, to balance energy- supply and demand. The vehicles' response time to grid signals needs to be considered, for delivering ancillary services. Moreover, a response time within a time range of 10 min is required to make vehicles function as a spinning reserve. For grid regulating services, a response time within 1 min is required. Both spinning reserves and grid regulations can be facilitated by electric vehicles in V2G operations, but signals need to be managed and communicated to vehicles at the right time. Therefore, the challenge is to match the driver's preferences with the time and need for grid services (Kemption & Tomic, 2005).

The integration of vehicles within the grid system has a big potential, because vehicles stand still for 95% of the time. Moreover, research has shown that the number of BEV's, PHEV's and Hydrogen Electric Vehicles (HEV's) will almost triple the amount in 2020 with respect to 2013. This relation is shown in Figure 15.

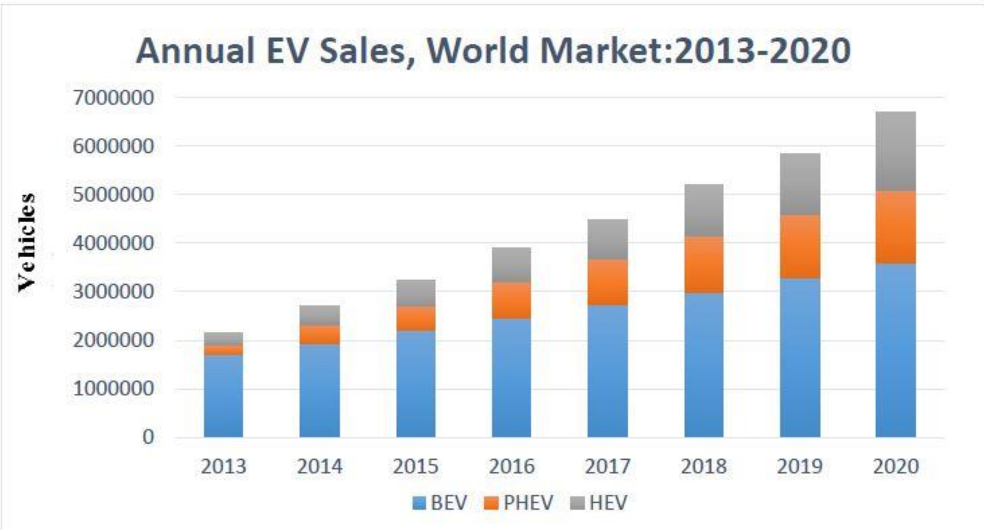

Figure 15: Worldwide sales forecast for passenger electric vehicles between 2013 and 2020. Adopted from (Garcia-Villalobos, Zamora, & San Martin , 2015).

Regional transmission operators (RTOs) can make use of the increasing number of electric vehicles by using them for grid regulatory purposes. Sustainable electricity is produced at different times throughout the day, so vehicles can be used to smartly react to sudden electricity supplies. The energy consumption and production of a typical household are shown in Figure 16. As can be seen, an excess amount of electricity is produced by solar electricity in the middle of the day. This electricity is supplied back to the grid when it's not used or stored. This is a waste of renewable energy. This electricity can be used efficiently by storing it in the batteries of EVs and making the vehicles deliver ancillary services in V2G, V2H or V2B mode. However, due to the increase in electric vehicles and their corresponding charge pattern during the night, new peak demands may arise that cause imbalances in the grid. As a result, this might lead to changes in electricity prices and increases the likelihood of dispatching more conventional generators. Therefore, it's important to regulate and schedule the implementation of vehicles within the grid in order to guide the operation in the right direction. Altogether, this could make the smart grid operate in a more efficient way and secure the stability of the electrical grid (Kinther-Meyer , Schneider, & Pratt, 2007). To fulfill such objective, demand side management techniques are usually employed in order to reduce electricity consumption from the grid at critical moments. This work focuses on price arbitrage and peak shaving.

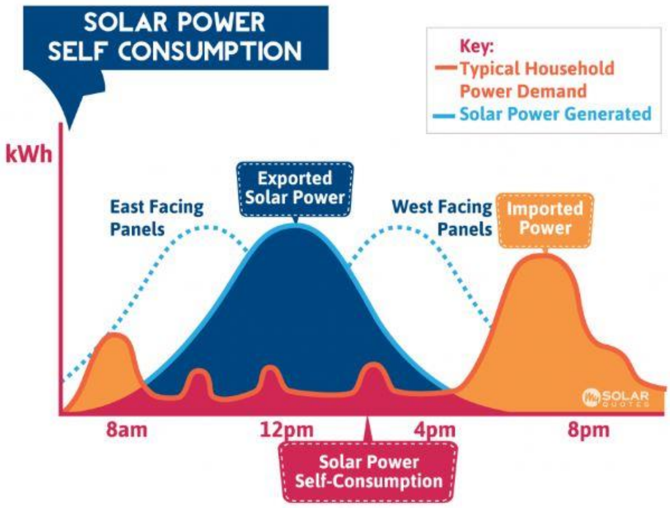

Figure 16: Schematic overview of the electricity consumption and solar electricity production by households on an average day. Adopted from (My Solar Quotes , 2018).

Price arbitrage

The principle of price arbitrage is to buy electricity from the grid against lower electricity prices, mostly during off-peak hours, and store this energy. This electricity can in turn be used or sold during peak hours; when electricity from the grid is more expensive. Since electric vehicles can be used as a battery electricity storage system (BESS), it's interesting to stress the environmental- and financial benefits of using vehicles for this purpose. For this end, battery degradation and availability need to be considered. (Wankmüller , Prakash, Gallagher, & Botterud, 2017). Time of use (TOU) tariff billing arrangements need to be established with the electricity provider in order to make this process operative (Staffell & Rustomji, 2016).

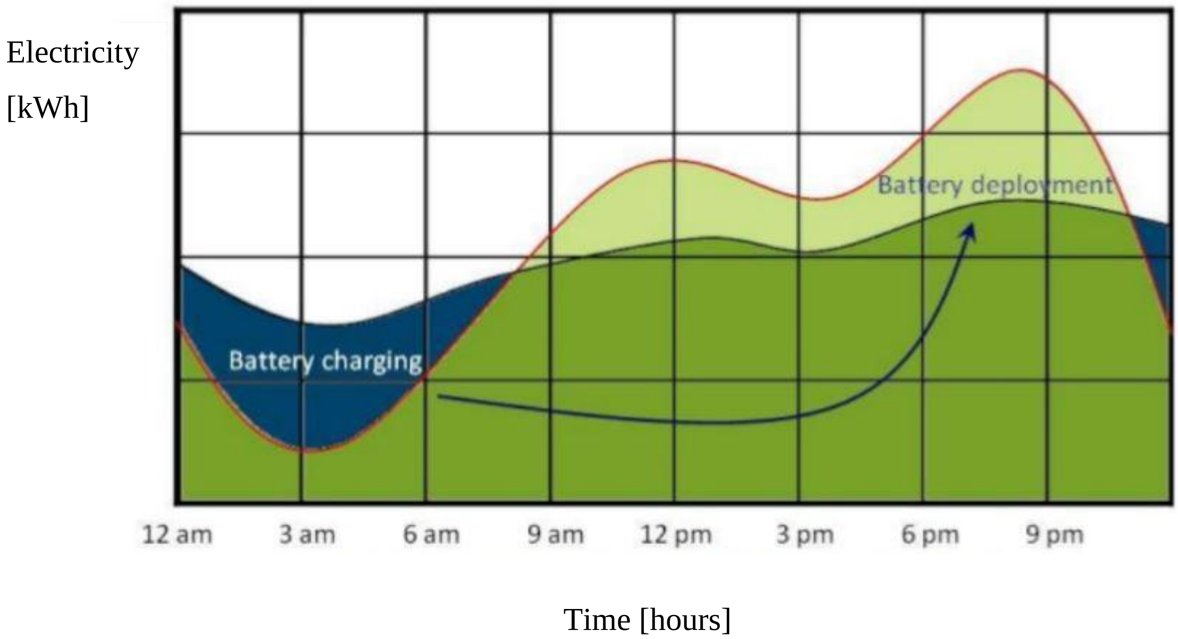

Figure 17: Schematic overview of the essence of price arbitrage. Adopted from (Voltio, 2017).

Figure 17 shows the principle of price arbitrage in a schematic way. Electricity is purchased cheaply from the grid and stored in batteries. Consequently, batteries can be discharged during times of higher electricity prices. This electricity can in turn be sold to the grid or used to serve loads. This offers financial benefits to customers. Also, grid owners benefit from price arbitrage services since the grid's power quality becomes more consistent during times of peak demand. This tackles power losses that are caused by delays and the grid's response time. Finally, grid arbitrage contributes to the overall sustainability of the system. Normally, unexpected peak demands are covered by dispatchable generators that mostly run on fossil fuels. The reason for generators to be used, has to do with the fact that generators are power sources that can directly be dispatched and are not dependent on weather circumstances to produce energy. This creates a bigger overall carbon footprint, in comparison with a situation in which electricity would be supplied from stored renewable electricity capacity. By including the option of price arbitrage within the power manager's EMS, the return on investment can become less due to the resulting financial benefits.

Peak Shaving

Peak shaving is a form of grid regulation. In the process of peak shaving, electricity storage devices reduce the electricity demand during periods of peak loads. High electricity peak demands instigate additional electricity capacity and infrastructural costs for utility companies. This allows utility companies to dispatch additional power sources to meet peak demand. These dispatched power sources are mostly older, more expensive and less sustainable. This has to do with the fact that they need to be turned on instantly, especially when a sudden electricity peak occurs. Consequently, peak loads can't always be served by sustainable electricity sources. To overcome this occurrence, sustainable electricity within batteries can be used to cover for peak loads that suddenly occur. In so doing, stored electricity can be used to 'shave' peak loads during times of high electricity demand. As a result, the system's electricity demand decreases and the share of sustainable electricity increases (Pimm, Cockerill, & Taylor, 2018).

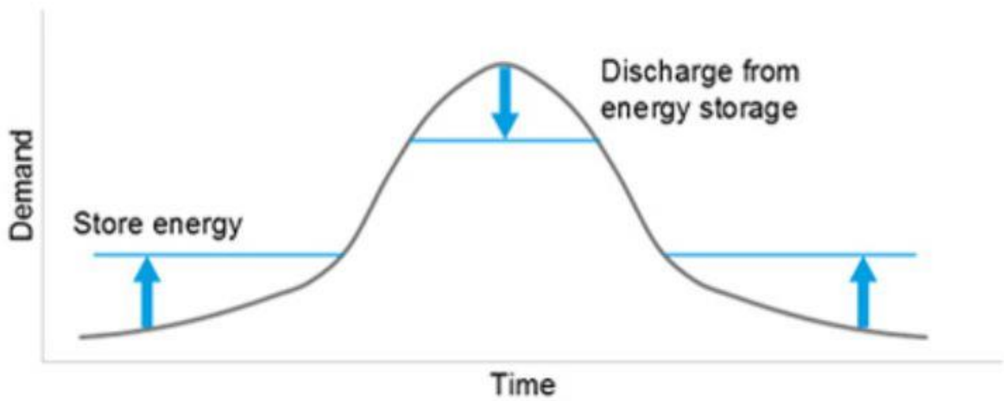

Figure 18: Schematic overview of the essence of peak shaving. Adopted from (Na4B, LLC, 2018).

Figure 18 shows the principle of peak shaving in a graphical way. The stored electricity is used to reduce electricity peaks during periods of high electricity demand. In so doing, customers can facilitate grid operators by exposing their storage capacity to the grid. Subsequently, less expensive generators have to be dispatched. Another advantage is that utility companies don't have to purchase new expensive power plants in the long term. According to Soon-Jeong's article, realistic peak shaving practices maintain EV penetration percentages between 10- and 30% in a V2G operation (Soon-Jeong, Yun-Sik, Sim, Min-Sung, & Chul-Hwan, 2017).

Operation of bi-directional charging

Nowadays, most of the buildings are equipped with either 110-V or 220-V chargers, dependent on the circumstances and preferences of charging speed. The latter one charges twice as fast compared to the first one. Research has shown that residential charging provides electricity that is needed by electric vehicles for approximately 65-80% of the time (Daim, Wang, Cowan , & Shott, 2016). Vehicle owners either pay the utility company for the supplied electricity or produce electricity for own consumption in a decentralized manner. Vehicles are able to produce the same 50 Hz frequency that's being maintained in most residential buildings (Gage, 2003). Since one vehicle won't be noticeable in a large grid operation, it's interesting to investigate possibilities for vehicle fleet implementation within the system. Hereby, substantial value can be offered (Yilmaz & Krein, 2013).

There are some classification rules for AC and DC charging; which has been established by the SAE (Society for Automotive Engineers) and NEC (National Electrical Code). Since this research mainly focuses on DC grid operations, it's important to stress that the AC-DC conversion happens outside the DC system. Therefore, DC charging mostly has favorable power transfer characteristics over AC charging. Electric vehicle supply equipment (EVSE) is used at charging facilities. A charging device that also manages the exchanged power is situated between the vehicle and the grid. Level 3 charging provides the shortest charging time of all 3 existing charging levels (4E, 2017). The mentioned charging levels are depicted in Table 1.

Charging level	DC		
	Voltage (V)	Current (A)	Power (kW)
Level 1	200 – 450	< 80	< 36
Level 2	200 - 450	< 200	< 90
Level 3	200 - 600	< 400	< 240

Table 1: Power levels for AC- and DC charging. Adopted from (4E, 2017).

As can be seen in the table, DC charging level 1 is characterized by a 200 to 450 volts direct current (VDC), 80 A maximum current and 36 kW maximum power. This charging level is commonly used in private and office charging facilities and is considered as being the basic charging level. Level 2 charging is commonly used for fast charging purposes when considering the public and private charging applications. It utilizes voltage levels ranging from 200 to 450 VDC. Additionally, it has a maximum current of 200 A and a maximum power of 90 kW. Figure 19 schematically shows the operation including level 1 and level 2 DC charging.

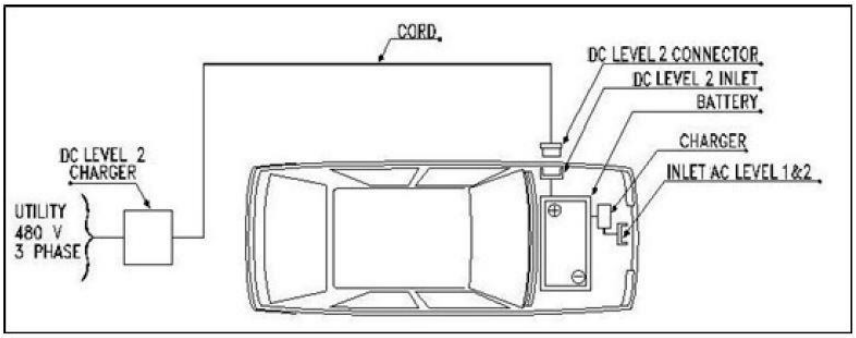

Figure 19: Schematic overview of the level 1 and level 2 DC charging process. Adopted from (Briones , et al., 2012, p. 17).

A DC Level 2 charging facility service is comparable to present-day's gas stations. The facility charges a vehicle (having some 85-100 miles range) for 80% within 30 minutes. This corresponds to a capacity of 24 kWh. A DC level 3 charging facility is widely considered as the charging facility for future purposes. It will potentially be adopted as a charging solution for heavy-duty vehicles and other industrial applications that require large amounts of energy. Therefore, this charging level is currently not competent for this report's residential- and commercial charging facilities. Consequently, the potential of a DC level 2 charging facility is stressed in the report (4E, 2017).

Load demands and charging process

The overall electricity consumption by buildings is displayed within Figure 20. As can be seen, electricity demand peaks for residential buildings mostly occur around 7:30 in the morning and 17:00 in the afternoon. In contrary, commercial buildings have a more equally distributed load between 8:00 in the morning and 18:00 in the evening. Since electric vehicles are continuously parked in front of buildings in an ideal scenario, they could favorably store electricity during off-peak hours and subsequently use that electricity to deliver ancillary services during peak hours. Since these load patterns are characteristic for every weekday, dispatch strategies can be ingeniously designed to use the parked vehicles' battery capacity efficiently. Also, advice can be given concerning best moments to use vehicles for driving purposes, since vehicles can be used flexibly (Hayes, 2013).

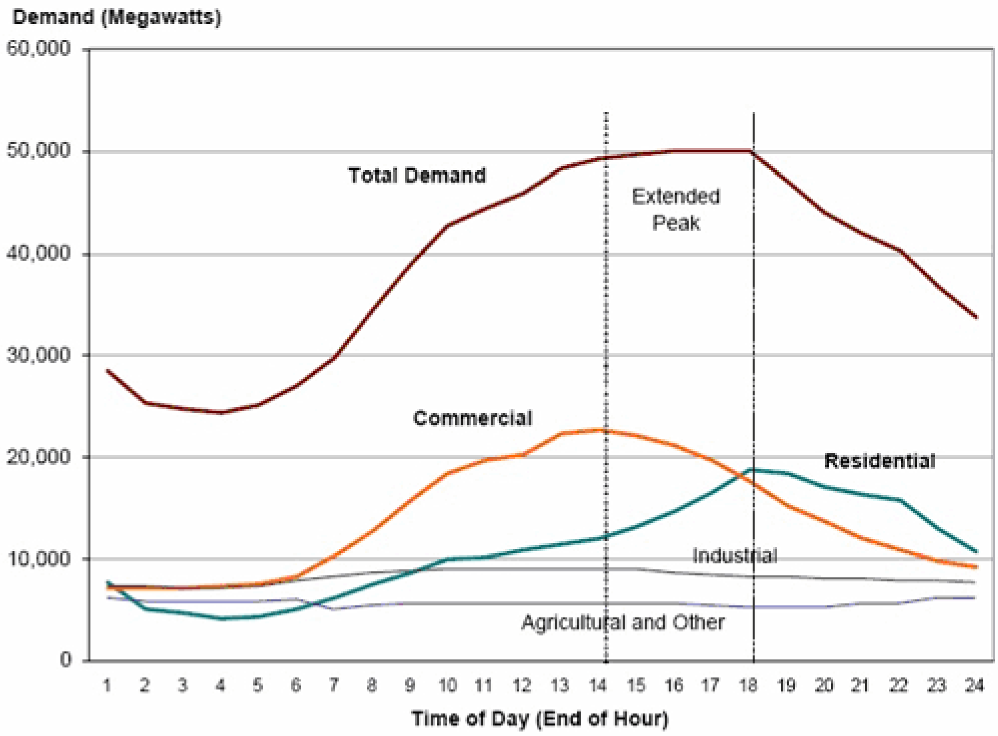

Figure 20: Schematic overview of residential-, commercial- and industrial load patterns on an average day. Adopted from (Woodbank Communications Ltd, 2018)

Control systems are needed to schedule charging- and discharging practices throughout the day. They need to operate such that all parties benefit from the delivered ancillary services. This can be realized by designing a smart dispatch strategy that satisfies the battery's SoC requirements, intermittencies in the grid and the parties' additional preferences (Briones , et al., 2012).

In the case of residential buildings, utilities make bi-directional charging services practically- and economically viable, by installing an advanced metering infrastructure (AMI) between the utility's grid services and consumers. This device enables utilities to measure the consumers' power demand, energy-consumption and demand pattern, after which data can be used to inform consumers about these aspects. It might be tried to change consumers' electricity behavior by making them aware of their electricity usage. In so doing, consumers start to contribute to grid regulating services by shifting their peak demand. Subsequently, utility companies can conduct peak shaving practices successfully. Financial benefits indirectly regulate electricity supply and demand since they can change consumers' behavior. AMI's can also identify a vehicle in the grid system and make it cooperate as a power supply- or storage component. Therefore, the AMI functions as a communication device between the consumer and utility company. A user assessment needs to be established before participating buildings are qualified to provide a reliable and permitted V2G operation. These regulations could, in the end, contribute to a successful bi-directional charging operation. Codes and requirements differ per authority and need to be verified before execution (Briones , et al., 2012).

It's important to consider that battery degradation occurs when the vehicle feeds electricity to- and takes electricity from the grid. Therefore, the battery's ideal SoC and depth of charge (DoC) need to be stressed to keep the operation within preferred limits. Consequently, battery degradation effects can be minimized. The battery's lifetime is increased by a factor 3 when maintaining an 80% depth of charge (Peterson, Apt, & Withacre, 2010). Moreover, according to Guille, deeper charging cycles have a negative impact on the vehicles' batteries (Guille, 2009)**.**

Business opportunities

Battery electricity storage is applicable in various industries and sectors. As can be seen in Figure 21, the battery's flexible characteristics enable the device to be used in a centralized-, decentralized- and mixed setting. Additionally, Figure 22 shows that conventional stabilization, industrial peak shaving and balancing electricity are among the most profitable business case potentials. These applications can be considered as being the most suitable for utilizing bi-directional (dis)charge facilities; including the delivery of V2G and V2B services. Increasing the feasibility of such business models and applying ancillary services in the industrial sector are among the biggest challenges to overcome.

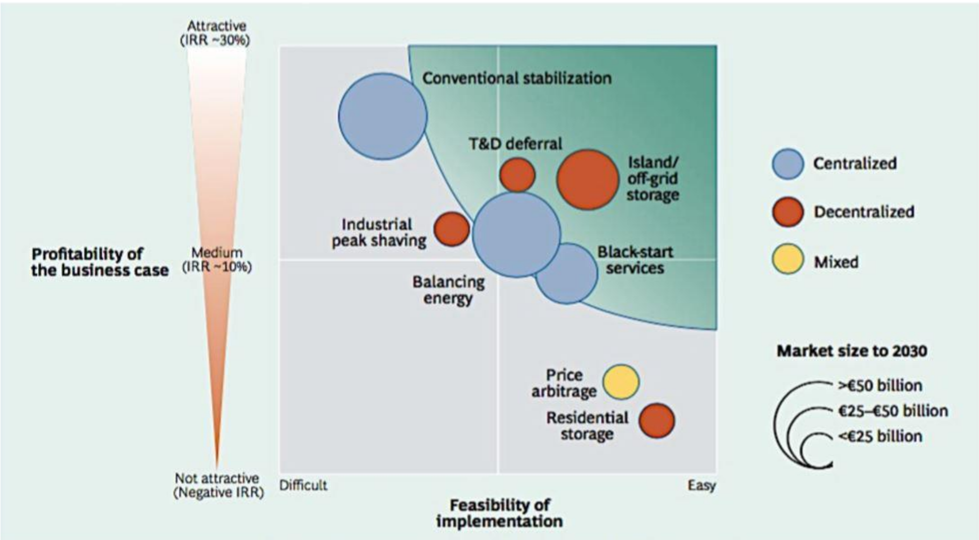

Figure 21: Suitability of a business model stressed for several battery storage applications. Adopted from (Pieper & Rubel , 2011, p. 13).

Several cost structures apply for installing a bi-directional charging-/discharging facility at a commercial building. These include suitable cost- and revenue structures. Capital costs, operational costs and infrastructure costs need to be considered when designing an optimal facility. In general, the vehicle primarily functions as a way of transportation and is thus being used for mobility purposes. Therefore, the capital cost of a V2G operation in which a vehicle's battery is used to deliver ancillary services, is relatively low. This is because no significant costs apply for the process of integrating the battery into the electrical system's operation. In addition, the opportunity costs for using the vehicle's battery as a storing component are considerably low, because the battery is functionless in case it's not used while being parked (Kaufmann, 2017). Even though the capital- and installation costs are considerably low, it must be noted that battery degradation occurs faster in case they are used to deliver ancillary services. The extent to which degradation occurs depends on the battery's frequency of use. It's hard to estimate the entailing infrastructure- and operational costs since the bi-directional charging-/discharging operation is still new and upcoming (Fournier, Baumann, Buchgeister, Weil, & Seign, 2013).

