DIPLOMARBEIT

Electric vehicle charging coordinated by electricity suppliers – An economic impact analysis

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To my family and friends

Dedicated to my deceased grandma

Abstract

Nowadays the energy demand in the transport sector is increasing steadily. This results in rising green house gas emissions which causes environmental problems. Additionally, the price of kerosene is highly volatile and unpredictable leading to challenges for transport systems which are mainly relying on fossil fuels.

The introduction of more electric (EV) and hybrid vehicles is one out of many approaches towards finding alternatives for the common transport sector. Therefore, this thesis identifies economic benefits and the influence of controlled charging in collaboration with the grid operator/utility compared to charging the EV fleet without specific concepts.

To do this, a model with MATLAB is developed, which examines the influences and differences of various scenarios and case study areas addressing different electric vehicle penetrations. For easy altering of the input parameters, which define the areas of interest a Graphical User Interface (GUI) has been implemented. The GUI enables the possibility to easily differ the various input parameters like the generation and demand mix based on standardized profiles, the market penetration rates of the EV fleet and the size of the areas. The main assumption in the thesis is a distinction between two main areas, a rural and an urban one.

Based on the results from the MATLAB model of the urban and the rural area, results are derived addressing the economics. Because the research mainly is done from point of view of the electricity supplier different aspects have to be taken into account. On the one hand buying and purchasing electricity on the market at peak and off peak times and on the other hand an analysis of the resulting grid load due to the different starting times of charging have to be considered.

Firstly the economic analysis from the electricity supplier's point of view is done. The revenues related to household level due to controlled charging are for a 10% EV market penetration ~€ 320, for a 30% market penetration 390€ and € 460 for a 50% case respectively. These revenues are increasing linearly until revenues of € 640 at 100% market penetration rate are reached for the analyzed case studies and made assumptions. On the opposite in the urban area per household, for a market penetration rate of 10% revenues of € 35 are gained, for 30% market penetration revenues of €105 and €176 for 50% market penetration can be reached. Due to a linear approximation, maximum revenues of € 353 in the 100% market penetration rate are derived correspondingly.

So the results show that in the rural area due to the controlled charging strategy, e.g. specific interfaces such as home terminals (excluding internet connection) can already be financed at an EV market penetration rate of 25%. On the contrary, home terminals which include internet connections cannot be purchased until 95% market penetration of the EV fleet. Following case study related results in the urban area it is not possible for the electricity supplier to pay off the needed infrastructure for the controlled charging strategy with the yield revenues in the area. Not even at 100% market penetration rate of the EV fleet. This is due to the low generation caused by the PV cells. So the electricity supplier has to purchase more energy at the market than in the rural area, and therefore the revenues are getting smaller.

By analyzing the grid, no significant economic gains have been found regarding the controlled charging strategy in the rural area. Since the maximum grid load is only affected from the generation, which is mainly influenced by the wind power plant in the case study, the same maximum grid load for all market penetration rates occur.

On the opposite, in the urban area a different situation becomes evident. In this area, the maximum grid load is caused by the demand including the demand of the EVs. Thus, different maximum grid load values occur for the various market penetration rates and controlled charging leads could lead

to a smaller grid load than individual charging if implemented correctly. But the differences are too small to draw high economic benefits from them, at the assumptions of the before defined case study regions. Therefore, each case study region has to be tested in advance (especially by detailed load flow analysis) on detailed level, in order to evaluate overall benefits of Grid to Vehicle strategies compared to overall costs.

Kurzfassung

Der heutzutage stetig steigende Energieverbrauch im Transportsektor stellt ein großes Problem dar. Einerseits führt dies zu dramatisch steigenden Treibhausgasemissionen, welche in Umweltproblemen resultieren, auf der anderen Seite ist der Preis für das benötigte Erdöl im höchsten Maß volatil und nicht vorhersagbar, wodurch die Problematik für den Transportsektor vertieft wird.

Eine Möglichkeit diese Probleme zu lösen besteht durch den vermehrten Einsatz von Elektroautos und Hybridautos. Deshalb beschäftigt sich diese Arbeit mit dem Ermitteln von wirtschaftlichen Vorteilen die durch kontrolliertes Laden der Elektroautoflotte, koordiniert durch den Elektrizitätsversorger, im Gegensatz zu individuellem Laden entstehen.