The V2G operation's costs depend on the rewarding system that is being offered to employees, as well as the extent to which the utility company is willing to offer a fair price for delivering ancillary services to the grid. An employee rewarding system should be integrated since the company requests employees to be loyal by allowing vehicle exposure to the grid. Additionally, a compensation might be desirable that covers the vehicle's battery degradation costs. Namely, more charging- and discharging cycles occur on a daily basis. This can alter the quality of the vehicle's battery. Battery degradation caused by delivering ancillary services is considerably lower than degradation caused by driving support. However, it's still important to consider (Kaufmann, 2017). Consumers also demand a convenient and comfortable way of using their vehicle. Moreover, they want to substantiate their desired state of charge at a certain moment during the day. This is based on their personal preferences. Altogether, customers might be willing to give up part of their flexibility in exchange for an appropriate compensation. Utility companies prefer batteries to be exposed to the grid for a longer period of time, so the flexibility of the vehicles' storage capacity can be optimally used. Empty- or not yet fully charged batteries are preferred since the storage capacity can be used as a buffer. Based on these perceptions, several strategies for charging services can be established and developed. Moreover, a longer exposure time to the grid should be rewarded and can be established in an employee benefit plan. Delivering ancillary services can then be covered by offering a price premium (Sovacool & Hirsh, 2009) (Kemption & Tomic, 2005).

In general, several considerable cost structures exist for V2G operations. One option might be to reward people who are willing to expose their vehicle's battery for a longer period of time. This can, for instance, result in lower electricity tariffs and higher financial rewards for exposed batteries. In this way, both employees and employers can benefit from the advantages that ancillary services bring along. Secondly, it's important to implement rewarding schemes to change people's behavior so to make them aware of peak demand hours and differences in the electricity price. By providing amenities, people might be willing to increase their loyalty to the utility company and expose their vehicle to the grid during times of peak demand. In so doing, they facilitate grid regulation by providing peak shaving services. Altogether, it's beneficial to optimally schedule the battery's charging procedure and maximize the potential of ancillary services that are delivered to the grid (Kaufmann, 2017).

2.3 Value adding dispatch strategy

Demand side management can be conducted by making use of an intelligent grid and EMS (Brooks, Lu, Reicher, Spirakis, & Weihl, 2010). An EMS can manage electricity efficiently by considering humans' preferences and the intermittent character of renewable electricity sources. For this end, an EMS extensively makes use of smart algorithms and software. This enables consumers to efficiently use available electricity in a self-directed way (Vojdani, 2008) (Zhang, Li, & Bhatt, 2010). Opportunities for integrated electricity management systems significantly increased due to the development of smart communication devices. These devices are operating on the interface between end-users and utility companies. The home area network (HAN), home energy storage systems (HESS), smart sensor technologies and advanced metering infrastructure (AMI) are commonly known among these devices. These technologies and devices form a versatile platform within a grid-connected building to which EMSs can be connected (Liu, 2010).

The purpose of an EMS is to minimize the overall electricity utilization (Wang & Xu, 2004). It's a challenge to develop an all-embracing dispatch algorithm that considers all components within the system. Moreover, many communication challenges, infrastructural challenges and the devices' dynamic characteristics apply. For instance, electric vehicles are being randomly exposed to the grid and need to be charged during the day accordingly (Han & Lim, 2010). In so doing, it's important to consider the consumers' lifestyle and make use of human-interface devices to make consumers part of the electricity control system (Ma, Yang, & Lin, 2014). Research has shown that peak load demands can be diminished by 29.8% and electricity-related operational costs by 23.1%, in case an EMS is added to the system (Beaudin & Zareipour, 2015). EMSs also contribute to consumers' well-being, eco-friendliness and by achieving an electricity waste reduction (Kailas , Cecchi, & Mukherjee, 2012) (Beaudin & Zareipour, 2015).

Nowadays, the utilization of sustainable electricity sources contributes to a large extent to the overall produced electricity. This causes the grid to get aggravated more at certain times during the day. Therefore, this trend emphasizes the need for decentralized EMSs that can manage electricity based on consumers' electricity demand. Moreover, consumers become increasingly flexible in terms of electricity consumption due to dynamically changing schedules and grid-connected vehicles. These developments increase the need for intelligent autonomous systems that can meet electricity demand and adapt to intermittencies in the grid. In addition, storage during grid oversupplies can be regulated by an EMS, which in the end, makes grid operations more reliable (Ma, Alkadi, Cappers, & Denholm, 2013) (Li, Zhang, Roget, & O'Neill, 2014). The two-way communication stream and electricity flow between the grid and consumers urge the need for demand response. People get financially supported to utilize electricity during times of oversupply because electricity is mostly cheaper at those times. Additionally, the retail price and electricity demand are continuously coherent to each other. This is because the electricity price is determined based on electricity supply and demand. As a result, electricity demand gets shifted towards off-peak hours. This is beneficial for the grid operation (U.S. Department of Energy , 2006) (Zhao, Sheng, Sun, & Shi, 2011). The flexibility of electricity within the grid causes the adoption of EMS to become significantly important.

Hubert and Grijalva's article describes an EMS's potential, by testing three scheduling schemes (Hubert & Grijalva, 2012). Namely, the article clarifies the cost- and environmental benefits of integrating battery storage and solar electricity production within a building's electrical system. Additionally, it stresses the effects of several dispatch strategies on the entire electricity operation. A residential base scenario is offered in which consumers were mainly able to schedule controllable loads. However, best electricity efficiencies and cost-benefits were achieved when people had the possibility to add an electricity storage system, sell electricity, install solar panels and include other DERs. This entailed an increase in the objective function from 34.9% to 86.6%; with respect to an established base-case scenario (Hubert & Grijalva, 2012). Subsequently, solar panels, load appliances and vehicles functioning in V2G mode, were included in this research's optimization model. With the dispatch strategy, it's aimed to maximize sustainably generated electricity and optimally reduce electricity losses. Average grid prices were used as an input for the model since day-ahead pricing and real-time pricing generally lead to higher electricity bills. Moreover, the algorithms determined the amount of electricity taken from- and supplied to the grid. In so doing, the article indicates the added value of an EMS in a realistic residential case scenario. This report follows up on Hubert and Grijalva's research by integrating a vehicle's battery as storage component and by investigating the economic- and environmental benefits of an EMS within a commercial building as well.

Operation of EMS

Savings on electricity bills and the efficient utilization of energy, are examples of the economic benefits that consumers might encounter (Tsui & Chan, 2012). These benefits can be achieved by making use of application programming interfaces (APIs); which are communication devices that are positioned between producers and consumers (Kahrobaee, Rajabzadeh, Kiat, & Asgarpoor, 2013). HANs make sure that information regarding the use of electricity is monitored and provided to the grid operator. In so doing, real-time monitoring can occur remotely, and system control is able to take place in a demand-controlled manner. This can also be obtained by making use of a human-interface or smartphone application; in which consumers can establish their preferences regarding the utilization or production of electricity throughout the day. Moreover, EMSs can efficiently dispatch electricity among distributed energy resources (DERs) and schedule load demands (Han, Choi, & Lee, 2011) (Jeong, Sic, Ki, Soo, & Woo, 2011). Figure 22 shows a schematic overview of a home energy management system that operates within a grid connected system.

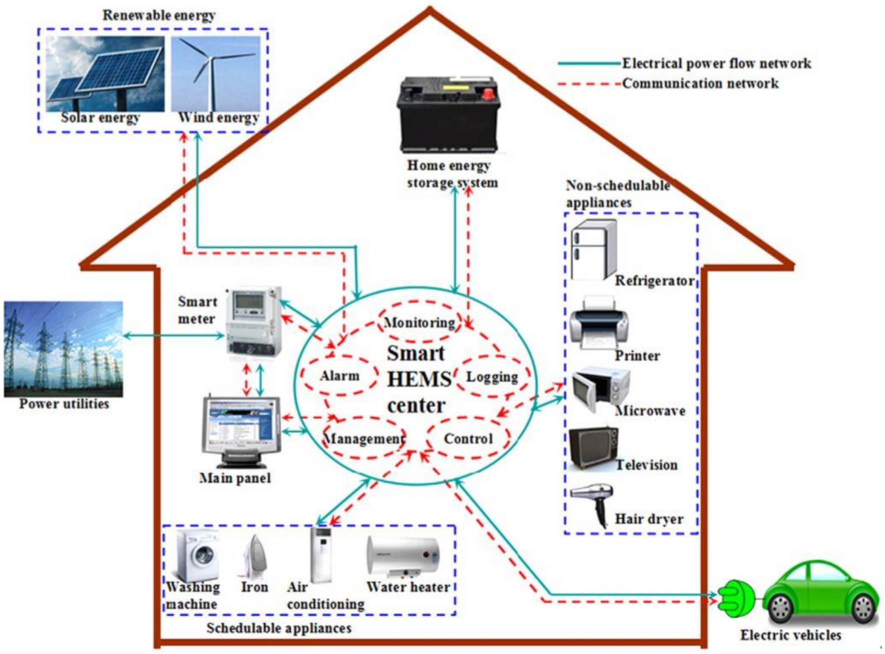

Figure 22: Schematic overview of the architecture of a HEMS. Adopted from (Zhou, et al., 2016, p. 32).

The smart EMS causes the demand to be optimally dispatched and connected to different modules. The smart meter functions as a communication source that receives a signal from power utilities, which later will be translated to an input for the EMS (Kuzlu, Pipattanasomporn, & Rahman, 2014). Smart meters have several functions that are extensively being used. They measure the multi-power and multi-period rates to compensate for active- and reactive power. It also functions as a communication source that requests data for electricity rates and other useful information. Thirdly, it sets load shedding and collaboration with interactive terminals in motion when a failure in the power grid occurs (Zheng, Gao, & Lin, 2013). The electricity management center is the heart of the demand side management operation. It collects data from several components within the system, such as advanced meters and smart sensors. Scheduled preferences can be forwarded to connected home appliances and electric vehicles via the EMS. In addition, the EMS can be extended to a controlling device that can set several indoor controls including water, electricity, gas and others. Moreover, future forecasting can be achieved by integrating stochastic control algorithms (Zhao, Lee, Shin, & Song, 2013).

Consumers benefit from adding solar panels to their grid-connected system since they become less dependent on the bulk power supplied by the main transmission network. Moreover, the vehicle's flexible storage character facilitates the system by successfully tackling grid intermittencies, over- and undersupply (Missaoui, Joumaa, Ploix, & Bacha, 2014) (Asare, Kling, & Ribeiro, 2014). Another important aspect of an EMS is that it allows users to indicate and adjust energy- demand and supply preferences. This can be done by making use of a human interface, which allows users to analyze their electricity data on a computer or smartphone. A preferred SoC, arrival- and departure time can be programmed for the BEV. In fact, consumers' behavior can be analyzed and controlled with the help of artificial intelligence-based systems. This enables the EMS to control and dispatch electricity even more efficiently. Altogether, the quality of an EMS significantly relies on the strength and progressiveness of the integrated control algorithms (Son, Pulkkinen, Moon, & Kim, 2010).

Solar panels are getting of significant importance in buildings equipped with EMSs since it allows users to produce and store renewable electricity in an efficient way. Moreover, the price of solar panels is rather favorable. In some cases, an integrated charge controller prevents the battery from being over- (dis)charged (Wan, Zhao, Song, & Xu, 2015). Additionally, low voltage values lower the battery's lifetime and decrease the availability of the load (Harrington & Dunlop, 1992).

Scheduling strategies

Users respond differently to the implementation of financial rewarding systems, by means of changing their habits and electricity behavior. In general, two types of cost schemes can be expounded. These are price-based demand response and incentive-based demand response (Chen, Wang, & Kishore, 2014). Price-based demand response originates from the idea that consumers are reacting dynamically to changing electricity prices throughout the day. The following price structures form part of the price-based cost scheme:

- *Real-time pricing (RTP)*: hourly varying retail charges for delivered electricity determined by wholesale market prices.
- *Critical peak pricing (CPP)*: the price for electricity is substantially raised by the utility company due to emergency conditions or high wholesale market prices.
- *Time-of-use pricing (TOU)*: blocks of time periods in which electricity has a constant and prearranged price.

These economic incentives are put in place to deal with electricity prices in a self-controlled way. Consequently, prices can be preserved. The price-based cost scheme is primarily based on the complementary process of changing electricity prices and electricity consumption (US Department of Energy , 2005) (Zhou, et al., 2016).

The incentive-based demand response formulates a deterministic or varying policy over time. The following underlying cost structures form part of the incentive-based cost scheme (Zhou, et al., 2016) (US Department of Energy , 2005):

- *Direct load control (DLC)*: signaling customers to decrease load demand by giving financial incentives.

- *Interruptible load (IL)*: load demand that a customer makes available to the utility company by an established contract.
- *Emergency demand response (EDR)*: mandatory commitment to reduce load demand to a specific baseline during times of supply scarcity.
- *Demand-side bidding (DSB)*: mechanism that allows customers to get actively involved in electricity trading by changing their electricity behavior.
- *Capacity/ancillary service program (CASP)*: services by power generators and electricity storage components to facilitate the utility company in maintaining a reliable grid operation.

This way of pricing is chiefly based on the temporarily increase and decrease of electricity prices. It is used to regulate potential intermittencies in the grid. Hence, this cost structure is mainly directed from the grid operation. In reality, price- and incentive-based demand response structures are directly related to each other. Figure 23 schematically shows the relation between several demand response dispatch strategies.

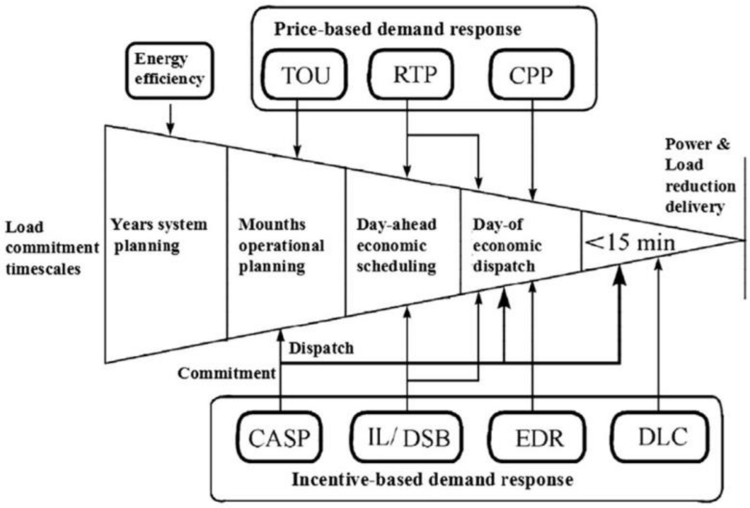

Figure 23: Dispatch strategies for electricity management systems, based on demand response actions. Adopted from (Zhou, et al., 2016, p. 37).

This figure also shows the applications of the underlying cost structures and the period for which the scheduling methods apply (US Department of Energy , 2005). The ever-increasing complexity of the smart grid, together with intelligent EMSs, need to ensure a better and more reliable demand response in the future. Altogether, EMSs should be able to adjust to changes in demand requirements, grid intermittencies and consumers’ preferences.

3. Method

In this chapter, the modeled cases are presented, where the potential of a power manager in a residential- and commercial building is investigated. Consequently, it's determined in a sensitivity analysis how different values for the feed-in tariff, load demand and solar capacity influence the economic- and environmental benefits of a power manager device. The starting points for conducting a sensitivity analysis are based on the results of the base case's- model and data. In so doing, a bigger spectrum of building types and sizes can be addressed apart from the specific case analyzed.

3.1 Cases analyzed

Two different cases were analyzed, namely a residential- and a commercial case. In the residential case the Prêt-à-Loger home's DC load was considered in the model. For the commercial case, the DC load was based on The Green Village office's electricity consumption. One vehicle was considered in the residential model and three vehicles were considered in the commercial model, with their corresponding connecting interface equipment. Figure 24 shows a scheme with all 8 analyzed cases. The base cases (labeled with the letter 'a') consisted of the load, electricity supplied by the grid, and electric vehicles connected through a conventional converter, only operating in G2V. This means that EVs were only charged, without delivering ancillary services. The 'b' cases include the addition of only a power manager with respect to the base case. The power manager allows for the EVs to charge and discharge, thus being capable of delivering ancillary services. The ancillary services taken into account were price arbitrage and peak shaving. In the 'c' cases only solar panels were added to the base cases. Lastly, the 'd' cases analyzed the incorporation of solar panels and a power manager to the base case.

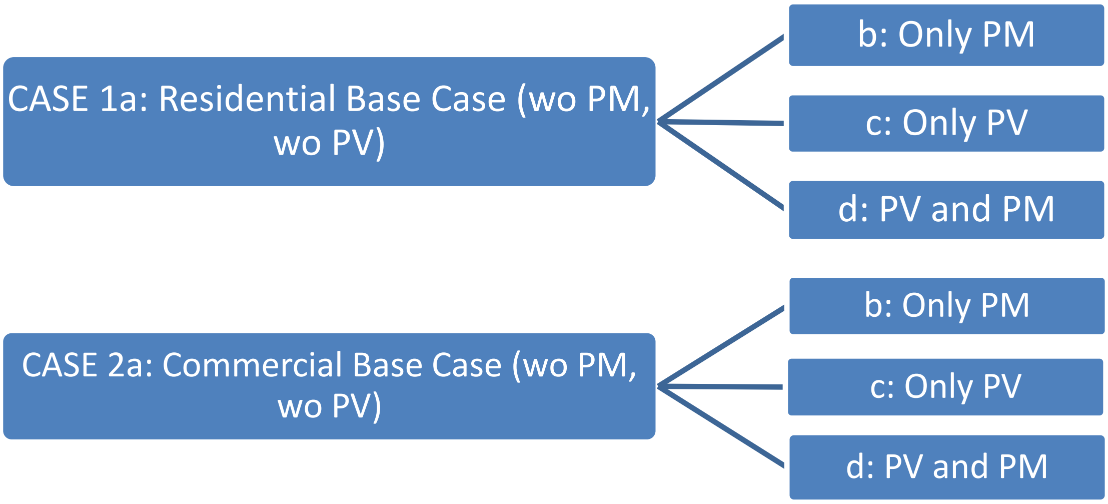

Figure 24: Layout of the cases analyzed, where PV stands for solar photovoltaic system and PM for Power Manager.

3.2 Simulation approach

Figure 25 describes the principle of the research methodology according to which the most cost-optimal way of matching electricity supply and demand has been simulated. Hourly data of an entire year has been used for the simulations. Therefore, the simulation consisted out of 8,760 hours per year. The optimization software HOMER was used to conduct the cost-optimization within the model. Components such as, the building's load, vehicle's battery, the power manager and solar panels were used to design the model. Certainly, this was dependent on the specific components' availability in the addressed cases.

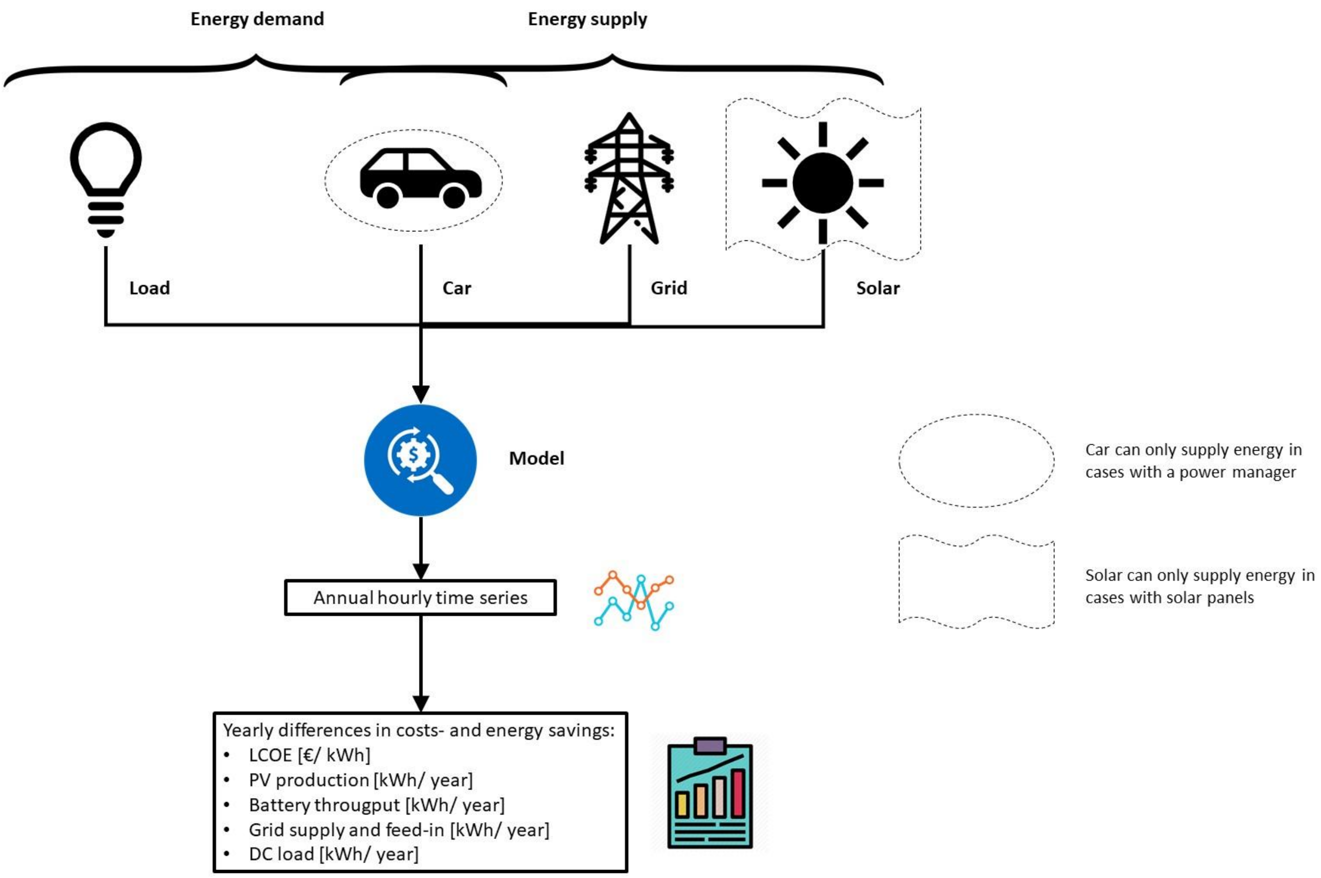

Figure 25: Schematic overview of the modeling approach.

After the allocation of electricity sources has been optimized, hourly time series could be retrieved that addressed the most cost-optimal annual electricity distribution. All outcomes expressed the results of simulated behind-the-meter models. This indicates that the added value of a power manager within the building's electrical system has been defined, by allowing for bi-directional (dis)charging, price arbitrage and peak shaving behind-the-meter. Electricity losses caused by the inverter, rectifier, battery and the PV system were taken into account in the electricity balance.

Economics

The levelized cost of electricity (LCOE) indicates the costs per amount of produced electricity by the entire system and is expressed in €/kWh. The difference in LCOE between cases analyzed is used to stress the economic- implications of implementing the power manager in the system under study. Moreover, total cost savings or losses per produced amount of electricity can be stressed, after comparing the LCOE values of the cases with and without the power manager. Herewith, the LCOE output value indicates the cost of electricity production for the entire system; including the grid-, battery-, solar panel-, load- and converter costs.

The LCOE is calculated by dividing the total annualized costs by the total amount of electrical load served. The LCOE is calculated by using equation (1) (Karki, Billinton, & Verma, 2014).

$$LCOE = \frac{C_{ann,tot}}{E_{served}} \tag{1}$$

In which:

$LCOE$ = levelized cost of energy, expressed in €/kWh

$C_{ann,tot}$ = system's total annualized cost, expressed in €/year

E_{served} = the total amount of electrical load met by the grid and PV system, expressed in kWh/year

The E_{served} indicates the total amount of electricity, that was used to serve loads, plus the amount of excess solar energy that has been sold to the grid. The amount of electricity served could have been supplied by the grid and/ or PV system, dependent on the case. This relationship is shown by equation (2).

$$E_{served} = E_{served,DC} + E_{grid,sales} \tag{2}$$

In which:

$E_{served,DC}$ = served DC load, expressed in kWh/year

$E_{grid,sales}$ = sold energy to the grid, expressed in kWh/year

The total annualized cost expresses the costs of all integrated components over the project's lifetime. This value gives the same net present cost as the real sequence of the cash flows relating to all available components. This implies that costs were equally divided over every year throughout the project's lifetime. These costs were modeled by making use of equation (3) (Fathima, et al., 2018).

$$C_{ann,tot} = CRF(i, R_{proj}) \times C_{NPC,tot} \tag{3}$$

In which:

$C_{ann,tot}$ = total annualized cost, expressed in €/year

$C_{NPC,tot}$ = total net present cost, expressed in €
i = real discount rate per year, expressed in %
R_{proj} = lifetime of the project, expressed in years
CRF = function that returns the capital recovery factor

The lifetime of the project considered in this work was 25 years. The real interest rate is used to convert the one-time costs and annualized costs. The yearly real discount rate is established by means of the expected nominal discount rate and inflation rate. The real discount rate is used to calculate the discount factor and annualized costs. By making use of the real discount factor, inflation gets canceled out of the economic calculations as opposed to the nominal discount factor. As a result, all costs become real costs expressed in euros. Equation (4) is used to calculate the discount rate (Mody & Rebucci, 2006).

$$i = \frac{i' - f}{1 + f} \tag{4}$$

In which:
i = the real discount rate, expressed in %
i' = the nominal discount rate, expressed in %
f = the expected inflation rate, expressed in %

The nominal discount rate is assumed to be 4%. A slightly lower nominal discount rate is chosen to increase its weight in the formula, and thus, value cost savings in the future more. This is chosen since the project's lifetime is presumed to be 25 years. The real interest rate is 2.26%, based on the assumed nominal discount rate input value and inflation rate. This value is used to convert one-time and annualized costs, so to account for the inflation rate during the project's lifetime (Mithraratne, Vale, & Vale , 2007). The inflation rate is assumed to be 1.70%, based on statistics from April 2018 that apply for the Netherlands (Trading economics , 2018). The inflation rate is assumed to stay constant over the project's lifetime. A total of 8,760 time steps have been simulated in a period of one year. This means that any case has been optimized for hourly input data. The maximum simulations per optimization were modeled to be 10,000. Any additional emission penalties were also neglected throughout the simulations.

The net present cost (NPC) describes the present value of the total system costs over the project's lifetime, minus the present value of all revenues over the project's lifetime. The total system costs include the components' installation- and operation costs. The revenues include any grid sales and the components' salvage value. The salvage lifetime expresses the remaining value of the systems' components after its project lifetime. The total NPC is calculated by taking the sum of all yearly cashflows. Initial investments, component replacements, maintenance and purchasing electricity from the grid are among the main costs of the system.

In the Netherlands, the net metering regulation will be interchanged by a subsidy regulation; which means that producers will get reimbursed for the electricity they supply to the grid in the form of a financial remuneration (Rijksoverheid , 2018). Therefore, the feed-in tariff is included in this report's model. The sell back price of electricity was assumed to be € 0.14 per kWh, which is determined based on speculations regarding the new feed-in tariff regulation in the Netherlands, starting from 2020 (Zonnepanelen Delen, 2018).

Sustainability

The power manager's environmental benefits can be stated by looking at the overall renewable electricity fraction that was used to supply the load. In this research, this fraction indicated the total amount of load served with electricity originating from solar energy, and therewith, excluded the renewable electricity percentage in the electricity supplied by the grid. The demanded load was supplied either directly from solar electricity or from the battery, depending on the availabilities and dispatch algorithm used.

The renewable fraction for each case was calculated using equation (5).

$$f_{ren} = 1 - \frac{E_{nonren}}{E_{served}} \tag{5}$$

In which:

f_{ren} = renewable fraction

E_{nonren} = electrical production originating from nonrenewable electricity sources, expressed in kWh/year

E_{served} = total served electrical load including the electricity sold to the grid, expressed in kWh/year

Dispatch strategy

The electricity components within the system are dispatched in such a way that solar, the vehicle's battery and the grid, supply the amount of electricity needed to meet the building's load. The grid was employed in case the load couldn't be supplied from solar electricity (1st priority) or the vehicle's battery (2nd priority). For every timestep, the controlled electricity sources were dispatched to meet load demands by means of the least total costs, while satisfying the operating reserve requirements. This operating reserve implies a small amount of electricity that has additionally been produced to cover for small unexpected fluctuations in the load, and herewith, ensure a reliable electricity supply. In so doing, the dispatch strategy took the fuel-, Operation &

Maintenance (O&M)- and replacement costs of all available components into account. Overall, the components' fixed- and marginal costs within the system were considered.

HOMER is a cost optimizing program that is used to model off- and on-grid electricity systems. It is used to determine an optimized electricity system. Additionally, the software allows to optimally size components and to conduct sensitivity analyses. In so doing, the most efficient design for a power system could be created. The program considers factors; such as varying costs, technological options and availability of electricity sources. Additionally, HOMER offers a wide variety of electricity sources and loads that can be used as a system input. Furthermore, sensitivity analyses contributed to the optimal final output by optimizing different input parameters. The software simulates cases and draws up electricity balances to define the optimal electricity system.

3.3 Assumptions

The following assumptions were made for all simulations:

- For both commercial- and residential cases, it has been assumed that vehicles are already owned by either individuals or a company. Therefore, no vehicle investments had to be made. Hence, the considered costs for the operation of vehicles within a V2G system consist of battery capital- and replacement costs originating from its degradation.
- The power manager costs were taken into account in the economic calculations, since it functioned as both a charging facility and power converter. In the cases without power managers, charging poles and converter costs were taken into account instead.
- In all cases, the number of vehicles equals the number of power managers.
- One vehicle has been simulated in the residential building cases and three vehicles in the commercial building cases.
- Vehicles were assumed to be available all the time to deliver ancillary services. This is chosen in this way, since vehicles within communities or at commercial parking facilities can be aggregated based on the vehicles' availability and there is most likely always cars to be parked.
- The power manager's software facilitates peak shaving and price arbitrage services in a 'behind-the-meter' operation.
- The simulated model presumed a feed-in tariff that will be issued by the government in 2020. For this, a future electricity feed-in tariff of 0.14 €/kWh is assumed.
- Cases have been simulated under the assumption that buildings have an internal DC electrical distribution system and function within an AC electricity grid.
- All cases are modeled according to Dutch regulations and grid infrastructures.

3.4 Components description and model inputs

This section describes characteristics of the components and the input data for the modelled system. These apply to the system's load, solar system, battery in the vehicles and the power manager's energy management system. A summary of all input values is shown in the appendix (see A. Model input).

Load

Residential

The residential load profile that has been applied has peak loads in January, due to the higher electricity consumption for space heating and heating of domestic water during winter time in the Netherlands. All load appliances in the building are premised to run on DC since that brings efficiency benefits in future buildings. According to Robledo et al., the annual AC electricity use of the PaL residential building was 5,972 kWh in 2015 (Robledo , Oldenbroek, Abbruzzese, & van Wijk, 2018). This is equivalent to an average of 16.36 kWh/ day, according to equation (6).

$$\frac{electricity\ use\ per\ year\ [\frac{kWh}{year}]}{number\ of\ days\ per\ year\ [days]} = \frac{5972\ kWh}{365\ days} = 16.36\ kWh/day \tag{6}$$

According to Vossos *et al.*, about 10% of electricity is lost by converting AC appliances to DC (Vossos, Pantano , Heard , & Brown , 2017). Therefore, the equivalent electricity use with DC appliances, would be 14.73 kWh/ day as calculated in equation (7).

$$Efficiency\ [\%] \times electricity\ use\ per\ day\ [kWh/day] = 0.90\% \times 16.36\ kWh/day = 14.73\ kWh/day \tag{7}$$

This value is higher than the Dutch average residential electricity usage amounting to 2,980 kWh/year (8.16 kWh/day), since the PAL house is entirely heated by electricity and the Dutch average excludes the heating energy (Robledo , Oldenbroek, Abbruzzese, & van Wijk, 2018).

Commercial

The commercial load profile that has been applied has peak loads in January, due to a higher electricity consumption for office heating and lights during the winter. All load appliances in the building are premised to run on DC electricity. The yearly electricity use of The Green Village Office was calculated as shown in equation (7), amounting to 30.59 kWh/day.

$$Electricity\ use\ office \left[\frac{\frac{kWh}{m^2}}{year}\right] \times floor\ area\ [m^2]$$
$$= 44.3\ \frac{\frac{kWh}{m^2}}{year} \times 252\ m^2 \qquad (8)$$
$$= 11{,}163.6\ kWh/year = 30.59\ kWh/day$$

In equation (7), the electricity use of an office building is 44.3 kWh/m^2/year (Sustainable Energy Helpline , 2002). The surface area of the base case office at the Green Village is 252 m^2 (Sustainerhomes , 2018).

Load pattern

The distribution of the daily electricity consumption is retrieved from the Open Energy Information (OpenEI) database, which used several reference buildings in different climate zones to determine the load pattern (NREL, 2011). An example of the daily electricity consumption for the residential load for a random day is shown in Figure 26**.**

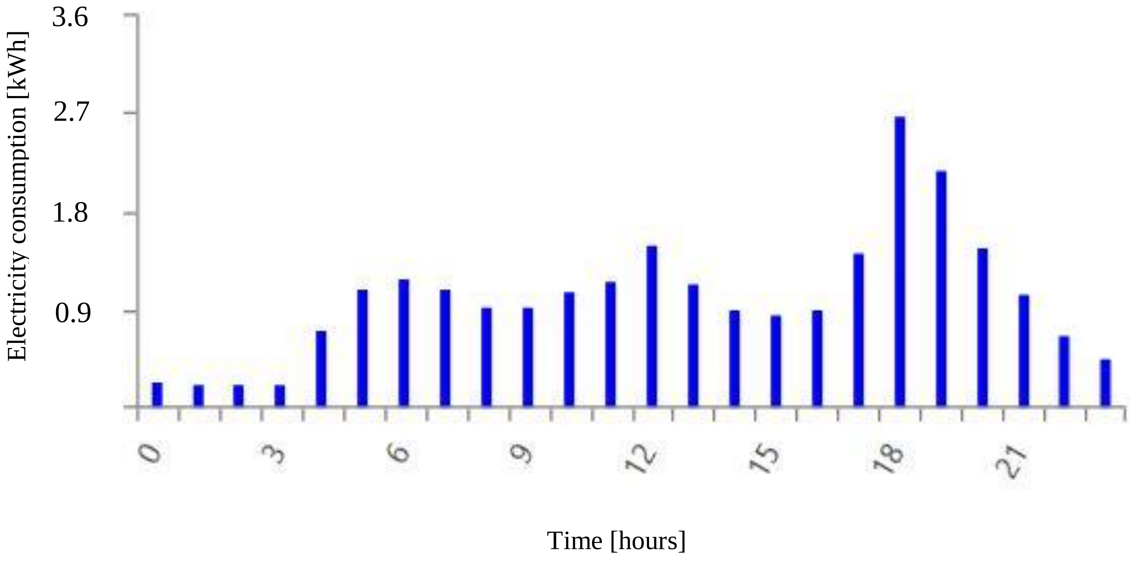

Figure 26: Daily residential load profile used in model.

The residential pattern describes some small electricity peaks in the morning and afternoon which is due to home appliances being turned on. Especially when residents wake up in the morning and take a lunch break in the afternoon. The high electricity peaks between 18:00 and 20:00 originate from residents turning on home appliances and start cooking when returning from work in the evening. The viewed pattern is an example for one particular day. The way in which daily patterns for the rest of the year are obtained, is explained in the next subsection.

The distribution of a daily commercial load profile is shown in Figure 27.

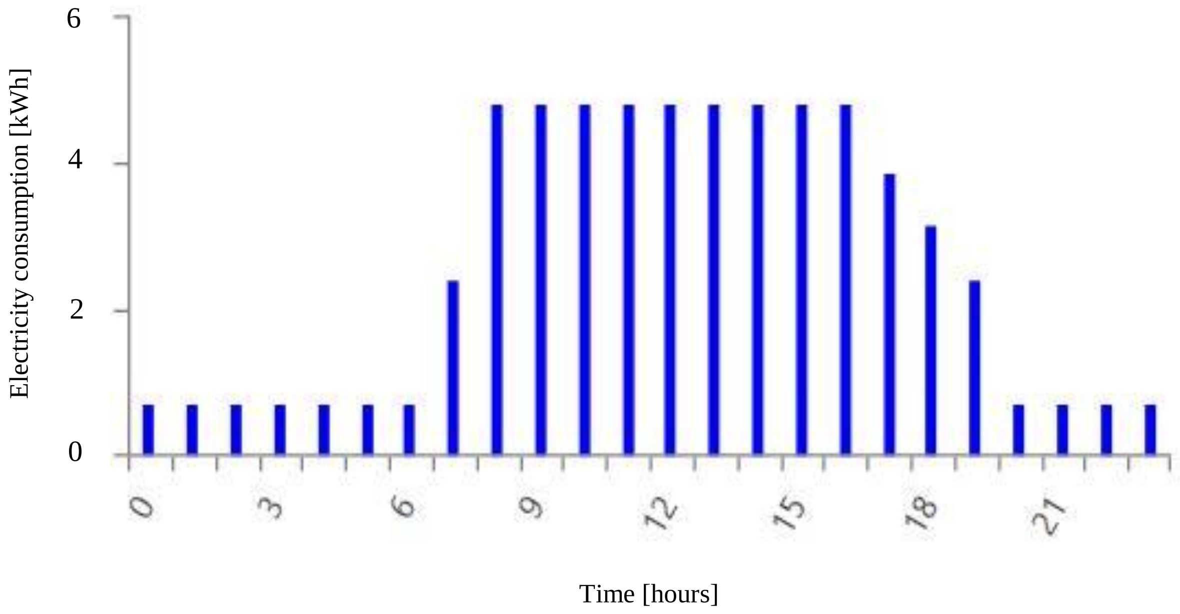

Figure 27: Daily commercial load profile used in model.

The commercial pattern presents one large electricity peak that is kept constant in the middle of the day. These peaks indicate the office hours and times that employees generally work in the building. Computers, coffee machines, lights, domestic heating and so on are switched on during these hours.

Load variability

A day-to-day variability is applied to make the load data more realistic. Moreover, in reality, the load demand's size and shape vary on a daily basis. By adding a 10% day to day variability, the size of load randomly changed within a 10% range from the original value, at any given point during the day. In so doing, the load could become slightly smaller or bigger at some moments. In addition, a time step value is applied to reset the day-to-day variability to zero and vary the shape of the load pattern within a 20% range at any timestep. Altogether, the load pattern's shape and size become more realistic by applying both variables to the model. The model retrieves the day-to-day variability factor from a normally distributed function with a zero mean and a standard deviation. It also retrieves the time-step value. The load has been multiplied in every time step with the so-called perturbation factor α, which is calculated by means of equation (9) (Homer , 2018).

$$\alpha = 1 + \delta_d + \delta_{ts} \tag{9}$$

In which:

δ_d = daily perturbation value

δ_{st}= time step perturbation value

Solar

Residential case

The residential building's (Prêt-à-Loger) total installed solar capacity was modeled to be 4,900 Wp (Xexakis & van den Dobbelsteen). The installation consisted of 25 modules with 1170 monocrystalline silicon solar cells. The modules were connected in series in order to achieve maximum PowerPoint tracking. The panels had a 42 degrees deviation from the South. In addition, the tilt of the panels was 21 degrees (Robledo , Oldenbroek, Abbruzzese, & van Wijk, 2018).

The capital costs for the installation were assumed to be € 7,350. According to Milieucentraal, the price for a solar installation included installation costs and amounted 1,50 €/Wp for a solar installation in the 5-kW power capacity range (Milieu Centraal , 2018). Therefore, the input value for capital costs was € 7,350 as calculated in equation (10).

$$\text{Price solar system [€]} = \text{Price installation [€/Wp]} \times \text{installed solar capacity [Wp]} = 1.50\,\frac{€}{Wp} \times 4{,}900\ Wp = €\ 7{,}350€ \tag{10}$$

The replacement costs were assumed to be the same price as the capital costs, even though prices for solar panels are expected to lower significantly in the upcoming years. The O&M costs were assumed to be € 1,500 over the solar installation's entire lifetime (Milieu Centraal , 2018). The O&M costs include panel cleaning and replacement of the inverter in the middle of the solar installation's lifetime. The total O&M costs are divided over the 25 years project lifetime, so to get the average O&M costs per year. Therefore, this amounts to € 60 per year.

Commercial case

The commercial building's total installed solar capacity was 12,600 Wp (see appendix: B. Optimizing design DC office). The installation consisted of 45 monocrystalline modules. The modules were connected in series to achieve a maximum PowerPoint tracking. In addition, the tilt of the panels was 32 degrees.

The capital costs were assumed to be € 18,900, as calculated in equation (11).

$$\text{Price solar system [€]} = \text{Price installation [€/Wp]} \times \text{installed solar capacity [Wp]} = 1.50\,\frac{€}{Wp} \times 12{,}600\ Wp = €\ 18{,}900 \tag{11}$$

The replacement costs were assumed to be the same price as the capital costs and the O&M costs were assumed to be € 60, just as in the residential case.

For residential- and commercial cases, a degrading factor of 80% was assumed. The temperature effects, nominal operating cell temperature and efficiency at standard test conditions, were retrieved from the solar panels' brochure (Jinkosolar , 2018).

Power calculation

The solar panels' power output is calculated in every time step of the simulation. The power output of the MPPT is used to match the solar DC output with the connected DC bus. The PV power output is calculated by making use of equation (13). The influence of the temperature on the PV's power output is also considered in the electricity production calculation (Homer , 2018).

$$P_{PV} = Y_{PV} f_{PV} (\frac{\overline{G_T}}{\overline{G_{T,STC}}}) [1 + \alpha_P (T_c - T_{c,STC})] \qquad (12)$$

In which:

P_{PV} = power output of PV array, expressed in kW

Y_{PV} = the installed capacity under standard conditions*, expressed in kW

f_{PV} = derating factor of PV, expressed in %

$\overline{G_T}$ = the incident solar radiation on panel array, expressed in kW/m^2

$G_{T,STC}$ = the incident radiation measured at standard test conditions*, expressed in kW/m^2

α_P = power's temperature coefficient, expressed in %/℃

T_c = temperature of PV cell in a current time step, expressed in ℃

$T_{c,STC}$ = temperature of PV cell under standard conditions, which is 25 ℃

*Standard test conditions are assumed to be at a 1 kW/m^2 radiation level, 25℃ cell temperature and in the absence of wind.

Battery

The characteristics of the Nissan Leaf's 30 kWh Li-ion Nickel-Manganese-Cobalt (NMC) battery has been used in the model to simulate the battery in the electric vehicles (Electric Vehicle Database , 2018). The capital- and replacement cost for the vehicle's battery amount to € 4,527. Only costs for integration- and daily use of the battery in G2V/V2G mode have been considered, since vehicles are assumed to be possessed by customers already. Furthermore, it's presumed that, the investment required for the integration of the battery within the system to operate in G2V/V2G mode, is equal to the vehicle's battery replacement costs. The battery's replacement cost is determined based on the costs of battery degradation. Therefore, the capital costs are assumed to equal the replacement costs since that's the amount of money needed when batteries are fully degraded. The battery degradation costs are based on Nissan's recycling program; which allows customers to get their degraded battery replaced for € 4,527 (Nissan, 2014). The battery's SoC is modeled to stay within a 20 to 100% SoC range to optimize the battery's functionality. The battery's nominal voltage is 360 V, its roundtrip efficiency 95% and its maximum charge- and discharge current 32 A (U.S. Department of Energy, 2011) (Automania , 2018). The battery's nominal capacity is 83.33 Ah**.** The battery's lifetime is assumed to be 10 years, in case a maximum annual throughput of 67,500 kWh hasn't been reached due to frequent use (Nissan , 2018).

The battery roundtrip efficiency is the efficiency of one storage cycle, which implies the DC to storage to DC conversion. The battery's charge- and discharge efficiencies are both equal to the square root of the battery's roundtrip efficiency. This relation is shown in equation (13) (Rubenbauer & Henninger, 2016).

$$\begin{aligned} \eta_{batt,c} &= \sqrt{\eta_{batt,rt}} \\ \eta_{batt,d} &= \sqrt{\eta_{batt,rt}} \end{aligned} \tag{13}$$

In which:

$\eta_{batt,c}$ = battery charge efficiency

$\eta_{batt,d}$ = battery discharge efficiency

$\eta_{batt,rt}$ = battery roundtrip efficiency, expressed in %

Power manager

Converter

For the residential and commercial cases without a power manager, the capital- and replacement costs for a converter and charging pole were modeled to be equal to the Honda power manager's capital- and replacement costs. Therefore, the converter- and charging pole price are combined in the model's converter price. This is stated since a power manager is one overarching device that facilitates both functions. For residential cases with a power manager, the Honda power manager is primarily modeled as the system's converter. The power manager is a single phase, 3 wire 50 Hz/60 Hz converter and has a capacity of 5.5 kW (Honda, 2018).

The inverter's lifetime and efficiency are presumed to be 15 years and 95% in all cases. Additionally, the rectifier's efficiency is presumed to be 90% (Beggs, 2002). It must be noticed that the Honda power manager's inverter efficiency, as stated in the brochure, is based on Japanese standards. Therefore, its efficiency might slightly vary when operating according to European standards.

Energy management system

In all cases without a power manager, there was no energy management system in place. In these cases, the vehicle's battery wasn't integrated in the system since it lacked the possibility of storing electricity and feeding electricity to the grid. Moreover, there wasn't any possibility to change electricity consumption behavior in these cases, given the established residential- and commercial building's load pattern and the absence of a battery. Therefore, it's assumed that a single electricity tariff applied to these cases; amounting € 0.20 euro per kWh. The sell back price was assumed to be € 0.14 per kWh, which is determined based on speculations regarding the new feed-in tariff regulation in the Netherlands, starting from 2020 (Zonnepanelen Delen, 2018). Even though the battery couldn't be used in the system's operation, a vehicle has been included in the cost-optimization model since the unused available battery has a cost value as well. In so doing, a sincere cost comparison between cases with- and without an integrated power manager could be made.

In all cases with an integrated power manager, the system could make use of an energy management system. In these cases, the vehicle's battery was integrated in the system and thus price arbitrage and peak shaving could be modeled.

Peak shaving

Peak shaving is modelled by prohibiting an unlimited feed of electricity by the grid at any time during the day. In so doing, stored electricity was used more efficiently to shave high load peaks during times of high electricity demand. These maximum purchase capacities were determined based on conducted optimizations to achieve maximum financial benefits from peak shaving. In this way, peak shaving could be conducted in the most efficient way, because the fully charged batteries were able to conduct peak shaving during times of peak demand. Overall, it's assumed in the model that there weren't any grid outages throughout the simulation in cases with- and without a power manager.

In cases without solar panels, a 100% setpoint state of charge has been established in the dispatch strategy to enable batteries to charge till they reach this given setpoint. Peak shaving is modeled by charging batteries as much as possible during off-peak hours in cases without solar so to conduct peak shaving during times of high electricity demand. Because of this, batteries were able to conduct peak shaving in the most optimal way in the presence of a power manager.