Um dies zu bewerkstelligen wurde ein MATLAB Model entwickelt, welches die Einflüsse und Unterschiede verschiedener Szenarien und Annahmen betreffend unterschiedlicher Marktdurchdringungsraten beleuchtet. Um die Eingabe Parameter einfach verändern zu können wurde zusätzlich eine grafische Benutzeroberfläche entwickelt um damit diese Parameter unproblematisch betreffend der Erzeugung, des Verbrauchs bzw. der Elektroautoflotte verändern zu können.

Prinzipiell wird in dieser Arbeit zwischen zwei Hauptbereichen unterschieden, einem ländlichen und einem städtischen, die analysiert werden. Da dabei die Untersuchung immer aus der Sicht des Energieversorgungsunternehmens gemacht wird, sind zwei wichtige Aspekte zu berücksichtigen; die wirtschaftliche Analyse und die Netzbelastung. Bei der wirtschaftlichen Bewertung sind zwei verschiedene Strompreise in Erwägung zu ziehen. Auf der einen Seite der Strompreis den die Verbraucher für Elektrizität an das Energieversorgungsunternehmen zahlen müssen und auf der anderen Seite die Spitzenlast – und Normallastpreise an der Strombörse.

Zuerst wird die wirtschaftliche Analyse bewertet. Die Einnahmen des ländlichen Bereichs durch kontrolliertes Laden, aufgeteilt auf alle Haushalte in diesem Bereich ergeben € 320 bei 10% Marktdurchdringungsrate der Elektroautoflotte, € 390 bei 30% und €460 bei 50%. Diese Ergebnisse können linear hochskaliert werden bis zu Einnahmen von € 640 bei 100% Marktdurchdringung.

Im Gegensatz dazu im städtischen Bereich fallen die Einnahmen viel geringer aus. Für 10% Marktdurchdringung der Elektroautoflotte werden € 35 berechnet, für 30% €105 und schlussendlich €176 für 50%. Durch die angenommene lineare Annäherung der Umsätze für weitere Marktdurchdringungsraten wurden €353 bei 100% errechnet.

Somit zeigen diese Ergebnisse, dass in im ländlichen Bereich durch kontrolliertes Laden schon bei einer Marktdurchdringungsrate von 25% ausreichend Einnahmen entstehen um die benötigte Infrastruktur für jeden Haushalt anzuschaffen. Muss für diese Infrastruktur jedoch auch die Internetverbindung vom Energieversorgungsunternehmen bereitgestellt werden, sind die Einnahmen erst bei 96% Marktdurchdringung erreicht. Im städtischen Bereich wird auch bei 100% Marktdurchdringung kein ausreicher Umsatz akquiriert um in die Infrastruktur zu investieren.

Bei der Analyse der Netzbelastung konnten im ländlichen Bereich keine Vorteile durch das kontrollierte Laden gefunden werden, da die maximale Netzbelastung in jedem Fall durch die Erzeugungseinheiten entsteht und diese natürlich für kontrolliertes und individuelles Laden die Selben sind.

Im städtischen Bereich zeigt sich ein anderes Bild. Hier werden die maximalen Netzbelastungswerte durch den Verbrauch, inklusive dem Verbrauch der Elektroautos verursacht. Dabei entstehen zwar geringere Netzbelastungen durch kontrolliertes Laden, diese sind jedoch so niedrig, dass keine wirtschaftlichen Vorteile daraus gezogen werden können.

Table of Content

1. Introduction

Ever since the development of conventional vehicles, the provision of necessary fuel for them - either because of difficulties with exploring, harvesting or distributing kerosene or because of political circumstances - has been a vital issue. Moreover, the price of kerosene is highly volatile and unpredictable and due to above mentioned reasons as well as the goal for reducing greenhouse gases like CO_2, NO_x and $SO_{X,}$ researchers have been looking for a solution to replace combustion engines by several alternatives. Among other possibilities, they identified major alternatives in electric vehicles (EV), hybrid electric vehicles (HEV) and in plug-in hybrid electric vehicles (PHEV). Furthermore, the application of Vehicle to Grid (V2G) and Grid to Vehicle (G2V) concepts is of major interest regarding future e-mobility developments. In detail, EVs, HEVs and PHEVs are vehicles with an electric-drive motor powered by batteries, a fuel cell, or a hybrid drive train and are summed up in literature as Electric Driven Vehicles or Electric Vehicles (EV). [1]