In cases with solar panels, the dispatch strategy allows vehicles to firstly get charged by solar energy. In this way, cases were simulated in the most renewable- and cost-efficient way by providing ancillary services to the grid. In this way, solar electricity is used as much as possible to charge the vehicle's batteries. No setpoint state-of-charge has been applied in the cases with solar energy.

The occurrence of peak shaving has been calculated by stressing the percentage of load shaved per month at a particular time during the day. In the residential building cases, the same load pattern applied to all days during the week, so no distinction has been made between the amount of peak shaved during weekdays and during the weekend. Peak shaving has been observed for every day at 18:00, since highest peak demands generally occur at this time, so the vehicle's battery can contribute the most to the system. The residential peaks at 18:00 can be explained by residentials returning from work and start using home appliances in the evening. In the commercial building case, there has been made a distinction between weekdays and weekends, since a different load pattern applied for weekdays in contrary to weekends. Therefore, the occurrence of peak shaving has been observed for every day at 14:00, since highest peak demands generally occur in offices around this time and most of the vehicles are available to deliver peak shaving services. The percentage of load shaved by the battery in commercial- and residential cases at a particular time, has been calculated by using equation (15).

$$\begin{aligned} &Percentage\ of\ load\ shaved\ by\ battery\ at\ time\ X \\ &= \frac{energy\ discharged\ from\ battery\ at\ time\ X\ [kWh]}{Load\ at\ time\ X\ [kWh]} \times 100\% \end{aligned} \tag{14}$$

From all percentages at particular days, the average load shaved per month could be obtained by taking the sum of all percentages and divide that value by the number of (week)days during a month.

From optimization simulations conducted on the model, the most cost-optimal annual grid purchase capacity could be acquired. This is the maximum amount of electricity in kWh that can be taken from the grid. The optimum for this decision variable is obtained from the model's simulations. By searching for the lowest possible value, the vehicle's battery will conduct peak shaving services in a more efficient way. This might lead to an increase of the system's efficiency in terms of smart charging.

Price arbitrage

Price arbitrage is modelled by allowing the system to make a distinction between peak hour- and off-peak hour electricity prices. Moreover, the battery could be used effectively by means of the power manager's energy management system. Also, the cases with a power manager were modeled in such a way that vehicles couldn't be charged during peak-hour prices and couldn't sell discharged electricity to the grid during off-peak hours. Therefore, it's assumed that a double tariff applied to the cases with a power manager. Moreover, there was a possibility to shift the electricity consumption from peak hours to off-peak hours. Therefore, an electricity price of 0.20 €/kWh has been modeled for peak-hours (Milieu Centraal , 2018). Peak hours apply from Monday to Friday from 07:00 to 23:00 (Consuwijzer , 2018). It has been programmed within the energy management system that the grid couldn't charge the battery during peak hours. The electricity price was established to be 0.18 €/kWh during off-peak hours (Milieu Centraal , 2018). Off-Peak hours applied on weekdays from 23:00 to 07:00 and during weekends (Consuwijzer , 2018). During off-peak hours, the energy management system was programmed in such a way that the battery couldn't sell e electricity to the grid. In all cases, electricity could be sold to the grid for € 0.14 per kWh (Rijksoverheid , 2018).

The occurrence of price arbitrage has been calculated by summing up all electricity being used to charge the vehicle's battery during peak-hours and off-peak hours. In so doing, the annual percentages of vehicles being charged during these hours have been obtained. From the amount of charged electricity during off-peak hours, a distinction in percentage being charged during weekday- and weekend off peak hours have been made.

3.5 Sensitivity Analysis

Several sensitivity analyses have been conducted to stress the effect of load demand, installed solar capacity and the established feed-in-tariff on the LCOE difference. All sensitivity analyses were conducted to investigate the influence of certain factors on the LCOE value in residential- and commercial cases with solar energy. In so doing, other residential- and commercial cases could be stressed apart from the modeled base cases. This leads to a better overall conception of a power manager's added value. The LCOE difference indicates the increase or decrease in electricity costs when integrating a power manager instead of a standard system. Herewith, the relation between a flexible factor and its effect on the LCOE can be stressed.

4. Results and discussion

4.1 Energy balance

In the base cases 1a and 2a analyzed, where all the electricity was supplied by the grid, there were no solar panels and no power manager integrated in the model. Hereby, no electricity can be charged and discharged from the battery. Therefore, the energy balance corresponds to equation (15). In these cases, losses are caused by the rectifier.

$$\text{Grid supply} = \text{load} + \text{grid sales} + \text{losses} \tag{15}$$

The energy balance for the cases 1b and 2b, where the power manager was present, is described by equation (16). In these cases, losses are caused by the inverter, rectifier and battery. Battery losses imply general losses and battery depletion losses.

$$\text{Grid supply} + \text{battery discharge} = \text{load} + \text{battery charge} + \text{grid sales} + \text{losses} \tag{16}$$

In these cases, the battery discharge and battery charge terms are incorporated in comparison with the base case (equation (12), since now the electric vehicle's battery is integrated in the system.

In cases 1c and 2c with solar panels and without a power manager, electricity can be supplied by means of solar energy without the opportunity to charge- and discharge the vehicle's battery. Therefore, the energy balance described by equation (17) applies to cases 1c and 2c. Losses are caused by the rectifier, inverter and PV system in these cases.

$$\text{Grid supply} + \text{PV} = \text{load} + \text{grid sales} + \text{losses} \tag{17}$$

In cases 1d and 2d with solar panels and with a power manager, electricity can be supplied by means of solar energy with the opportunity to charge- and discharge the vehicle's battery. Therefore, the energy balance described by equation (18) applies to cases 1d and 2d. In these cases, the battery discharge and battery charge terms are incorporated together with PV supply. Losses are caused by the rectifier, inverter, battery and PV system in these cases.

$$\text{Grid supply} + \text{PV} + \text{battery discharge} = \text{load} + \text{battery charge} + \text{grid sales} + \text{losses} \tag{18}$$

Figure 28 and Figure 29 show the energy balance results of the residential- and commercial cases, respectively.

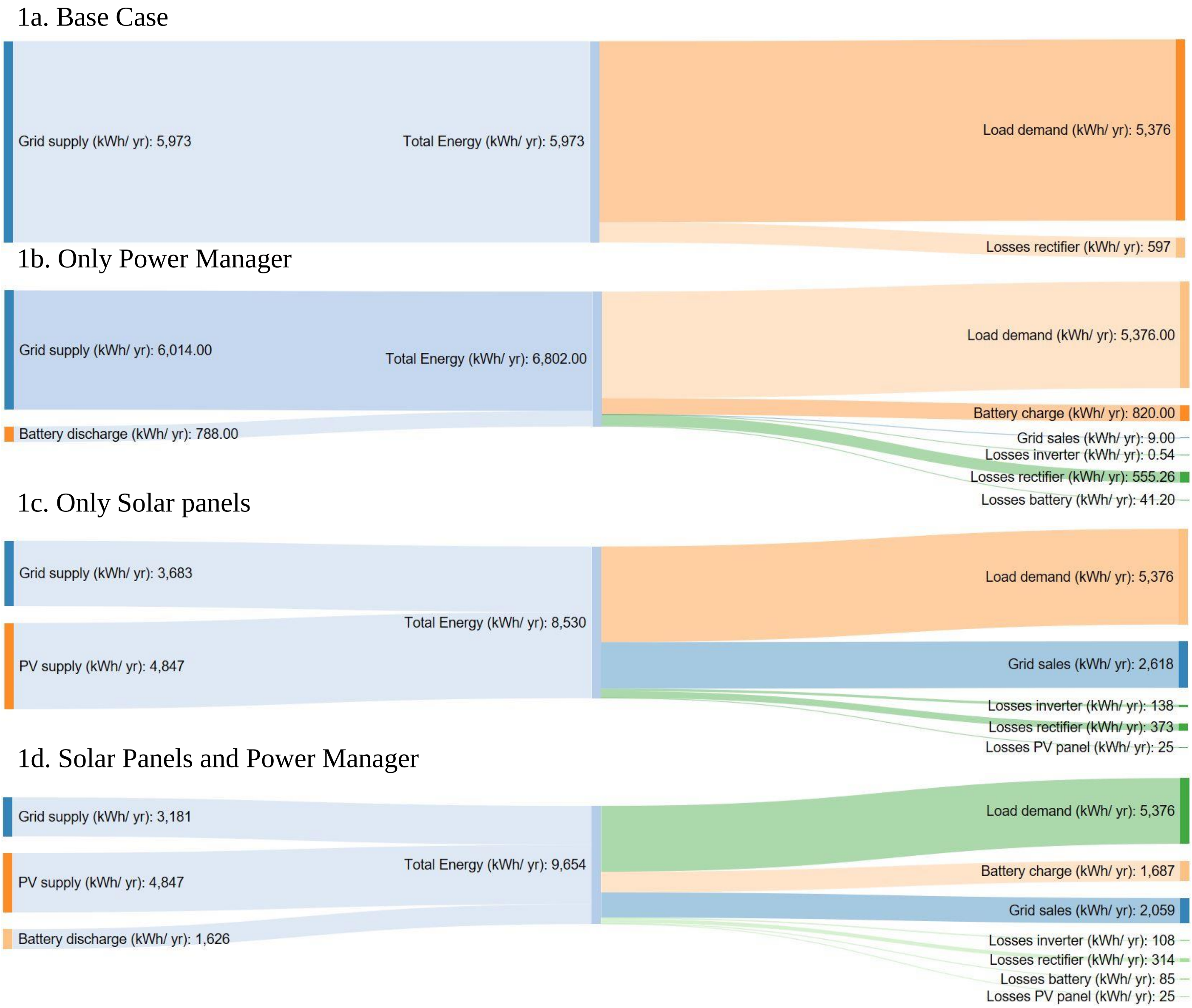

Figure 28: Distribution of the residential cases' energy- supply and demand.

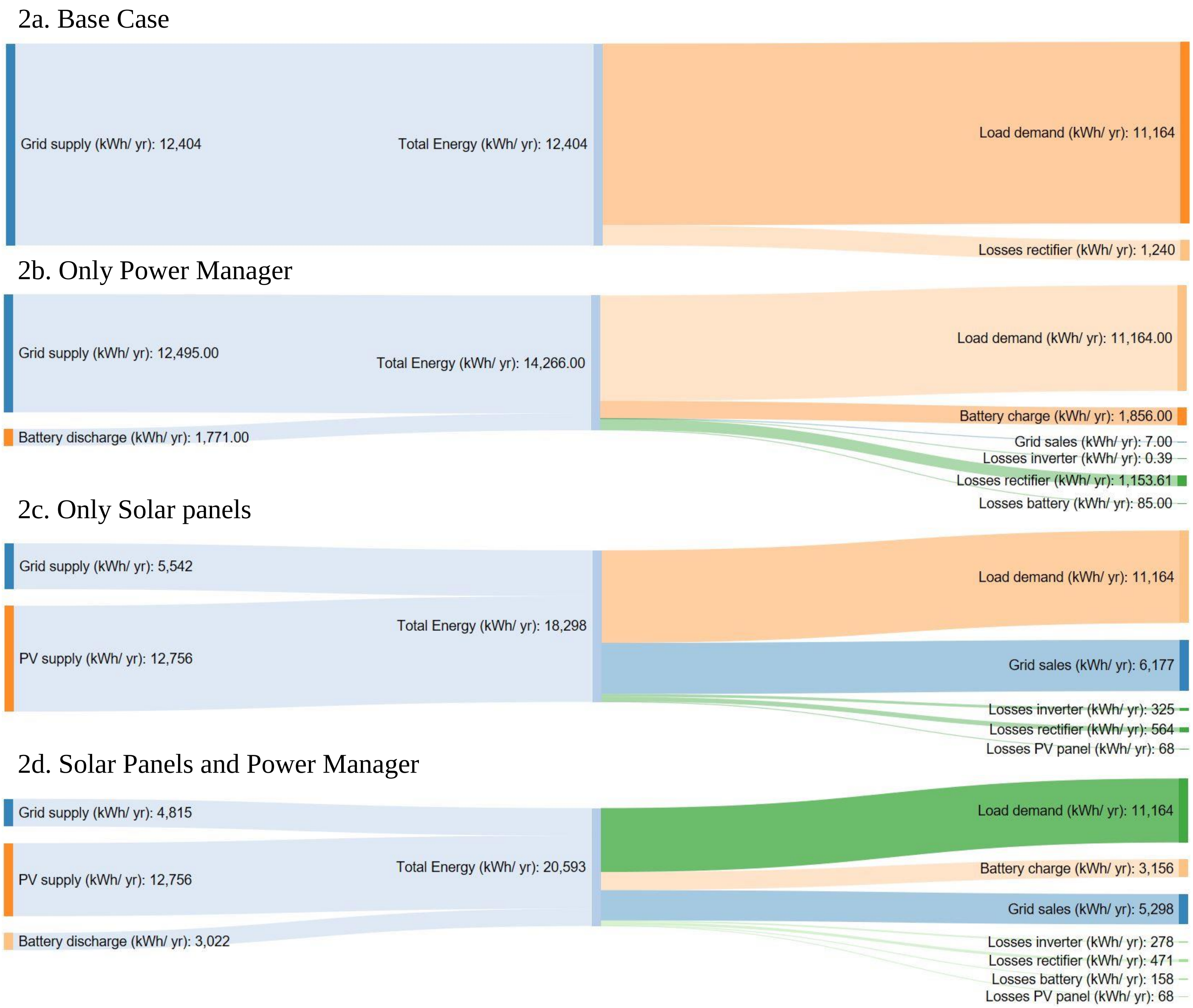

Figure 29: Distribution of the commercial cases' energy- supply and demand.

The energy flows displayed in Figure 28 and Figure 29 show that the sale of electricity to the grid turned out to be more cost-optimal in cases 'c' and 'd' where PV systems were integrated, rather than in the case where only battery electric vehicles where integrated. Moreover, in cases with PV systems, more electricity has been sold to the grid. This can be explained by the unfavorable costs associated with battery degradation in cases without solar panels and unfavorable electricity conversion losses when taking electricity from the grid.

The battery charge and discharge capacity, presented in Figure 29 for the commercial building, correspond to the use of only one vehicle's battery, from the three incorporated in the simulation. This turned out to be the most cost-optimal case for delivering ancillary services and store electricity in a behind-the-meter operation, in this case analyzed. From a behind-the-meter perspective, one vehicle's battery capacity turned out to be enough to contribute to the commercial building's electrical system in terms of electricity storage and an efficient V2G operation. From an economic perspective it can be stressed that the usage of more batteries turned out to be less cost-optimal when looking at the cost benefits that extra batteries could bring along. This can be explained by the additional degradation costs that would apply when more batteries are integrated in the building's electrical system. Altogether, that didn't turn out to make the operation economically more attractive. Overall, battery losses were generally higher than just the difference between the amount of charged- and discharged battery, since battery losses consisted of conversion losses and battery depletion.

In cases 1b and 2b, the grid supply increases with 0.69% in the residential case and 0.73% in the commercial case, with respect to the base cases, with the presence of a power manager. This states that price arbitrage advantages could be acquired by storing electricity in the vehicles' battery during off-peak hours, and therefore, a higher grid supply turned out to be economically beneficial. However, the grid supply decreases tremendously in cases 1d and 2d with the integration of a PV system and power manager, namely with 46.74% and 61.19% for the residential- and commercial case, respectively. First of all, this is due to the bigger amount of the electricity demand is supplied by the PV system. Additionally, solar electricity could directly be stored in the vehicles' battery to deliver peak shaving services during times of high electricity demand. With this, financial- and economic benefits were achieved.

Comparison residential and commercial cases

The differences between the total energy- supply and demand of case 1a and 2a can be explained by the electricity conversion losses that occurred throughout the simulations. These losses are related to the rectifier's AC to DC conversion losses. The additional renewable energy fraction by the model, on top of the supplied electricity by the grid that contains 12% renewable electricity, turned out to be zero for both cases since no renewable electricity sources were included in the system's model.

There barely has been any grid sales in residential and commercial cases 1b and 2b with a power manager. This is due to two factors. Since no renewable electricity has been produced by the system, there were no grid sales corresponding to this. On the other hand, grid sales from price arbitrage services didn't turn out to be a cost-optimal option. This is due to the unfavorable electricity loss that applies when converting- and storing electricity in the vehicle's battery. The small amount of sold electricity originated from the small amount of leftover electricity in the battery at the end of the year, to increase the system's economic viability.

The system's losses amount approximately 5 to 6 percent of the total supplied electricity in cases 1c and 2c. This value corresponds partly to the rectifier's efficiency, inverter's efficiency, and some small losses in the PV modules. Since more electricity has been produced by solar panels, less electricity had to be converted from the grid to charge the vehicle's battery or serve the load. This resulted in less energy conversion losses from the grid, in cases with solar panels compared to cases without solar panels. Also, the inverter's conversion efficiency is lower than the inverter's efficiency which resulted in a lower loss percentage. The renewable energy fraction, which indicates the fraction of renewable energy within the system, turned out to be 53.9% for residential case 1c and 68% for commercial case 2c.

Just as the case before, when comparing the residential- and commercial cases 1c and 2c, it can be verified that the residential's renewable fraction is lower than the commercial's. This can be explained by the share of self-produced electricity per m^2 in relation to the building's entire electricity consumption per m^2. Namely, this share was higher in the residential building case compared to the commercial building case. In both cases, there wasn't a power manager integrated in the model. The share of produced solar was 56.82% in the residential case and 69.71% in the commercial case (19)(20)(21).

$$solar\ production = \frac{Yearly\ solar\ production\ [kWh/year]}{Gross\ area\ building\ [m^2]} \tag{19}$$

$$Residential: \frac{4{,}847\ kWh/year}{148\ m^2} = 32.75\ kWh/m^2/year$$

$$Commercial: \frac{12{,}756\ kWh/year}{252\ m^2} = 50.62\ kWh/m^2/year$$

$$total\ production = \frac{Yearly\ total\ energy\ supply\ [kWh/year]}{Gross\ area\ building\ [m^2]} \tag{20}$$

$$Residential: \frac{8{,}530\ kWh/year}{148\ m^2} = 57.64\ kWh/m^2/year$$

$$Commercial: \frac{18{,}298\ kWh/year}{252\ m^2} = 72.61\ kWh/m^2/year$$

$$Share\ of\ solar\ energy\ [\%] = \frac{solar\ production\ [\frac{kWh}{m^2}/year]}{total\ production\ [\frac{kWh}{m^2}/year]} \times 100 \tag{21}$$

$$Residential: \frac{32.75\ \frac{kWh}{m^2}/year}{57.64\ \frac{kWh}{m^2}/year} \times 100\% = 56.82\%$$

$$Commercial: \frac{50.62\ \frac{kWh}{m^2}/year}{72.61\ \frac{kWh}{m^2}/year} \times 100\% = 69.71\%$$

There were less grid sales in the solar cases with a power manager in contrary to cases without a power manager. This is partly due to the dispatch strategy that firstly stores excess electricity in the vehicle's battery before selling it to the grid. However, the power manager increased the share of renewables and caused the system to buy less electricity from the grid. The battery's lifetime in the commercial- and residential case didn't decrease by means of its usage, which indicates that the electricity throughput for delivering ancillary services in the system didn't have a big impact on the batteries' degradation process. The battery's lifetime in all commercial- and residential cases didn't decrease significantly by means of its usage. Namely, all batteries' expected lifetime remained 10 years after simulating the models. This indicates that the battery's annual electricity throughput has been too small to have a big impact on the batteries' degradation process.

LCOE values

The LCOE for installing a residential- and commercial system 1a and 2a without a power manager amounted 0.3246 €/kWh and 0.2739 €/kWh respectively. Installing the same system with a power manager, results in a LCOE value of 0.3096 €/kWh for residential case 1b and 0.2625 €/kWh for commercial case 2b. This indicates that the costs of electricity production in residential and commercial cases without solar energy, slightly decreased by adding a power manager. This decrease in LCOE by means of a power manager, is explained by price arbitrage advantages that were achieved by means of a power manager since all electricity has been purchased against lower electricity tariffs in off-peak hours.

The LCOE for installing a residential- and commercial system without a power manager in the cases with solar energy, amounts 0.1718 €/kWh and 0.1107 €/kWh respectively. Installing the same system with a power manager, results in a LCOE value of 0.1806 €/kWh for the residential case and 0.1166 €/kWh for the commercial case. The lower LCOE for cases with solar, in contrary to cases without solar, originates from the lower grid purchases, resulting from the increase of the system's energy self-sufficiency. This indicates that an integrated power manager slightly increases the costs of electricity production in residential- and commercial cases with solar energy. Since the energy management system is optimized to increase the renewable energy fraction against the least costs, the LCOE turned out to be higher for the cases with both solar panels and a power manager. This is partly due to the fact that more produced electricity has been stored to increase the renewable energy fraction by means of sustainable energy usage and peak shaving services. However, this didn’t result in direct turnovers as is the case for the solar cases without a power manager. Consequently, less revenues could be achieved and the LCOE increased. Also, less financial benefits could be acquired from price arbitrage services since electricity barely hasn’t been purchased from the grid in cases with solar energy. However, the dispatch strategy in the EMS can be changed in all models according to consumers’ preferences. Altogether, the profitability depends on the customer’s preferred combination between profitability and sustainability.

Residential and commercial without solar

In all cases with solar energy, the LCOE value decreased by means of a power manager. the difference in LCOE for the residential cases by implementing the power manager turned out to be € 0.015 per kWh. The difference in LCOE for the commercial case by implementing the power manager turned out to be € 0.011 per kWh. In all cases without solar energy, the LCOE value increased by means of a power manager. The difference in LCOE between case 1c and 1d turned out to be € -0.009 per kWh. The difference in LCOE between case 2c and 2d was € -0.006 per kWh.

The results for residential- and commercial cases with- and without solar energy are summarized in Table 2.

Residential	LCOE* [€/kWh]	LCOE difference [€/kWh]	Renewable fraction [/]	Battery lifetime [years]
Case 1a (wo PM, wo PV)	0.3246	0.015	0	10
Case 1b (only PM)	0.3096		0	10
Case 1c (only PV)	0.1718	-0.009	53.9	10
Case 1d (PV and PM)	0.1806		57.4	10
Commercial				
Case 2a (wo PM, wo PV)	0.2739	0.011	0	10
Case 2b (only PM)	0.2625		0	10
Case 2c (only PV)	0.1107	-0.006	68.0	10
Case 2d (PV and PM)	0.1166		70.8	10

Table 2: Summary of the LCOE, renewable fraction, battery lifetime and energy savings values for all modeled cases.

*LCOE values depend on the preferred combination between sustainability and profitability and can be adjusted in the EMS.

Since the simulation has been conducted from a behind-the-meter perspective, the full potential of delivering ancillary services by means of a power manager; in combination with the available battery capacity, isn’t fully considered. Moreover, if the entire capacity of a vehicle’s fleet’s capacity can be aggregated to deliver ancillary services to the grid ‘before-the-meter’, the cost savings from integrating a power manager might be increased.

4.1.1 Peak Shaving

Peak shaving has been conducted by batteries during hours of peak electricity demand in cases with a power manager. Highest peak demands have been observed at 18:00 in the residential cases and at 14:00 in the commercial cases. In contrary to the residential case, high electricity demand peaks were more equally scattered over the entire day. A distinction is made between weekdays and weekends since a significantly lower electricity demand applies for weekends in commercial buildings. The results of the residential case without solar panels for a week in May are shown in Figure 30.

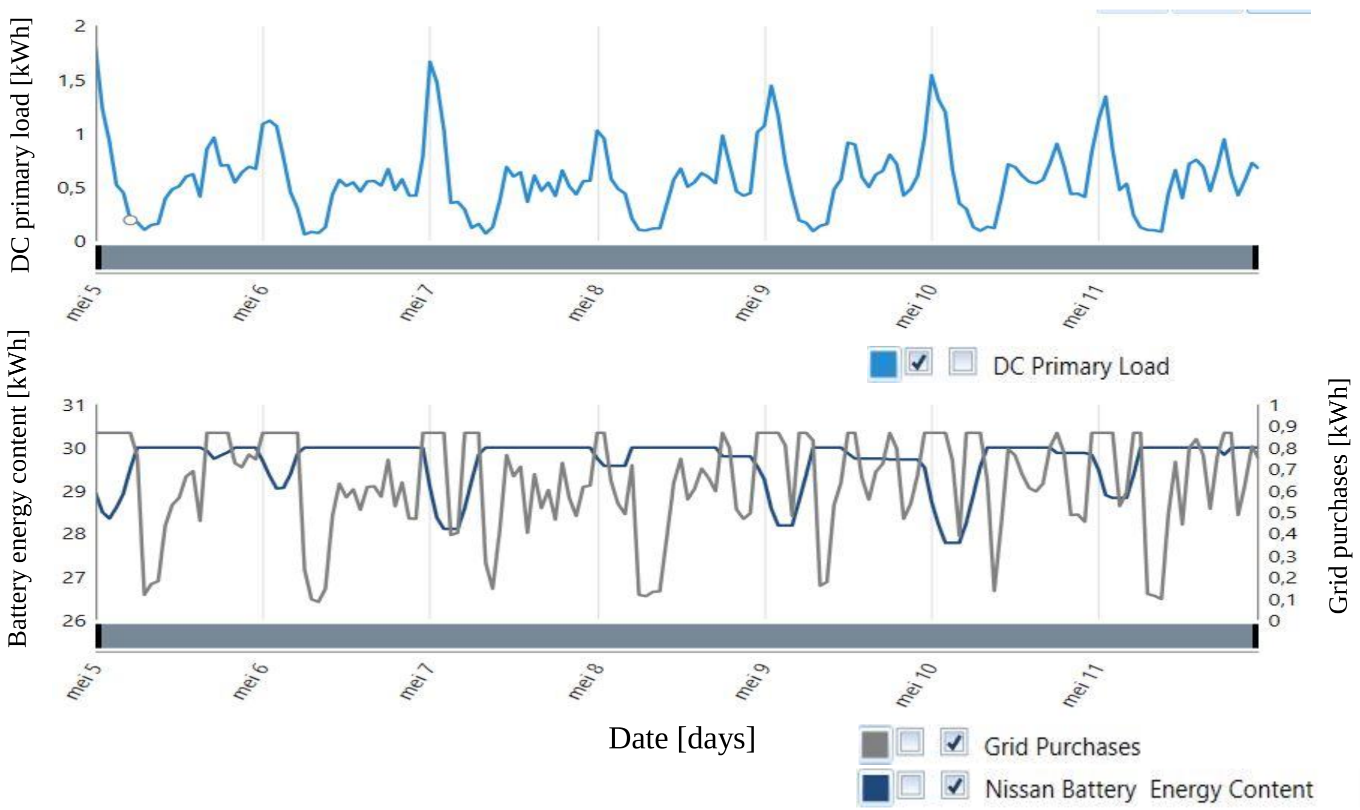

Figure 30: Overview of conducted peak shaving example in the residential building case without integrated solar panels during a week (May 6th-May 13th).

It can be seen that a maximum grid purchase capacity amounting 0.87 kWh turned out be optimal for a residential case without solar panels and with a power manager. In so doing, electricity has been effectively supplied by the vehicle's battery during hours of high electricity peak demand, which resulted in less electricity purchases. This can result in benefits for the gird operators, if all residential/commercial buildings would achieve this peak shaving in a behind-the-meter operation.

In cases with a power manager and with solar energy, a maximum annual grid purchase capacity of 2.48 kW and 4.45 kW were acquired for the residential- and commercial cases, respectively. In cases with a power manager and no solar energy, a maximum annual grid purchase capacity of 0.87 kW and 2.14 kW were acquired for the residential- and commercial cases respectively. The grid purchase capacity was generally higher in cases with solar panels, since more electricity is required to be taken from the grid during times of solar energy shortage. In cases without solar energy, the amount of purchased electricity can better be planned and stored accordingly. Therefore, people are less dependent on sudden changes in solar conditions in the latter cases.

Residential cases

Figure 31 shows the average percentage of peak demand shaved by the vehicle's battery at 18:00. It shows that bigger percentages of the peak load have been shaved during summer months in building cases with integrated solar energy. This is explained by the fact that in the case with solar energy, more energy from the sun could be utilized and stored in the vehicle's battery; which later could be used for peak shaving purposes. In winter months, less solar energy could be utilized and stored. Therefore, peaks couldn't be shaved as much in winter as during the summer. In July, a highest average percentage of shaved peak loads has been achieved; amounting 45%. This highly contributed to an increase of system's renewable energy fraction.

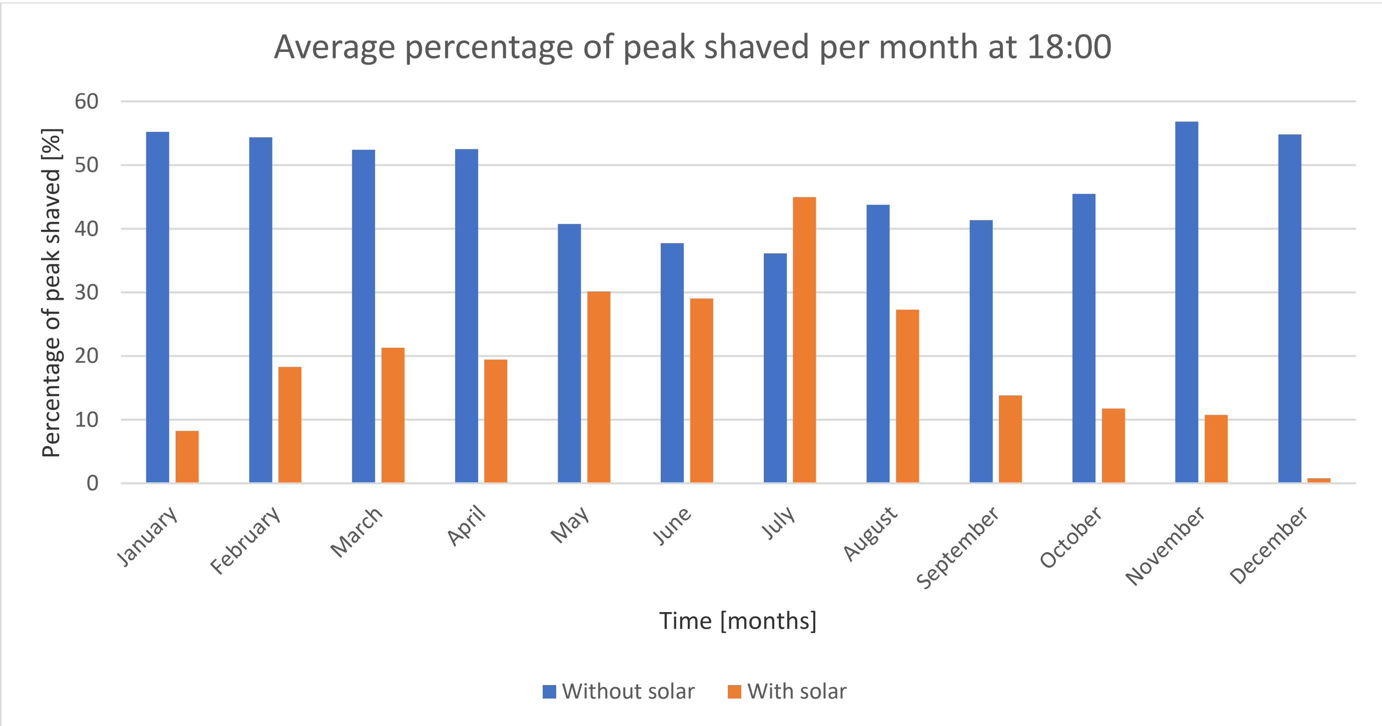

Figure 31: Average percentages of peak electricity demands shaved per month at 18:00 in residential cases without- and with solar energy integrated in the system.

In the cases without solar panels, peak demands were shaved over the entire year with some outliers during the winter months, reaching maximums of 55% of the total peak loads shaved. This is due to the higher load demand in the winter, due to the required power for space heating and heating of domestic water. Therefore, higher financial benefits could be achieved from energy storage during off-peak hours, which can be interpreted from the graph. The stored energy in the vehicle's battery could consequently being used to conduct peak shaving in the end of the day. Overall, the vehicle's battery has effectively been charged and discharged to conduct peak shaving.

Commercial cases

Figure 32 and Figure 33 show the monthly average percentage of peak demand shaved by the vehicle's battery at 14:00. Figure 32 illustrates that, in cases with solar energy, a bigger percentage of peaks have been shaved on weekdays during summer months compared to winter months. This is explained by the fact that, in the case with solar energy, more energy from the sun could be utilized and stored in the vehicle's battery. This could later be used for peak shaving purposes. Since there has been more- and higher peak demands on weekdays, more benefits could be achieved by shaving peaks on weekdays, in contrary to the weekends. In winter months, less solar energy could be utilized and stored which resulted in lower percentages of peak demands being shaved by the vehicle's battery. In August, a highest average percentage of peak loads shaved, with renewable energy has been achieved; amounting 95%. This highly contributed to an increase in the system's renewable energy fraction.

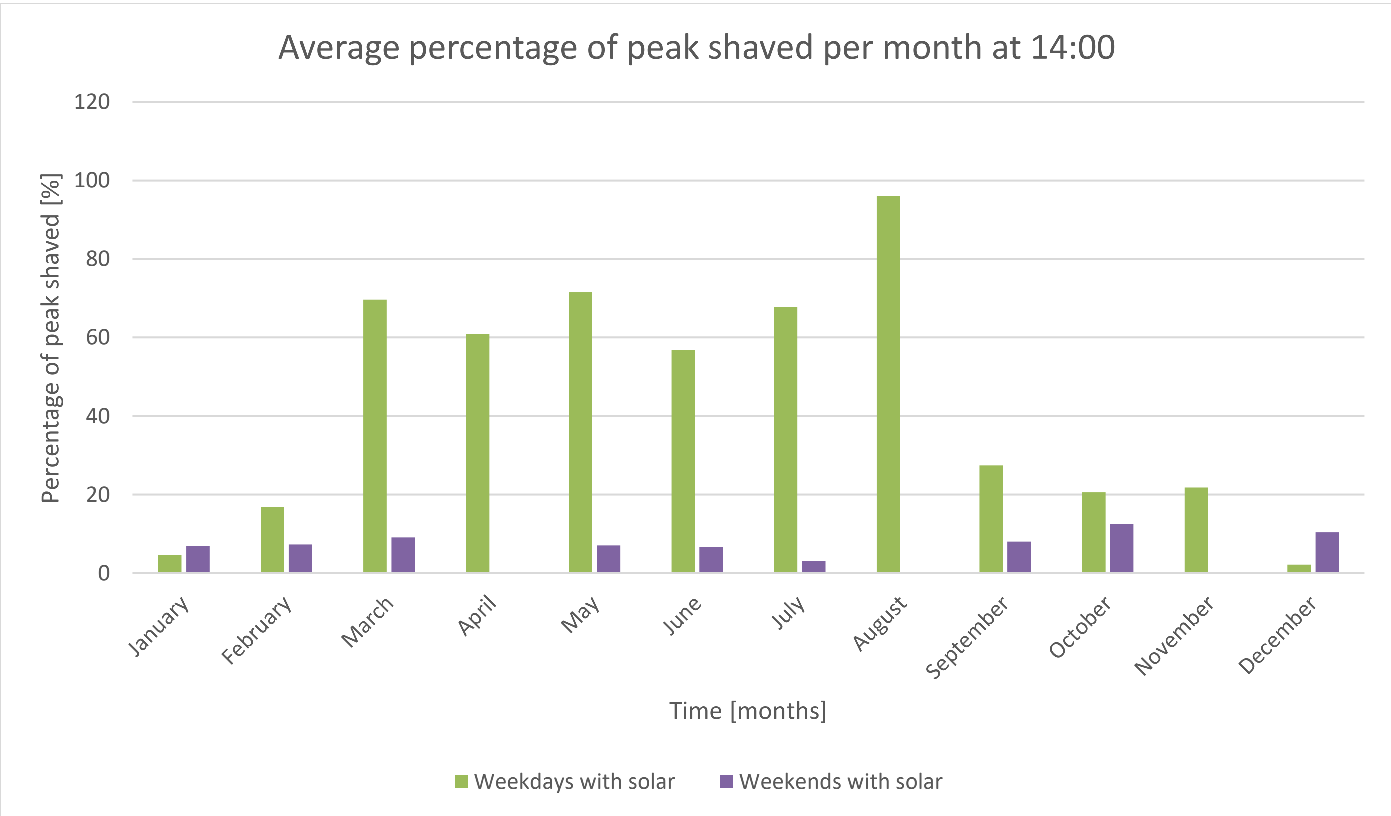

Figure 32: Average percentages of peak electricity demands shaved per month at 14:00 in commercial cases with solar energy integrated in the system. Figure makes a distinction between weekdays and weekends.

Figure 33 illustrates that, in cases without solar panels, a bigger percentage of peak demands were shaved during winter months, with the highest cases achieving almost 35%. Load demand is higher in winter months due to the required power for space heating and heating of domestic water. Therefore, higher electricity demand peaks applied for these months, and thus more electricity was supplied from the batteries in the EVs. Peaks have been shaved less frequently during the weekends in both cases. This is a result of the lower already electricity tariffs throughout the weekend, since these are given to be off-peak hours. Therefore, it was less common to conduct peak shaving during the weekend since less financial benefits could be achieved from storing electricity. Overall, the vehicle's battery has effectively been charged and discharged to conduct peak shaving.

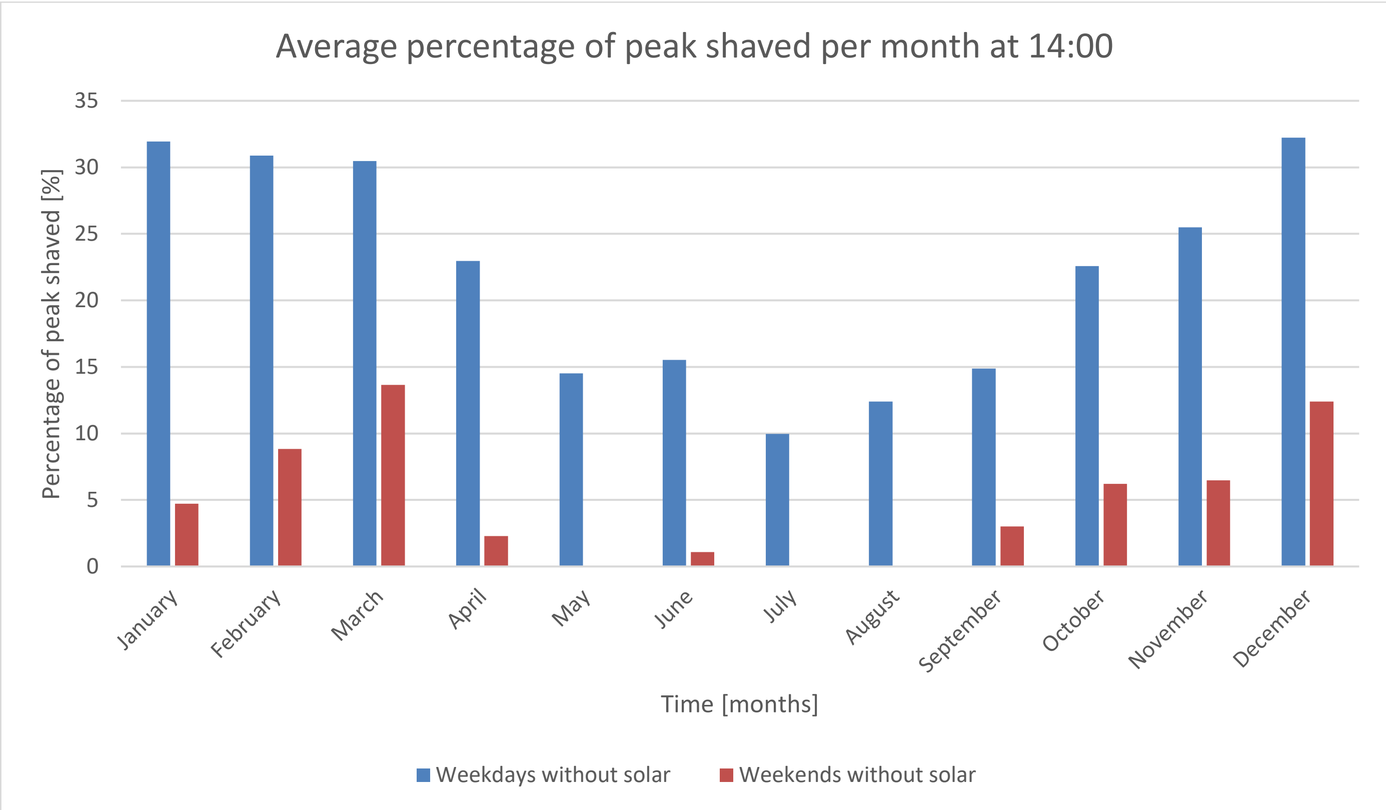

Figure 33: Average percentages of peak electricity demands shaved per month at 14:00 in commercial cases without solar energy integrated in the system. Figure makes a distinction between weekdays and weekends.

4.1.2 Price arbitrage

Figure 34 shows the annual percentage of a vehicle's battery being charged during peak- and off-peak hours.

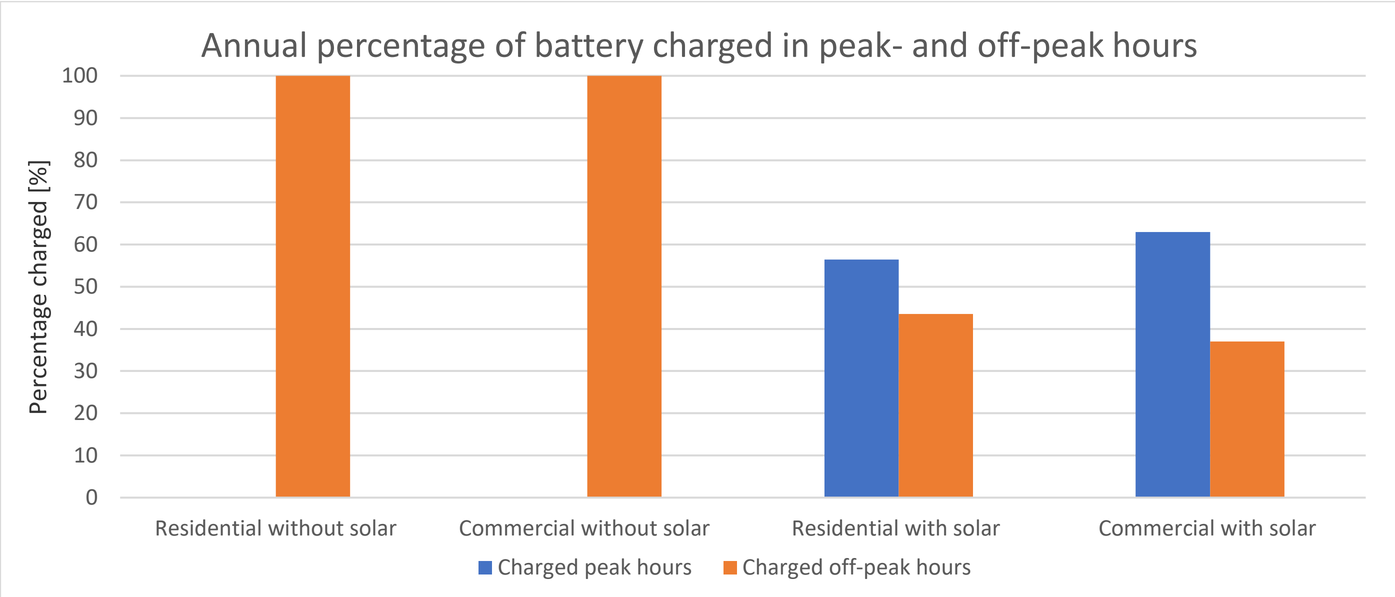

Figure 34: Annual percentage of the battery being charged during peak- and off-peak hours in residential- and commercial cases with- and without solar panels.

In cases without solar energy, both in residential and commercial cases, batteries have been exclusively charged during off-peak hours, making maximum use of price arbitrage methodology. The figures show that the energy management system has caused the system to exclusively purchase electricity from the grid during off-peak hours, increasing the economic viability of the system. This does not hold true for cases with solar, where most of the vehicle's battery have been charged during peak-hours. This can be explained by the fact that it was cheaper to use solar energy to charge the vehicle's battery. Since, solar radiation is highest throughout the day, batteries are more frequently charged during peak-hours, without taking electricity from the grid around those times.

Regarding the difference between weekdays and weekends, Figure 35 shows that for the residential case without solar, almost 64% of the battery has been charged on weekdays in the residential building case.

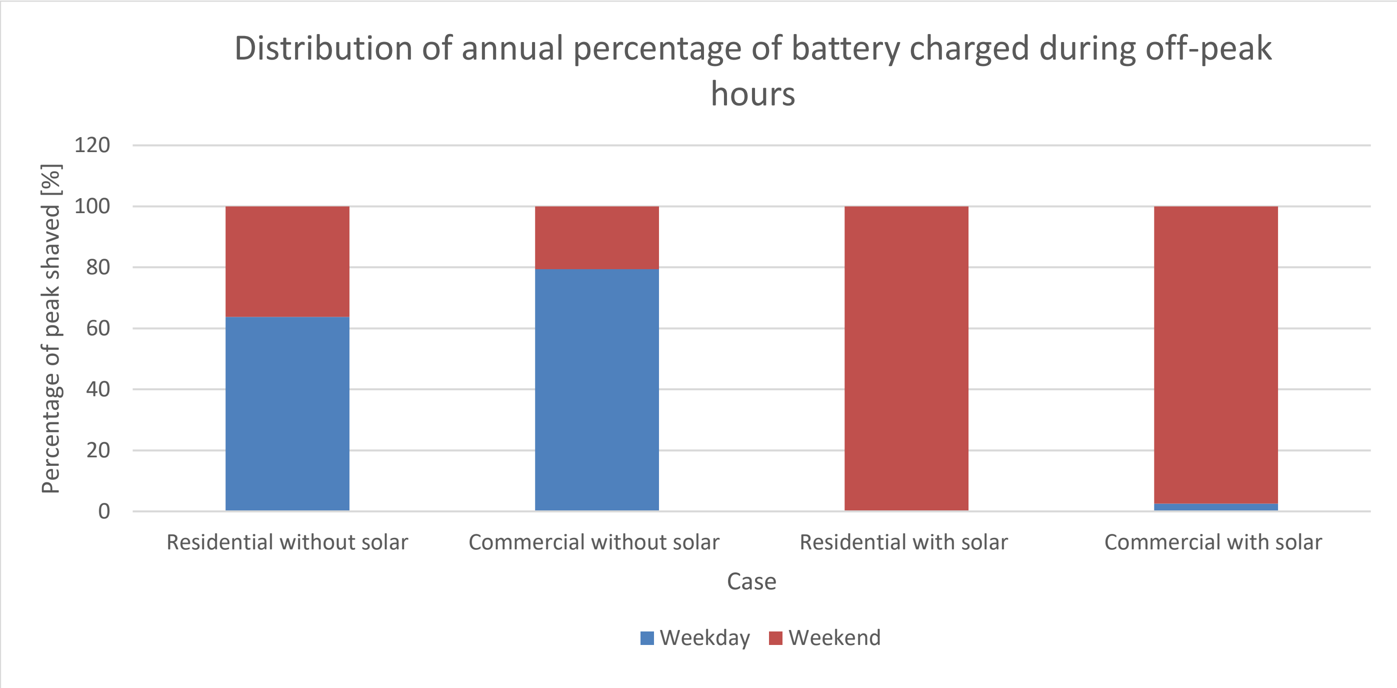

Figure 35: Distribution of the annual percentage of the battery being charged during off-peak hours in residential- and commercial cases with- and without solar panels. A distinction has been made between weekdays and weekends.