The advantages occurring due to a high market penetration rate of these EVs are versatile. System benefits occur because the electric drive motor is more efficient than a conventional motor powered by gasoline. Modern direct injection diesel engines have a maximum efficiency of about 45%, whereas an electrical drive has an efficiency of up to 80%.(see e.g. [37],[3]) Nowadays an additional gain, especially in urban areas, is that due to the electric engines less to almost no noise exposure can be achieved. Furthermore the following issues of EVs can be summarized:

- EVs can be used as a backup power for homes and schools as they can provide AC power when needed even if a major electricity supply system failure occurs.
- Another major benefit caused by EVs might appear for the electricity suppliers and utilities. If economical, they could use addressable battery capacities to maintain the grid, e.g. for local voltage stabilization, power generation during peak demand periods or for ancillary grid services such as spinning reserves, regulation and transmission stabilization (see e.g. [9]).
- On the other hand the EV fleet has to be charged over the grid with current generation mix, which is common in Europe. This generation mix is mostly based on fossil energies, so a high rate of greenhouse gas emissions occur and the EVs are not more ecological than conventional cars. Therefore it just makes sense to charge the EV fleet via renewable energy sources to lower the greenhouse gas emission output.

In general, the possibilities to use an EV fleet for grid management issues are currently discussed regarding two different concepts. On the one hand the Grid to Vehicle (G2V) concept where the battery of the EVs are charged in certain time periods. And on the other hand a Vehicle to Grid (V2G) concept where additional to specified charging times, the energy of the batteries could be fed back to the grid as grid related system services. In the following chapters, these two concepts will be described in more detail.

1.1. Some important definitions

1.1.1. Grid to Vehicle

The most common and already practiced way to charge the EV fleet is to utilize the existing grid infrastructure. For this, G2V concept customers just need a conventional power socket to charge their vehicles - which commonly lasts a couple of hours with the current battery technology. For example, it takes eight hours to fully charge a Li Ion battery using a common power socket.

Figure 1 shows the functionality of the G2V concept. A unidirectional communication line is needed for this, so the utility can communicate with the EVs.

Thus, for these before mentioned charging times the EVs are additional loads for the grid. And it gets even worse if the owner of the EVs charge their cars in peak demand times like at midday or in the afternoon.

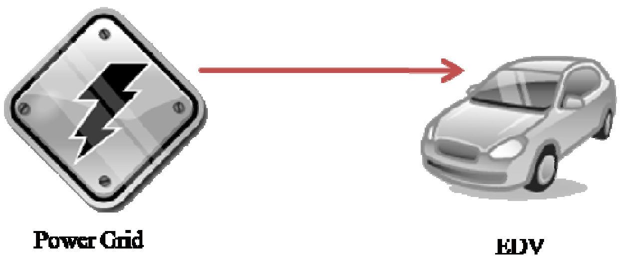

Figure 1 Functionality of Grid to Vehicle

But in return, the general expectation is if no G2V is used, that due to a low market penetration and a slowly increasing growth, capacity planning will have to respond adequately to cope with the additional EV load. But anyhow, it is important to keep in mind that costumers won't charge their EVs when it's best for utilities or the grid, if there isn't any incentive to do that. Otherwise they would charge EVs when it seems convenient for them. [10]

1.1.2. Vehicle to Grid

The second possibility is the Vehicle to Grid (V2G) concept. With this concept it is possible that EVs can feed back electricity to the grid if it is required. Of course again, time specific loading profiles can then be applied. To maintain this function in this concept a bidirectional communication is necessary, as shown in Figure 2. Thus, communication and energy transfer is now possible in both directions.

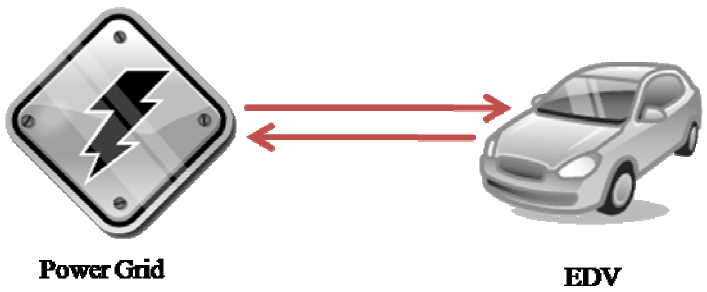

Figure 2 Functionality of Vehicle to Grid

In general, electricity grids and electricity supply systems have very limited storage capabilities. Therefore, generation and demand must be balanced continuously. This is done by scheduling large generators accordingly which leads to the necessity of backup generation capacities within the electricity supply system.