This was approximately 79% for the commercial building case, meaning that during weekdays the most price arbitrage intense activities can be performed. Most of the vehicle's battery has been charged at off-peak hours during the weekend in residential- and commercial cases with solar. This is because a same amount of solar energy is produced during the weekend as during the week, while load demand decreased. Therefore, more excess electricity was available which has been stored in the vehicle's battery over the weekends.

Financial benefits of price arbitrage without solar

In the residential- and commercial case without solar energy, financial benefits have been achieved from price arbitrage services, by charging the vehicle's battery during off-peak hours and sell/use the stored electricity during peak-hours. The cost saving resulting from price arbitrage are calculated with equation (22).

$$\begin{aligned} &Battery\ charging\ costs\ with\ price\ arbitrage\ \left[\frac{€}{year}\right] \\ &= \left(charged\ electricity\ \left[\frac{kWh}{year}\right]\right. \\ &\left.\times purchase\ price\ electricity\ \left[\frac{€}{kWh}\right]\right) \\ &- (sold\ electricity\ [\frac{kWh}{year}] \\ &\times sales\ price\ electricity\ [\frac{€}{kWh}]) \end{aligned} \tag{22}$$

In the residential- and commercial case with price arbitrage, the yearly costs for charged electricity plus grid sales amount 140.58 €/year and 333.10 €/year, respectively (see equation (23)(24)). The useful amount of discharged electricity amounted 788 kWh/year for the residential case and 1,771 kWh/year for the commercial case. If the same amount of useful discharged electricity has to be supplied by the grid, so without price arbitrage services, a total amount of 875.56 kWh/ year and 1,967.78 kWh/year is required in the residential- and commercial case, respectively. These values originate from the 10% additional rectifier losses. For this, the yearly costs for the same amount of electricity amount 175.11 €/year for the residential case and 393.56 €/year for the commercial case (see equation (25)(26)). Overall, this leads to residential- and commercial cost savings of 34.53 €/year and 60.46 €/year respectively, by allowing for price arbitrage.

$$\begin{aligned} &Battery\ charging\ costs\ residential\ with\ price\ arbitrage \left[\frac{€}{year}\right] \\ &= \left(820\ \frac{kWh}{year} \times 0.18\ \frac{€}{kWh}\right) - \left(9\ \frac{kWh}{year} \times 0.14\ \frac{€}{kWh}\right) \\ &= 140.58\ \frac{€}{year} \end{aligned} \tag{23}$$

$$\begin{aligned} &Battery\ charging\ costs\ commercial\ with\ price\ arbitrage \left[\frac{€}{year}\right] \\ &= \left(1{,}856\ \frac{kWh}{year} \times 0.18\ \frac{€}{kWh}\right) - \left(7\ \frac{kWh}{year} \times 0.14\ \frac{€}{kWh}\right) \\ &= 333.10\ \frac{€}{year} \end{aligned} \tag{24}$$

$$\begin{aligned} &Battery\ charging\ costs\ residential\ without\ price\ arbitrage \left[\frac{€}{year}\right] \\ &= 875.56\frac{kWh}{year} \times 0.20\frac{€}{kWh} = 175.11\frac{€}{year} \end{aligned} \tag{25}$$

$$\begin{aligned} &Battery\ charging\ costs\ commercial\ without\ price\ arbitrage \left[\frac{€}{year}\right] \\ &= 1{,}967.78\frac{kWh}{year} \times 0.20\frac{€}{kWh} = 393.56\frac{€}{year} \end{aligned} \tag{26}$$

4.2 Sensitivity analysis

Load

Since the results here presented highly depend on the input value for the load, this parameter has been varied within a 5- 25 kWh/day range for a residential case and within a 15- 45 kWh/day range for a commercial case, considering the use of a power manager and an integrated PV system. Figure 36 shows the development of the LCOE in relation to a residential- and commercial building's load under these variations. There is an overall increase of the LCOE when the load becomes higher. In all cases, the implementation of a power manager in the system increases the LCOE value.

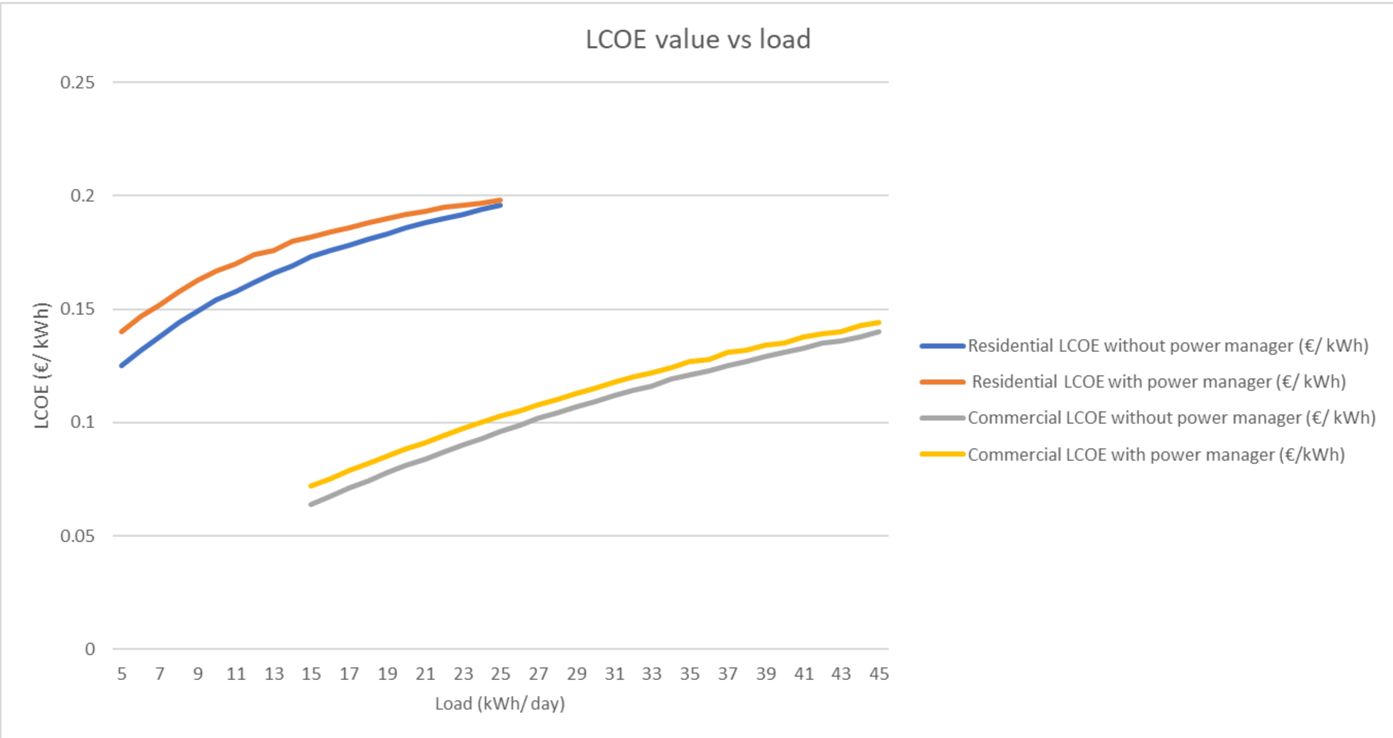

Figure 36: Sensitivity analyses curve for the relationship between the LCOE and a varying load in cases with- and without a power manager.

However, it can be seen from Figure 37 that the difference in LCOE for the cases with- and without power manager, becomes smaller once the load increases. Especially in the residential case, the financial benefit of a power manager increases once the load increases. The same pattern can be observed in the commercial case.

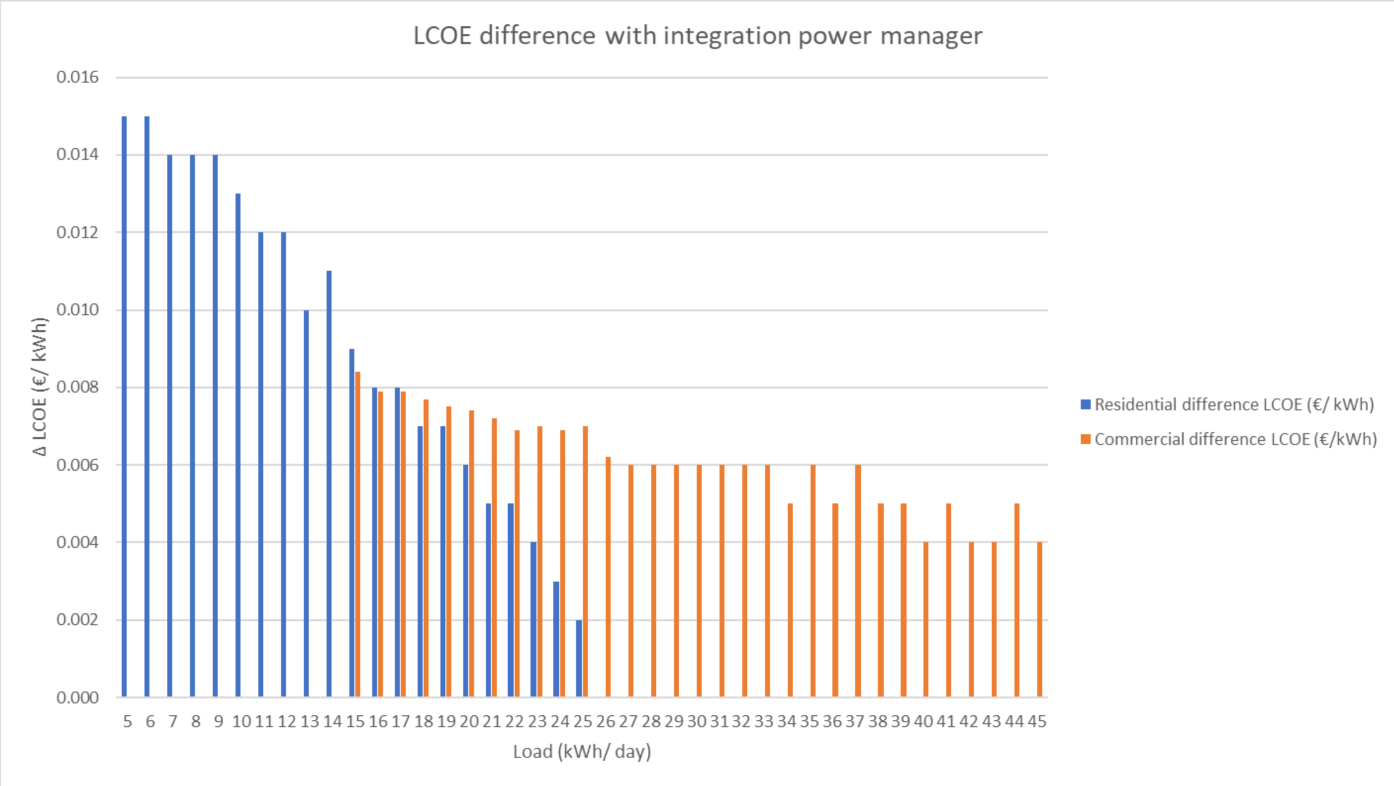

Figure 37: Distribution of the LCOE difference between cases without- and with a power manager in relation to a varying load.

This indicates that the power manager's economic viability increases once it's integrated in a building with a greater load. A lower amount of load can directly be served by the fixed capacity of solar panels when the building's load increases. Consequently, less solar energy could be directly stored in the vehicle's battery since there was less excess electricity available. Therefore, more electricity has to be purchased from the grid in this occasion. The advantages of price arbitrage by means of an EMS apply here, which decreases the difference in LCOE. Henceforth, electricity could be purchased from the grid and stored in the vehicle's battery during off-peak hours. In so doing, economic advantages could be achieved by means of a power manager. Namely, the energy management system can decide when to purchase electricity and how to use it effectively. This resulted in additional economic benefits.

A Dutch household consumes on average 8 kWh/day (CBS, 2018). When looking at the LCOE difference of a power manager for the residential case, a LCOE difference of 0.014 €/kWh could be observed (see Figure 37). This means that having a power manager doesn't directly result in economic benefits when having the energy management system programmed according to the base case's model inputs. A Dutch office with approximately 20 employees consumes on average 41 kWh/day (CBS, 2018). This corresponds to a LCOE difference amounting 0.005 €/kWh (see Figure 37). These values indicate that the integration of a power manager in average Dutch residential- and commercial buildings doesn't lead to behind-the-meter cost saving when integrating a power manager, assuming the energy management system to be programmed with the base case's input values. Even though this LCOE difference is slightly unfavorable, a power manager does increase the renewable energy fraction significantly.

Solar

The solar factor has been varied within a 3.6- 6.4 kW range for a residential case and within a 11.2- 14.2 kW range for a commercial building. The installed solar capacity on buildings' rooftops can differ in real-life cases, dependent on weather circumstances and availability of capital. Figure 38 shows the development of the LCOE of the system with- and without a power manager in relation to varying solar capacity.

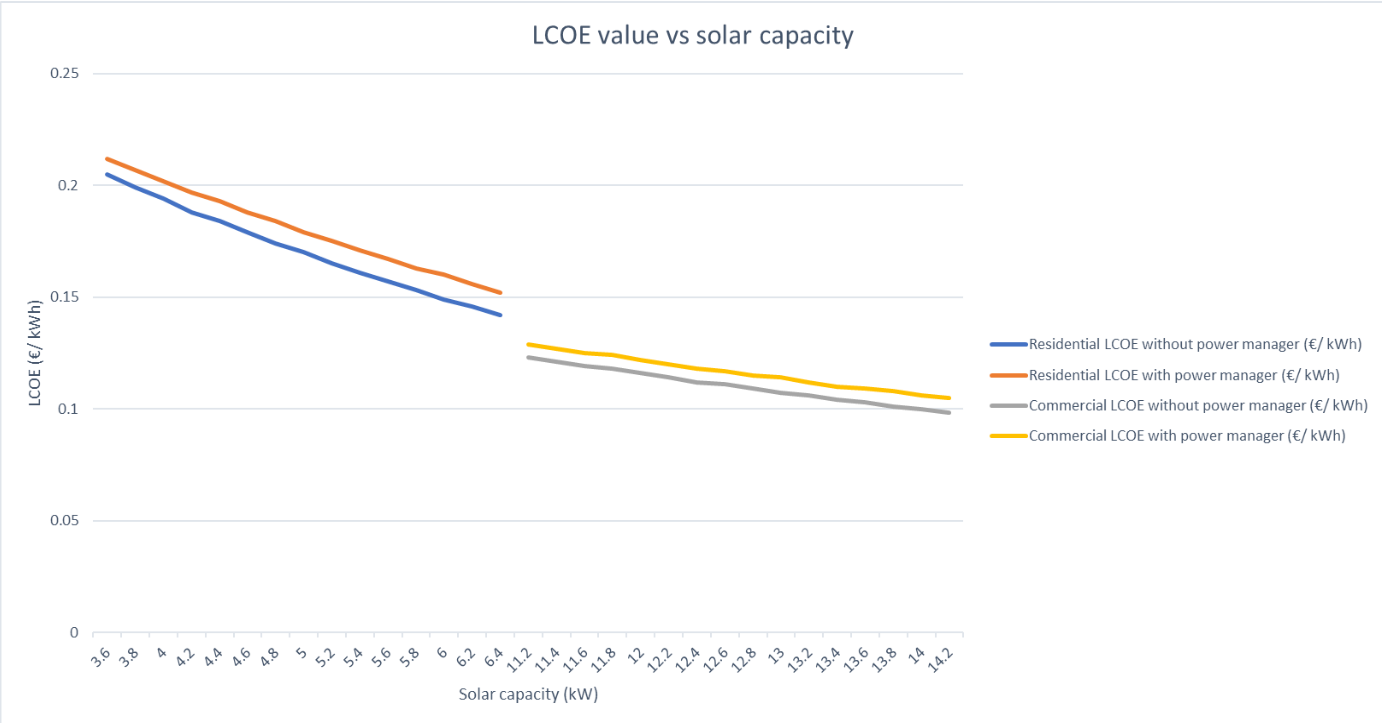

Figure 38: Sensitivity analyses curve for the relationship between the LCOE and a varying solar capacity in cases with- and without a power manager.

Figure 38 shows that the LCOE for residential- and commercial cases with a power manager is slightly higher compared the cases without a power manager. As can be seen in Figure 39, for the residential case the difference in LCOE between a case without- and with power manager decreases, once the installed solar capacity decreases. This can be explained by the increasing price arbitrage benefits that can be achieved once less electricity is supplied by solar energy. In the commercial case, the LCOE difference between the case with- and without a power manager stays constant once the installed solar capacity decreases. Even though the solar capacity decreased, the produced solar electricity is still enough to serve commercial loads for a big extent. Therefore, no significant additional benefits could be achieved from price arbitrage, as where the case in the residential case with a lower installed solar capacity. Herewith, cases with a higher installed solar capacity mostly contributed to an increasing renewable energy fraction by conducting peak shaving and storing a bigger share of sustainable energy. However, less financial benefits can be achieved by conducting peak shaving in contrary to price arbitrage. This explains why the LCOE difference decreases when less solar capacity is installed.

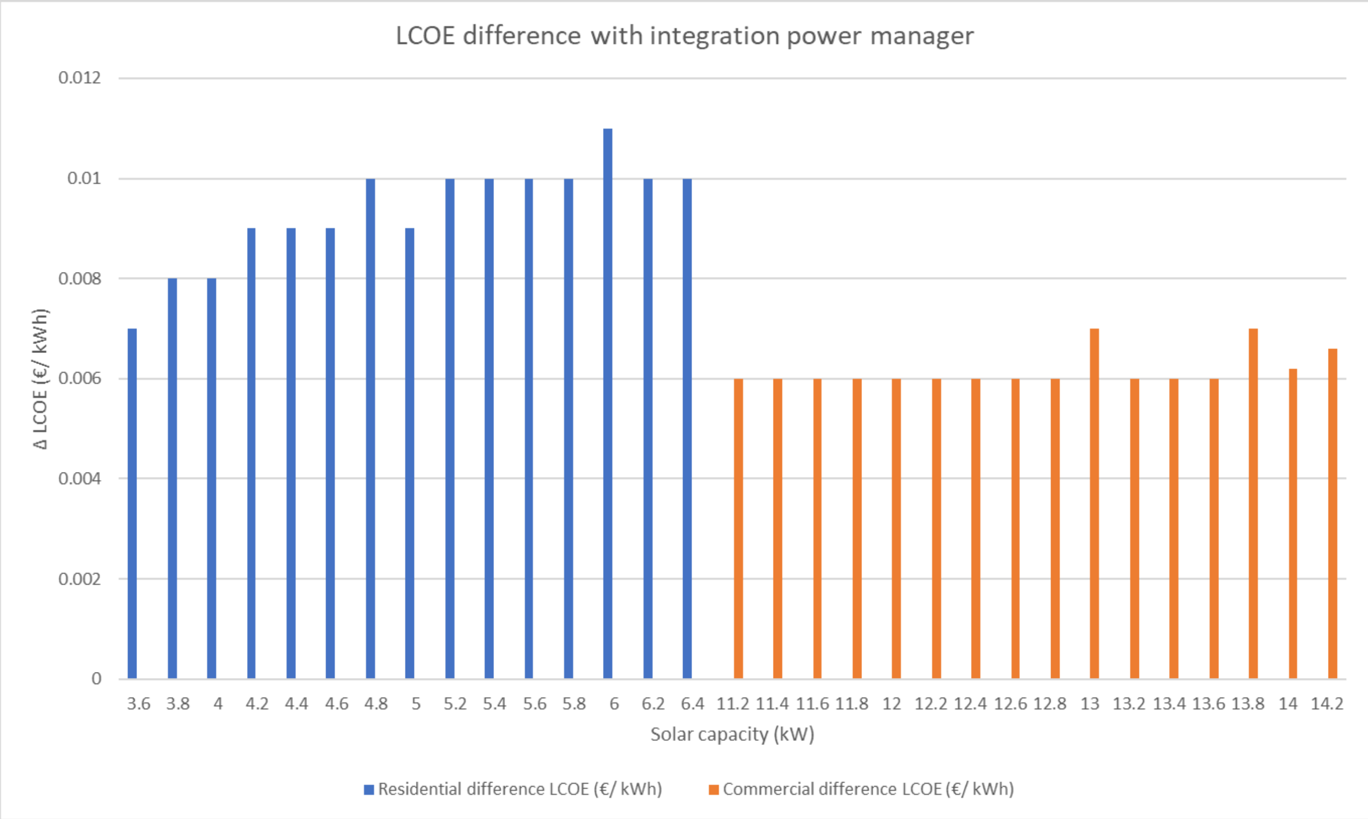

Figure 39: Distribution of the LCOE difference between cases without- and with a power manager in relation to a varying solar capacity.

These values indicate that the integration of a power manager, in residential- and commercial buildings with a national average installed solar capacity amounting 4.9 kW for residential buildings and 12.6 kW for commercial buildings, doesn't lead to behind-the-meter cost saving when integrating a power manager. For this, it is assumed that the power manager's energy management system is programmed according to the base case's input values. Moreover, a power manager does increase the renewable energy fraction, even though the LCOE difference becomes slightly more once the installed solar capacity increases. However, if the building owner becomes an aggregator of more homes/offices by using her battery- and solar capacity to deliver ancillary services to the grid, it's presumed that more financial benefits can be achieved in a before-the-meter operation. For this, it's most likely to establish a contract with a local utility company.

Feed-in tariff

The exact value for the feed-in tariff that interchanges the current 'salderingswet' by 2020, still needs to be determined by the government. This can influence the economic potential of an integrated power manager.

Since the exact feed-in tariff is still unknown, it's interesting to see how this tariff might affect the power manager's potential in the future.

The feed-in tariff has been varied within a 0.10- 0.18 €/kWh range for all cases. Figure 40 shows the development of the LCOE in relation to the varying feed-in tariff. The figure shows that the LCOE curve for cases with a power manager exceeded the LCOE curve for cases without a power manager. The LCOE value lowers when the feed-in tariff is increased. This is reasonable, since more revenues were generated by selling utilized solar energy to the grid.

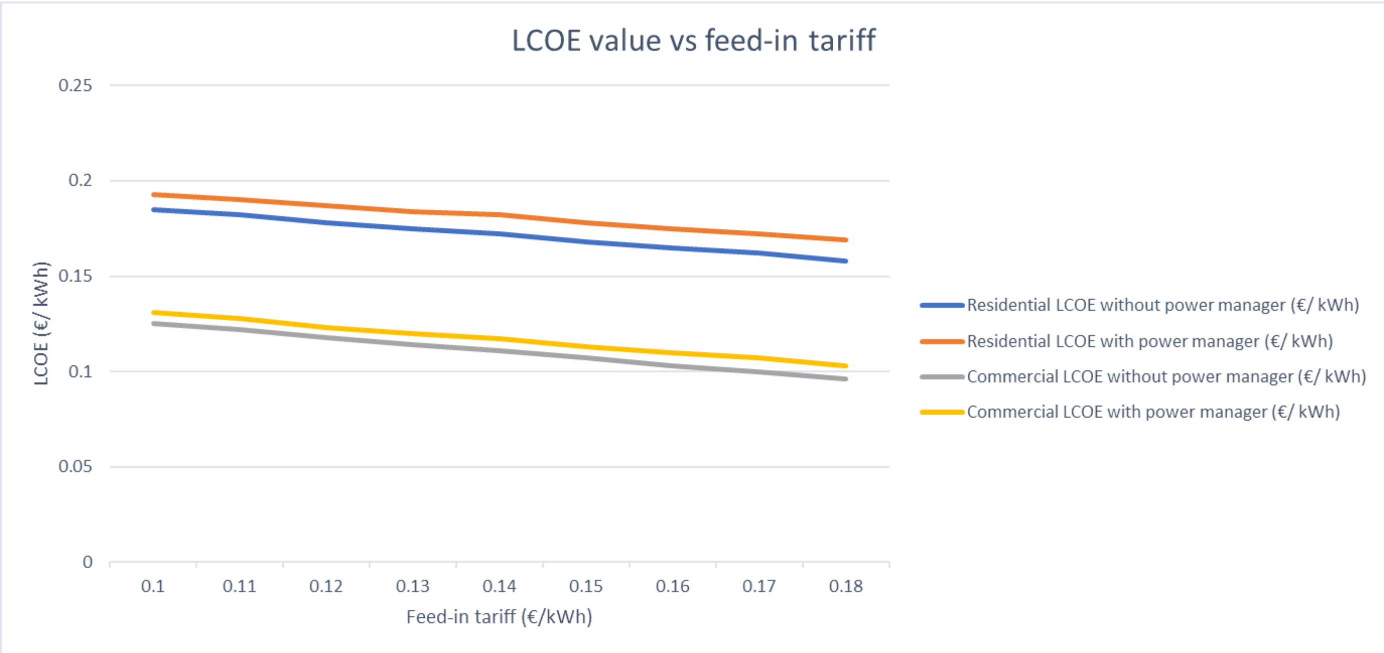

Figure 40: Sensitivity analyses curve for the relationship between the LCOE and a varying feed-in tariff in cases with- and without a power manager.

Figure 41 shows the difference in LCOE values for different applied feed-in tariffs. It can be stressed that the difference in LCOE between residential- and commercial cases increases when the feed-in tariff increases. In the commercial case, the difference in LCOE barely changed in consequence of changing values for the feed-in tariff.

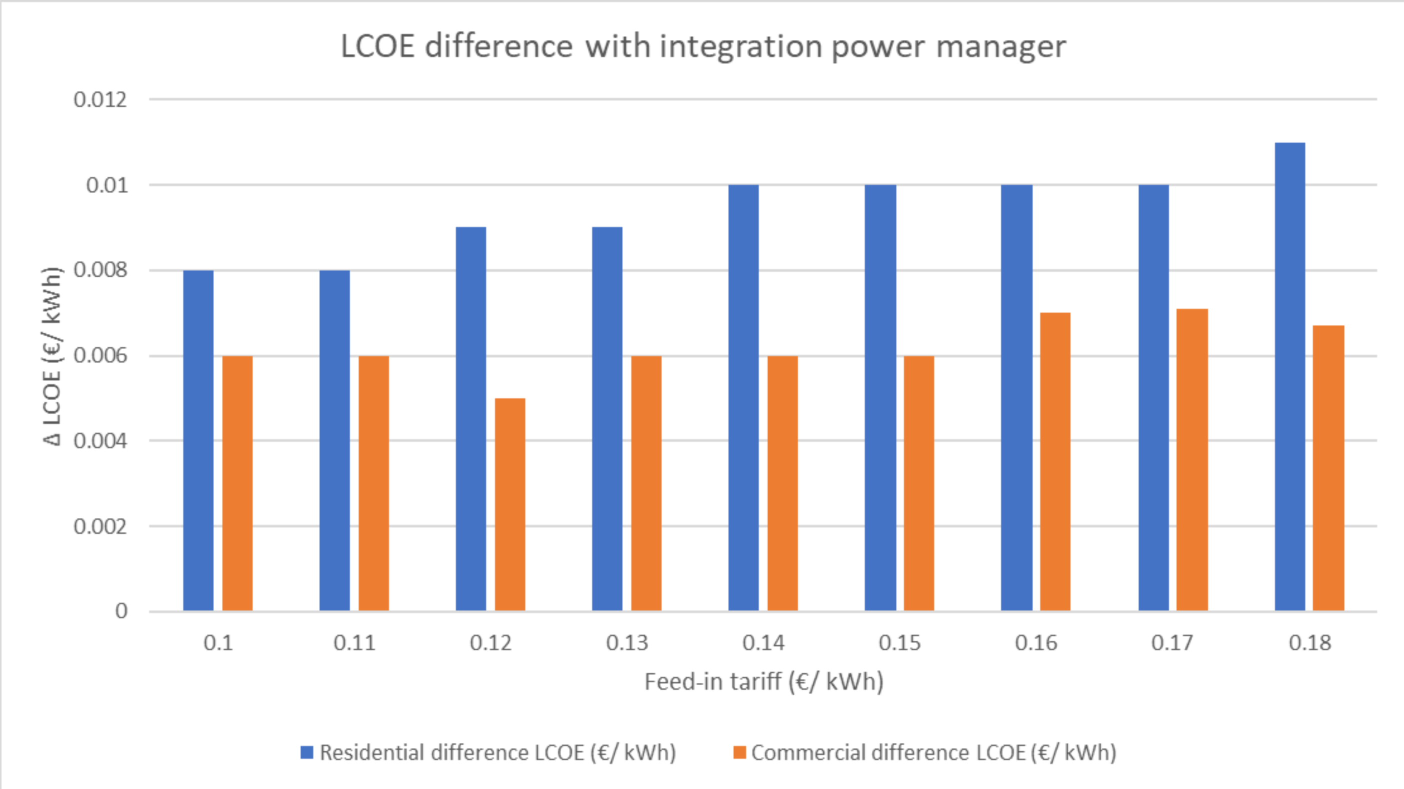

Figure 41: Distribution of the LCOE difference between cases without- and with a power manager in relation to a varying feed-in tariff.

The fact that barely any LCOE differences occurred in residential- and commercial cases, can be explained by the proportion of sold solar energy in cases with a power manager in relation to cases without. In both cases with solar energy, excess electricity could be sold against a higher price which lead to higher revenues and a lower LCOE. However, in cases without solar, no benefits could be achieved from varying feed-in tariffs since changes primarily apply for cases in which solar energy could be sold to the grid. This distribution has also been reflected in the base case models by the amount of electricity sold to the grid. As a result, LCOE differences between cases without- and with a power manager stayed more or less in proportion. This LCOE behavior has been reflected in Figure 41. Overall, the LCOE decreased when the feed-in tariff increased in all cases, regardless the presence of a power manager.

5. Business ideas and recommendations Honda

Price arbitrage services by means of a Honda power manager can lead to behind-the-meter costs savings in residential- and commercial buildings without solar panels. In buildings with solar panels, the power manager can effectively increase the system's renewable energy fraction by allowing for peak shaving services and a V2G operation. However, in the latter case, this doesn't result in direct behind-the-meter cost savings in any of the cases analyzed in this work. However, the potential of a Honda power manager reaches further than that, since it can be used to deliver ancillary services before-the-meter as well. This means that intermittencies in the grid can directly be covered by the total battery capacity and solar energy installed.

The Honda power manager is able to deliver ancillary services to the grid in a before-the-meter case as well, which might increase the profitability of an integrated power manager. Moreover, the financial- and environmental benefits of a power manager can increase when the size of the entire system; including storage capacity and solar production, increases. For this, Honda could fulfill the role of an aggregator by dispatching all Honda power manager users' battery capacity in such a way, to cover for energy- demand and shortage experienced by utility companies. Additionally, frequency control can be conducted by means of a vehicles fleet's battery capacity that is exposed to the grid.

This leads to new business opportunities for Honda since the company can combine its expertise by functioning simultaneously as a vehicle supplier, EVSE supplier and provider of ancillary grid services. Delivering ancillary services to the grid in a before-the-meter case can lead to promising business opportunities. Based on the correlations and information discussed in the report, several business opportunities for Honda were formulated. For this, a framework is designed in which all charging components are involved and a collaboration with a utility company is realized (Felicia Bendtsen , 2012). Figure 42 gives an overview of the proposed business model for Honda. This model provides a scenario in which benefits can be achieved for several parties; including Honda, Honda's power manager users and the utility company. Honda fulfills an aggregating role within this model.

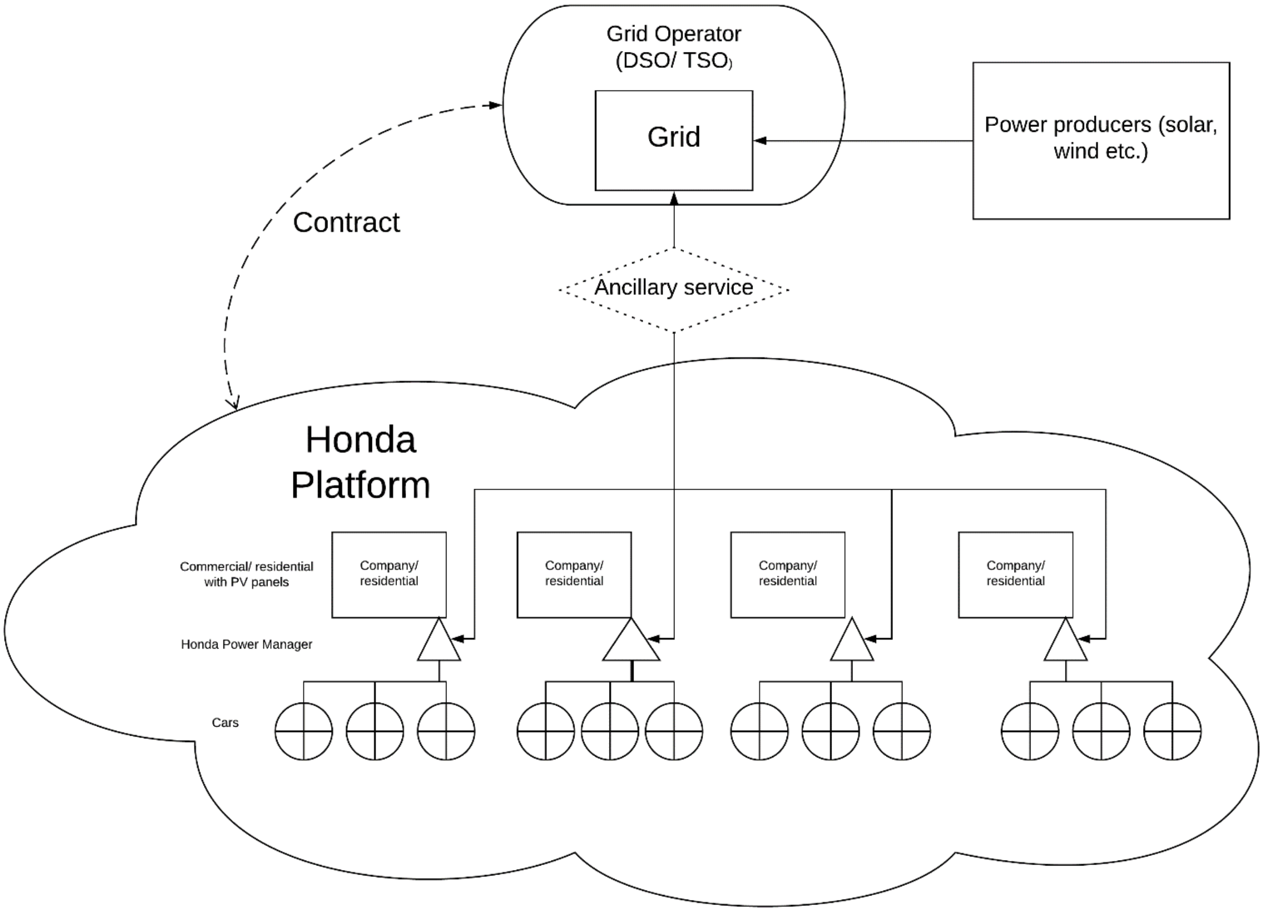

Figure 42: Business model opportunity Honda.

The figure shows the interaction of Honda's customers within the grid-connected service. In the proposed model, the local grid operator (DSO) receives electricity from big centralized power producers and companies/homes within the Honda platform. Commercial- and residential buildings within the Honda platform subtract electricity from the grid, in case they're not able to meet their own electricity demand with locally produced energy. Also, the Honda platform offers ancillary services to the grid operator, for which Honda gets paid. Moreover, it provides a significant amount of solar energy that can be used to regulate the grid during times of shortage. Also, the vehicles' storage capabilities within the Honda platform can be used beneficially.

Honda Platform

The Honda platform preferably consists of residential- and commercial buildings that are grid connected, have one or several Honda power managers installed and produce solar energy. Additionally, employees and residents ideally own a Honda electric vehicle or fuel-cell electric vehicle. Scaling up the number of participants in the Honda Platform is favorable since it will increase Honda's bargaining power against the utility company. A bigger platform can facilitate bigger grid regulating practices. Extra functionalities can be added by enabling people to share energy with other Honda platform users. In so doing, sustainably produced electricity can be used more efficiently against a lower tariff. Figure 43 shows the traditional case in which prosumers buy and sell electricity from- and to the grid, without the involvement of external parties.

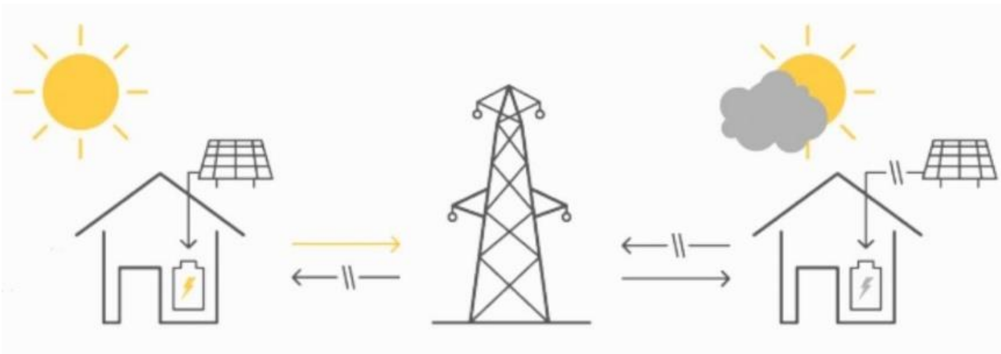

Figure 43: Energy exchange scenario without the involvement of the Honda Platform. Based on (Sonnen , 2018).

Prosumers within the Honda Platform can produce- and share electricity with other parties in the platform. This scenario is stressed in Figure 44.

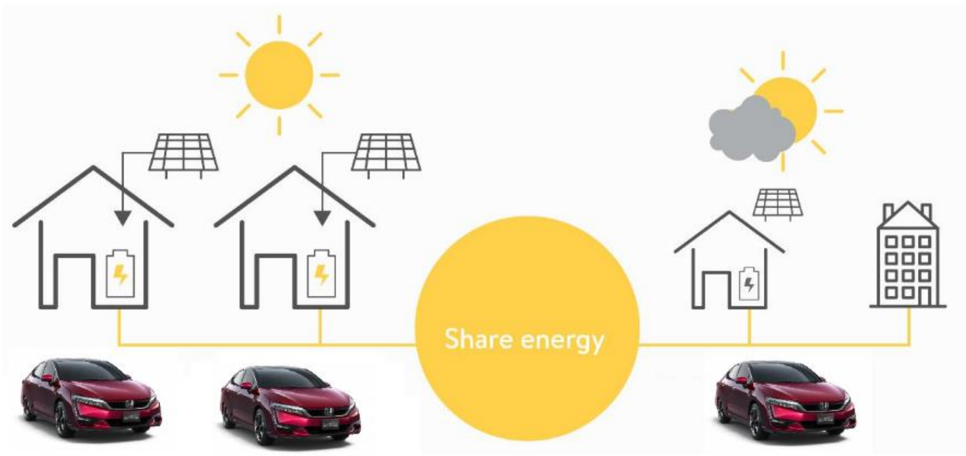

Figure 44: Electricity exchange scenario with V2G and Honda Power Platform connection.

An option for sharing electricity should be provided since there won't be one smart grid on which the entire Honda platform operates. This can be done by making use of a tracking system that systematically follows the electricity flows between users and the central grid. In this way, users can principally share electricity without physically interchanging electricity with their neighbors. This will be done by symbolically buying electricity certificates from each other; which ensures users to utilize the electricity that has been provided by other users within the platform. Data about the platform's power- supply and demand can be provided to the utility company within a 15 minutes time span (Progress Energy). Agreed electricity transactions can be tracked, for instance, by making use of blockchain technology or other related technologies. This electricity sharing system will presumably stimulate people to install more solar panels and/or become aware of their electricity consumption.

Cooperation is asked from customers since they should be willing to expose their vehicle's battery or building's electrical system to the grid. For this, a credit building system can be created in which customers get rewarded for delivering ancillary services to the grid. By establishing such a system, customers are stimulated to change their electricity behavior to suffice utility's preferences. Nowadays, some sustainable electricity platforms make use of a similar system in which they provide a mobile application where customers program their preferred time of charging and discharging throughout the day. Users receive more credits once they expose their vehicle to the grid for a longer period of time, because the utility company can use the vehicle's battery in a more efficient way.

Customers are among Honda's first priority, and therefore, charging and operational practices should be functional and user-friendly. Research has shown that customers prefer charging to be functional and provided by a company with which they're familiar (Bohnsack, van den Hoed, & Oude Reimer, 2015). This points out that Honda would be highly competent for this role, especially since most customers have already chosen Honda as their vehicle provider. Honda can only function as an aggregator once they establish strong partnerships with qualified local utility companies. The bigger the size of the Honda platform, the more likely it will be to establish value adding contracts with utility companies (Bohnsack, van den Hoed, & Oude Reimer, 2015). A schematic overview of such a structural partnership between Honda and an utility company is shown in Figure 45.

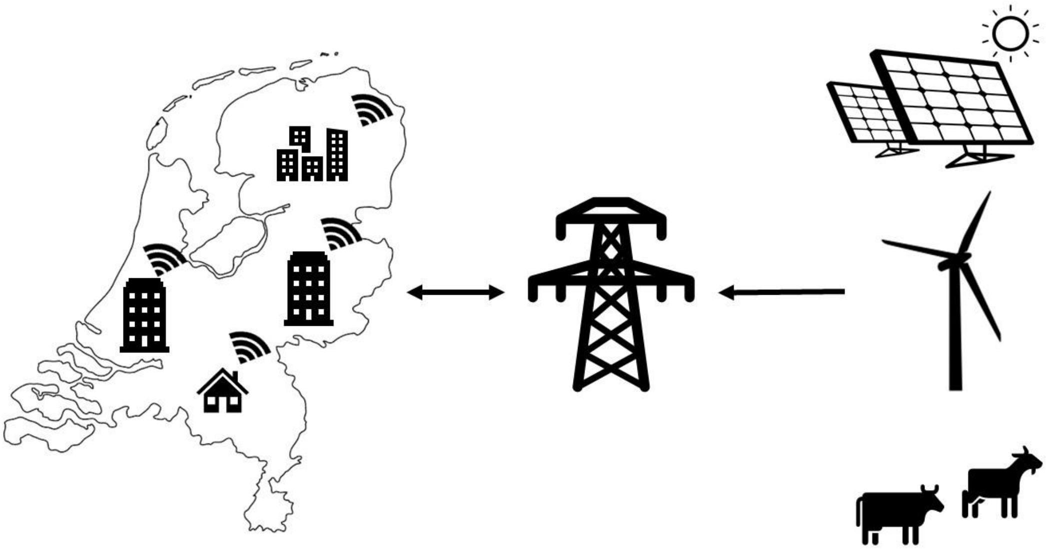

Figure 45: Position of the Honda Power Platform within the electricity network.

Advantages parties

Customer

Honda's customers experience benefits by contributing to- and operating within the Honda Platform. First, customers experience financial benefits since the power manager efficiently dispatches electricity flows within the electricity system. In addition, customers can earn money by exposing their vehicle to the grid. This enables them to receive credits on their charging card, which later can be translated into money or services. Secondly, people become aware of their electricity consumption by actively being involved as a pro/consumer in the system. As a result, customers will use less energy. Thirdly, people might utilize so-called Time-of-Use (TOU)-tariffs, indicating peak- and off-peak hour prices. These tariffs indicate the changing electricity price, due to energy- shortage and oversupply in the grid. In so doing, investment- and electricity costs decrease. This is due to the customer's flexible response to electricity demand. Customer benefits are mentionable from the beginning since Honda takes on the responsibility of installing- and maintaining charging facilities. According to Chukwu et al., the benefit of sending surplus electricity to the grid is bigger than the losses caused by battery degradation costs. Therefore, customers will mostly economically benefit economically from delivered ancillary services (Chukwu & Mahajan, 2011). Figure 46 and Figure 47 show the proposed bi-directional charging-/discharging operation for residential- and commercial buildings respectively.

Figure 46: Honda's power manager concept for residential buildings. Adopted from (Honda , 2017).

Figure 47: Overview of Honda's power manager solutions for commercial buildings. Adopted from (Honda , 2018).

Besides being part of the Honda Platform community, people also benefit from sustainable regulations that have been established by the Dutch Government. Moreover, the government is planning to invest 300 million euros in climate supporting projects (Rijksoverheid , 2018). This will most probably lead to the development of regulations for emission-free vehicles and a good charging infrastructure. Some of the subsidies where Honda’s customers can already apply for, are mentioned below (Rijksdienst voor Ondernemend Nederland , 2018).

<u>BPM</u>

The so-called BPM regulation stresses the tax for vehicle ownership. This tax stimulates people to acquire low-emission vehicles because the amount of tax is determined by the overall environmental characteristics of the vehicle. However, EV owners don’t have to pay for this tax. This makes driving an EV in the Netherlands highly favorable. Additionally, they benefit from not having to pay for the MRB; which addresses the tax for vehicle ownership. The MRB tax price is based on the vehicle's weight, environmental friendliness, and place of registration.

Tax benefits companies

Several regulations are established for companies to acquire fiscal benefits from investing in sustainable products/services. Among these are fiscal regulations for low-emission vehicles and charging facilities. Moreover, the environmental investments regulation (MIA) maintains a 36% fiscal investment reduction on hydrogen vehicles and a 36% reduction on electric vehicles. Also, employees can lease electric vehicles according to the 'bijtelling' regulation. In this case, leasers have the benefit of paying less per month for the lease of a zero-emission vehicle.

Other subsidies

Most of the Dutch municipalities maintain different subsidies and regulations. In some municipalities, subsidies are being assigned to people who buy an electric vehicle. This subsidized amount of money can go up to € 5,000 per vehicle. Additionally, in some municipalities, you can request for a charging pole which will be installed and delivered for free. It's important to consider funding differences between municipalities and choose a pilot-project location wisely. Subsequently, based on these factors, a well-considered business plan can be developed.

Utility company

The utility company is much in favor of the ancillary services that the Honda platform can deliver for grid optimization purposes, since it saves them O&M- and grid installation costs. Additionally, they don't have to purchase additional electricity from dispatched power plants to meet electricity demand. The platform can contribute by supplying electricity to the grid, offering demand response, shaving peak loads, regulating frequency, controlling voltage, and powering homes.

Honda

Honda benefits from the business model in two ways. At one hand, the utility company provides the grid network and rewards Honda for delivering ancillary services. Additionally, the utility company is much in favor of the energy capacity that Honda's platform delivers. On the other hand, Honda gets more products/services to offer to her customers. Moreover, Honda can expand her business and penetrate new markets by selling individual products or package deals; including vehicles, solar panels and power managers.

Cost structure within the Honda Platform

Residential- and commercial buildings can increase their sustainability fraction by integrating solar panels, electric vehicles, and power managers within the system. In the new scenario, Honda is profiling itself as a high-quality supplier of vehicles and power managers, and can herewith, provide an all-embracing sustainable solution for customers. Honda has already established a partnership with Solar City in the US. This allows Honda drivers to take control of their electricity and buy solar panels against a discounted price. Moreover, such a partnership can even be further extended to a structure in which Honda offers a complete package of solar panels, vehicles and power managers to their customers. In so doing, Honda can penetrate and expand markets by offering a wider range of products and services.

Honda Smart Charging functionalities

Honda’s customers can benefit from additional charging services within the Honda platform. The facilities provided by Honda can be described as follows:

- Customers can charge their vehicle at any charging facility within the Honda platform.
- Customers get rewarded for exposing their vehicle to the grid and for delivering ancillary services.
- Customers can share electricity with other parties operating within the Honda Platform. This leads to price savings for all parties involved.

To successfully make use of all charging services, Honda owners apply for a charging card with which they get access to Honda’s charging facilities. The operation of such a system is presented in Figure 48. Customers pay a monthly fee for the charging facilities; which are provided and maintained by Honda. Honda can track the amount of charged- and discharged electricity accordingly. The charging card is linked to the users’ account. This enables customers to collect credits by adjusting their charging pattern to the utility’s preferences. Moreover, customers get rewarded for exposing their vehicles to the grid for a longer period of time. The vehicle can also be smartly charged at certain moments during the day when the electricity price is low. In so doing, the intermittent character of sustainable electricity as well as the fluctuations in the grid, can be covered by smartly making use of the vehicle’s battery capacity.

Figure 48: Charging procedure by making use of a charging card. Adopted from (The New Motion, 2018).

Externally controlled hardware and software, which can be accessed by the utility company, are needed to regulate the charging procedure. In this way, the utility company gets access to the vehicle’s internal data, and therefore, tracks the vehicle’s activity in terms of electricity consumption. Also, information about charging- and discharging practices continuously needs to be monitored. For this purpose, real-time information from the vehicle management system (VMS) and the battery management system (BMS) can be provided. The BMS gives insight in the battery’s- nominal electricity use and SoC. Data can also be acquired from the charging facilities’ eliminated power. Smart meters and Power Line Carriers (PLC) can be used for the latter case. Hereby, the Honda Power Platform can even be coupled to the day-ahead electricity market to optimally match energy- demand and supply. Additionally, the aggregator must synchronize the power flow between electric vehicles and the grid. Altogether, a bigger number of participants within the Honda Power Platform will lead to a system in which better ancillary services can be delivered to the utility company (Kempton, Marra, Andersen, & Garcia-Valle, 2012).

Human-interface/ smartphone application

An application should be provided to make the bi-directional charging/discharging operation run more efficiently. It’s important that customers get the possibility to program their charging preferences in an application since customers’ charging patterns are different for each case. These preferences can later be communicated with accessible charging facilities.

Some of the features the application might have are listed below:

- The charging facility should have the option to include customer’s preferences regarding arriving- and departure time. Additionally, customers should be able to give in personal preferences for the battery’s SoC. An example of the application’s human interface is shown in Figure 49.

- In the future, there might be an option to pay for a parking facility in the application, by using a certain amount of collected credits acquired from delivering ancillary services.
- A search function should be integrated in the app which can direct vehicle owners to available charging facilities. Additionally, this search option can be expanded by indicating other facilities; such as cafes, shops, restaurants etc. These functionalities can be adopted in a business model.
- The app should be transparent in giving the exact price for charging at a particular facility. Although, this price might vary among several charging facilities since electricity availability factors play a substantial role.

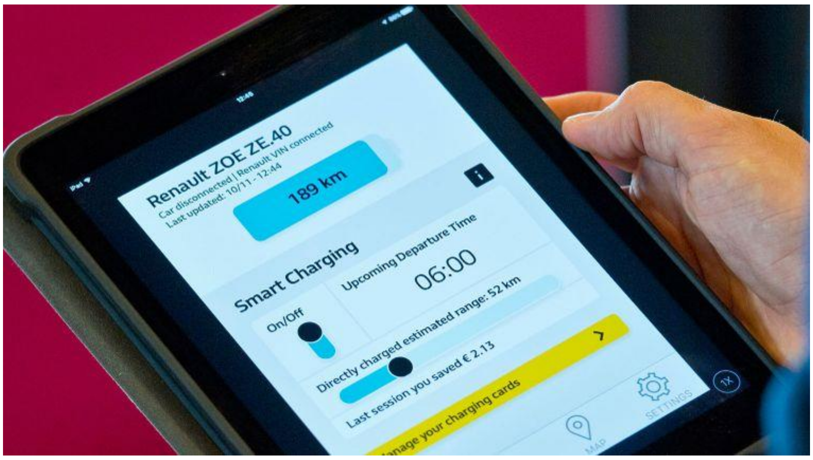

Figure 49: Example of the application's interface. Adopted from (ANWB, 2018).

From a customer's perspective

The following scenarios show the possibilities for offering products and services to Honda's customers.

Scenario 1: Residentials and commercials in grid-connected buildings; without electric vehicles, solar panels and power managers.

The following packages can be offered to this target group:

- Honda sells a vehicle and provides a power manager for free. Additionally, customers pay a monthly fee for using the Honda platform's charging facilities.
- Honda sells a vehicle and solar panels in a package deal and provides a power manager for free. Additionally, customers pay a monthly fee for using the Honda platform's charging facilities.

Scenario 2: Residentials and commercials in grid-connected buildings that already have an electric vehicle and charger.

- Honda offers her customers the possibility to replace their traditional charger for a power manager without additional costs or for a small price. Additionally, customers pay a monthly fee for using the Honda platform's charging facilities.
- Honda offers her customers the possibility to replace their traditional charger with a power manager for free when they are willing to expand their system with solar panels. In this case, solar panels are offered against a discounted price. Additionally, customers pay a monthly fee for using the Honda platform's charging facilities.

Scenario 3: Residentials and commercials in grid-connected buildings that have an electric vehicle, charger, and solar panels.

- Honda offers her customers the possibility to replace their traditional charger with a power manager for free, when they are willing to apply for the Honda platform's charging facilities.

5.1 Follow-up plan Honda

Several steps that Honda should take to achieve this desirable scenario are listed below. Pivotal elements are described on which Honda should put more emphasis. These elements and steps are classified into 3 action groups; namely Create, Clarify and Convince. These 3 C's are explained in the following sections.

Convince

It's essential for Honda to start conducting pilot projects with local utility companies to build trust and gain experience in the field of V2G operations. In so doing, customers will be able to experience the potential of the proposed Honda Platform and might experience cost- and efficiency benefits already. Valuable feedback can also be acquired from the operation. The projects can also be used to raise awareness which can be translated into advertising and branding value creation. Peoples' preferences are mostly dependent on the system's functionality, rather than its profitability. Therefore, the ease of use and functionality of the system should be among Honda's top priority.

Clarify

It's important to scale-up the number of users/charging facilities, so the platform can be expanded and more electricity can be smarty distributed within the Honda Platform. Substantial economic- and environmental benefits can be achieved when people start interchanging more energy.

Honda's responsibilities should be clearly addressed before making the platform operative. They can provide a cost-structure for the proposed charging facilities in the following 2 ways:

1) Honda becomes the supplier of the power manager and the accompanying EVSE (EV Supply Equipment)
2) Honda becomes the supplier of the Power Manager, the accompanying EVSE and the vehicle’s battery.

For now, option one would be more applicable since a lot of vehicles are already owned by residents or employees. This makes it hard to establish a contract in which Honda becomes the main owner of the vehicle’s battery. Additionally, it saves paperwork and complex ownership structures. However, the need for option 2 might arise soon since vehicles will increasingly become essential components within the local grid systems. In both cases, the user receives a charging card with which he/she can get access to Honda’s charging facilities. In so doing, the user is paying on a monthly basis for all charging facilities and services that Honda delivers. As described before, credits in the form of money or rewards can be transferred to the users’ account for delivering ancillary services. Honda can either facilitate these services themselves or partner up with established companies that provide charging facilities. For this purpose, the New Motion can for instance be a promising company to partner up with (NewMotion, 2018).

Create

Honda can sustain and expand its business by creating partnerships. These can be used for the following applications:

Solar energy

The Honda Platform can be expanded quicker and more revenues can be achieved, when solar panels are offered in a package deal together with the purchase of an electric vehicle. Therefore, a partnership with a leading solar company in Europe will be highly suggested to offer Honda’s customers a wide range of intertwining products and services. Since Honda already established a partnership with Solar City in America, it might be interesting to expand this collaboration in Europe. For instance, BMW has partnered up with Sungevity in the Netherlands to offer BMW’s customers solar panels against a discounted price (BMW, 2018). This might also be interesting for Honda.

Utility company

The Honda Power Platform can’t function in its announced form without having access to the grid. Users need the grid to efficiently make use of energy- sharing and supplying practices. Additionally, users within the Honda Platform do not obtain financial benefits from sharing energy. Especially in cases where the utility company doesn’t allow them to receive electricity against a lower electricity tariff. On the other hand, it’s in the utility company’s interest to get access to the Honda Platform since it offers them electricity production capabilities and a large storage capacity. Altogether, both parties will benefit from a collaboration and can jointly keep the grid balanced. Stedin, Liander and Enexis are among the biggest DSO's in the Netherlands that can be approached for a pilot-project.

In-app advertisement

Also, a business model can be established by allowing external parties to advertise within the Honda Platform's user application. The number of users can be interesting for retail- and other businesses since company names can be listed on the map. Several business models can be developed and applied for this purpose. Moreover, an expansion of the Platform gives Honda more bargaining power and enables them to establish contracts with external parties.

Battery recycling

Honda can set up a recycling trajectory for second-hand vehicle batteries. For instance, degraded electric vehicle batteries can be re-used, for instance, in streetlights and can be used for building storage purposes. In so doing, additional markets can be served after the battery has been degraded for driving purposes. This business idea can be combined with the beforementioned cost-structure 2, since Honda stays the owner of the vehicle's battery. Sonnen, PowerVault and Eaton might be interesting companies to partner up with as well, due to their expertise in the field of batteries and recycling trajectories. For instance, Nissan recently partnered up with Eaton to adjust a second-hand vehicle battery in such a way that it can be integrated as a home storage system (Nissan , 2018). This has led to a cooperation and extension of Nissan's business. Until now, Honda primarily focuses on the utilization of salvaged materials from Li-ion batteries. Therefore, this might be an interesting idea to develop.

Acknowledgments

The proposed business model is designed to stress the power manager's potential for the Dutch market. Since privacy issues, governmental regulations, grid prices and grid infrastructure might differ among countries, it's highly recommended to adjust the proposed business model other markets are penetrated. Also, some parts of the model are highly dependent on partnerships, which makes it hard to implement the model without established contracts. The business model is designed based on information about Honda's businesses and ongoing operations in 2018.

6. Conclusions and recommendations

Integrating a power manager could have advantages over a plain system with charging pole and converter, by allowing for the integration of a vehicle's battery within a building's electrical system. A power manager is proven to successfully integrate electric vehicles within the electrical system of commercial- and residential buildings, by adapting to different electricity profiles throughout the day and distributing electricity accordingly. Environmental- and economic benefits could be achieved by allowing for price arbitrage and peak shaving services, conducted by a vehicle's battery in a behind-the-meter operation. For this, it's important to adjust the dispatch strategy within the power manager's energy management system to optimize the combination of the system's profitability and sustainability. These adjustments consider a building's system design and available battery capacity.

Most of the behind-the-meter cost-savings in residential- and commercial buildings originated from price arbitrage practices, in comparison with peak shaving services. However, peak shaving significantly caused the system's renewable energy fraction to increase for buildings with installed solar panels. Therefore, the cost- and electricity savings resulting from the integration of a power manager highly depend on the customer's preferred combination of the system's profitability and sustainability. The power manager's potential also depends on the way in which an energy management system is designed and the way in which the business model is established. Several differences in load demand, solar capacity and the availability of vehicles' battery capacity apply for residential- and commercial building cases. These factors affect the power manager's dispatch strategy to accomplish the most cost- and environmental- optimal situation.

In modeled residential- and commercial building cases without integrated solar panels, annual cost savings of € 34.53 and € 60.46 could be achieved by allowing for price arbitrage, respectively. Biggest percentages of peak demand were shaved during winter months through which less electricity had to be purchases during peak hours. In modeled cases with integrated solar, the renewable energy fraction increased by means of a power manager; from 53.9 to 57.4 in residential buildings and from 68.0 to 70.8 in commercial buildings. In these cases, biggest percentages of peaks were shaved during the summer through which less electricity had to be purchased during peak-hours. Overall, peak shaving turned out to be more cost-optimal in commercial cases since bigger percentages of electricity peaks were shaved in contrary to the residential case. Additionally, the system's use of the vehicles' battery capacity for grid regulating purposes didn't influence the battery's degradation process significantly in residential- and commercial building systems.

A better business case for a power manager could potentially be achieved by allowing a larger number of electric vehicles to be aggregated. In so doing, the intermittent character of the grid could be regulated. Especially, large parking facilities at commercial buildings and exposed vehicles within residential communities are favorable for delivering ancillary services by means of a power manager. One could think of grid balancing services; such as frequency control and delivering backup power. Honda might increase the power manager's economic- and environmental potential by offering these services to utility companies. Financial- and environmental benefits that could potentially be achieved from this scenario, would be added to a system's cost- and electricity savings in a behind-the-meter case. For this, many developments still need to be made in terms of grid infrastructure and governmental regulations.

6.1 Further research

To stress the potential of a Honda power manager even better, it's interesting to include the potential of aggregated vehicles in a 'before-the-meter' operation in a follow up research model, so to account for additional benefits that could be realized when a large battery capacity delivers ancillary services directly to the grid in a V2G operation. For this, it should be clearly defined what party is going to fulfill the aggregating role and how participants will get financially rewarded for exposing their vehicle's battery to the grid. Special attention should be paid to the operation's impact on the batteries' degradation process. This impact is very likely to increase due to frequent battery use.

The power manager's energy management systems can employ several dispatch strategies to optimize- and allocate electricity components within an electrical system. In future research, it's therefore interesting to point out the power manager's financial- and efficiency benefits when the modeled dispatch strategy changes. Additionally, many variables within the system can be changed as well; such as types of additional grid services, number of integrated vehicles and different AC/DC component combinations. By addressing these factors, a better overview can be given of a power manager's potential within a grid-connected system.

It might be interesting in future research to allow customers'- electricity behavior and preferences to become an input for the energy management system. In this way, vehicle availability and preferred battery SoC can be used as an input by means of a computer- or smartphone application. Moreover, people can synchronize their daily schedule with the EMS. Also, artificial intelligence methods can be used to recognize customers' electricity behaviour. Forecasting consumers' behavior can contribute to the system's efficiency, by optimally meeting energy- demand and supply. In addition, this can provide the utility company with valuable information regarding the availability of storage capacity and electricity needs. This can later be communicated by means of a power manager. It should be investigated how this can be introduced on the market and how vehicle owners can be rewarded accordingly for their cooperation.

Power managers might become more favorable when battery degradation costs decrease, and system efficiencies increase. The influence of additional subsidies and investments; issued by the government, should be investigated in follow-up research. The grid's technical capabilities for these future operations should also be stressed. For this, further research into battery discharging efficiencies is needed to improve the practical aspects and business case for a V2G operation. Battery efficiencies in V2G operations should be improved since the power manager's cost aspect is important for customer adaptation. A power manager's applicability and economic favorability should also be investigated for other countries besides the Netherlands. In so doing, a case-specific consult can be composed for all building systems. Experimental- and modeling research is required for this end.

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Appendix

A. Model input

Load

All input values for the system's load are summarized in Table 3. A distinction is made between the load-demand and pattern in residential- and commercial cases.

		Residential	Commercial
Load (kWh/day)		14.73	30.59
Peak month		January	
Current		Direct current	
Random variability	Day-to-day variability (%)	10	
	Timestep (%)	20	

Table 3: Load input values for residential- and commercial buildings.

Solar

All input values for the system's solar installation are summarized in Table 4. A distinction in solar capacity and costs is made between dispatch strategies in residential- and commercial cases.

		Residential	Commercial
Total installed capacity (Wp)		4,900	12,600
Costs	Capital costs (€)	7,350	18,900
	Replacement costs (€)	7,350	18,900
	O&M costs (€)	60	60
Specifications	Derating factor (%)	80	
	Solar output	DC	
Advanced input	Ground reflectance (%)	20	
	Tilt (°)	21	32
	Azimuth (°)	22	22

Temperature	Temperature effect	-0.390
	Nominal operating cell temperature (℃)	45
	Efficiency STC (%)	17.11

Table 4: Solar panel input values for residential- and commercial buildings.

Battery

All input values for the system's battery are summarized in Table 5. A distinction is made between the number of batteries in residential- and commercial cases

		Residential	Commercial
Number of batteries		1	3
Technical specifications	Battery type	Li-ion NMC	
	Nominal voltage (V)	360	
	Nominal capacity (kWh):	30	
	Nominal capacity (Ah)	83.33	
	Roundtrip efficiency (%)	95	
	Maximum charge Current (A)	32	
	Maximum discharge Current (A)	32	
Lifetime	Electricity throughput (kWh)	67,500	
	Float life (years)	10	
Costs	Capital cost (€)	4,527	
	Replacement costs (€)	4,527	
Site specific input	SoC range (%)	20 -100	
	Initial SoC (%)	100	
	Min SoC (%)	20	

Table 5: Battery input values for residential- and commercial buildings.

Power manager

Converter

All input values for the system's converter are summarized in Table 6. A distinction is made between the number of converters in residential- and commercial cases.

		Residential		Commercial	
		Cases a	Cases b	Cases a	Cases b
Number of converters		1		3	
Specifications converter	Type	Standard system converter	Honda power manager	Standard system converter	Honda power manager
	Capacity (kW)	5.5			
Costs per power manager	Capital costs (€)	1,500			
	Replacement costs (€)	150			
	O&M costs (€/year)	0			
Inverter	Lifetime (years)	15			
	Efficiency (%)	95			
Rectifier	Relative capacity (%)	100			
	Efficiency (%)	90			

Table 6: Converter input values for residential- and commercial buildings.

Energy management system

All input values for the system's energy management system are summarized in Table 7, Table 8 and Table 9. A distinction is made between cases with- and without a power manager in residential- and commercial cases.

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="2">Residential</th><th colspan="2">Commercial</th></tr>
<tr><th>Cases a</th><th>Cases b</th><th>Cases a</th><th>Cases b</th></tr>
<tr><td rowspan="3">Grid prices</td><td rowspan="2">Grid power price (€/kWh)</td><td>Peak hours</td><td rowspan="2">0.20</td><td>0.20</td><td rowspan="2">0.20</td><td>0.20</td></tr>
<tr><td>Off-peak hours</td><td>0.18</td><td>0.18</td></tr>
<tr><td>Grid sellback Price (€/kWh)</td><td></td><td colspan="4">0.14</td></tr>
<tr><td rowspan="2">Price arbitrage</td><td rowspan="2"></td><td>Peak hours</td><td rowspan="2">/</td><td>Battery can't be charged by grid</td><td rowspan="2">/</td><td>Battery can't be charged by grid</td></tr>
<tr><td>Off-peak hours</td><td>Battery can't sell electricity to grid</td><td>Battery can't sell electricity to grid</td></tr>
<tr><td rowspan="2">Peak shaving</td><td rowspan="2">Demand rates</td><td>Without solar</td><td rowspan="2">/</td><td>0.87 kW annual grid purchase capacity</td><td rowspan="2">/</td><td>2.14 kW annual grid purchase capacity</td></tr>
<tr><td>With solar</td><td>2.48 kW annual grid purchase capacity</td><td>4.45 kW annual grid purchase capacity</td></tr>
</table>

Table 7: Grid input values for residential- and commercial buildings.

		Residential		Commercial	
		Case 1	Case 2	Case 3	Case 4
Dispatch strategy	Set-point of charge (%)	100	/	100	/
Costs	Capital costs (€)	0			
	Replacement costs (€)	0			
	O&M costs (€/year)	0			
Lifetime (years)		25			

Table 8: Controller input values for residential- and commercial buildings.

		Residential	Commercial
Economics	Nominal discount rate (%)	4.00	
	The expected rate of inflation (%)	1.70	
	Lifetime of the entire system (years)	25	
	Real interest rate (%)	2.26	
Optimization	Total time steps per year	8,760	
	Minutes per time step	60	
	Maximum simulations per optimization	10,000	

Table 9: Optimization variable input values for residential- and commercial buildings.

B. Optimizing design DC office solar installation

HelioScope **Annual Production Report** [redacted]

Design 1 The green village, mekelweg delft

Report	
Project Name	The green village
Project Address	mekelweg delft
Prepared By	[redacted]

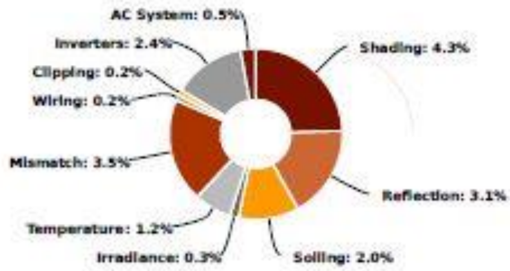
Universiteit Utrecht

System Metrics	
Design	Design 1
Module DC Nameplate	12.6 kW
Inverter AC Nameplate	10.00 kW Load Ratio: 1.26
Annual Production	12.86 MWh
Performance Ratio	83.6%
kWh/kWp	1,020.5
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	668a2f96b2-4d02f9e315-cd9f690cdf-46185030e3

Project Location

Monthly Production

Sources of System Loss



Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,040.8	
	POA Irradiance	1,221.1	17.3%
	Shaded Irradiance	1,168.3	-4.3%
	Irradiance after Reflection	1,131.9	-3.1%
	Irradiance after Soiling	1,109.3	-2.0%
	Total Collector Irradiance	**1,109.3**	**0.0%**
Energy (kWh)	Nameplate	13,984.3	
	Output at Irradiance Levels	13,945.0	-0.3%
	Output at Cell Temperature Derate	13,772.2	-1.2%
	Output After Mismatch	13,291.6	-3.5%
	Optimal DC Output	13,267.7	-0.2%
	Constrained DC Output	13,241.3	-0.2%
	Inverter Output	12,922.9	-2.4%
	Energy to Grid	**12,858.3**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		13.0 °C
	Avg. Operating Cell Temp		19.1 °C
Simulation Metrics			
		Operating Hours	4594
		Solved Hours	4594

Condition Set

Description	Condition Set 1											
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)											
Solar Angle Location	Meteo Lat/Lng											
Transposition Model	Perez Model											
Temperature Model	Sandia Model											
Temperature Model Parameters	Rack Type	a	b	Temperature Delta								
	Fixed Tilt	-3.56	-0.075	3°C								
	Flush Mount	-2.81	-0.0455	0°C								
Soiling (%)	J	F	M	A	M	J	J	A	S	O	N	D
	2	2	2	2	2	2	2	2	2	2	2	2
Irradiation Variance	5%											
Cell Temperature Spread	4° C											
Module Binning Range	-2.5% to 2.5%											
AC System Derate	0.50%											
Module Characterizations	Module	Characterization										
	JKM 280M-60-PR-2016 (Jinkosolar)	Jinko_JKM 280M-PR-2016.PAN, PAN										
Component Characterizations	Device	Characterization										
	Sunny Tripower 10000TL (SMA)	Spec Sheet										

Components

Component	Name	Count
Inverters	Sunny Tripower 10000TL (SMA)	1 (10.00 kW)
Strings	10 AWG (Copper)	3 (31.2 m)
Module	Jinkosolar, JKM 280M-60-PR-2016 (280W)	45 (12.6 kW)

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	13-15	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Landscape (Horizontal)	32°	159.6°	1.3 m	1x1	45	45	12.6 kW

Detailed Layout