To provide alternatives for this approach it is proposed to also utilized EVs storage and generation[1] capacities. In this case, EVs must have enough storage for driving various distances, depending on the used battery type and the size of battery capacity, as well as to provide battery capacities to the grid.

So with the aid of the EV fleet it should be possible to help keep the load continuous. This means on the one hand filling the valleys of demand through charging the EVs and on the other hand flattening the peak demands through feeding back energy to the grid. This can help save costs because of less used peak demand power plants. Moreover, EVs are cheap per installed kW- capacity in comparison with the high capital costs of generators and the EVs are parked (idle) most of the time, for the utilities to use [1]. According to [29], 82% of the battery capacity per day is not used from car owners in the case of Austria. This potential would be available for the utilities to use evenly across the day.

[1] The accumulated charged battery capacities of the EV fleet can feed back electricity to the grid when needed in peak demand times.

1.2. Goal and outline of this thesis

The core objective of this thesis is to identify economic benefits of controlled charging in comparison to individual charging of EVs from the suppliers' point of view.

The method of the approach is as follows:

To get a broad overview, various scenarios regarding different market penetration rates of the EV fleet in the rural and urban area are analyzed. The findings are in reference of assumed generation and demand mixes in different case study areas which are based on demand values for every quarter of an hour. The model is implemented using MATLAB and for easy altering of the input parameters, which define the areas, a Graphical User Interface (GUI) is used. Based on the results of the MATLAB model conclusions are drawn concerning the economics of the areas. In this thesis, the economics are evaluated from the view of the electricity supplier. It includes on the one hand buying and purchasing energy on the market at peak and off peak times and on the other hand an analysis of the resulting grid load due to the different starting times for charging. How the buildup of the thesis is done exactly, shows the following description:

This thesis is organized as follows:

After an introduction in Chapter 1, ***Chapter 2*** provides an overview of the most important published papers on electric mobility. Out of this paper overview the most important parameters are filtered and afterwards used to build up a bottom up model of e-mobility case studies.

Chapter 3 is dealing with necessary data for different case study analysis. It describes how an EV fleet could be created in urban and rural regions. The annual generation and demand profiles are shown and the development of these profiles is described.

The focus of ***Chapter 4*** lies on of the methodological approach to build up a rural and an urban model area. Therefore the size of the area and the inhabitants living there are constituted. Also, the generation and demand mix used in the area are fixed and the annual characteristics of them are shown. Moreover, the technical modeling of the battery is explained and different scenarios are defined. The scenarios are distinct due to different starting time allocations for charging the EV fleet. One scenario is in cooperation with the utility (controlled charging) and there is also one individual charging scenario. Furthermore, an additional differentiation is made because of various market penetration rates.

In ***Chapter 5*** the methodology to create a specific MATLAB Model is described. It is shown how it is build up and the different implemented functions are specified. First, the buildup of the battery is described and then the charging of a battery over time is illustrated in detail. With these findings a flowchart shows the exact implementation of a whole EV fleet in the MATLAB model. Besides that, a Business as Usual (BAU) and the G2V scenario are explained again by several flowcharts.

In addition, ***Chapter 6*** addresses the economic evaluation. First of all it is described how the different market players in the area work together and where possible revenues could yield. Then, the mathematical methodology for the interaction with the market and the grid evaluation is shown.

Within ***Chapter 7*** the results of the methodology described in Chapter 6 are shown. The findings for the two cases, controlled and individual charging and various market penetration rates, are described for the before defined rural and urban areas. The increased revenues due to a higher demand which is caused by EVs and due to controlled charging are illustrated and it is also shown how the grid load decreases because of the controlled charging strategy.

Finally, in ***Chapter 8*** conclusions are drawn for the before shown cases and scenarios. Moreover, an outlook is given towards future research topics especially regarding V2G concepts.

2. Recent research – A review of critical parameters

This chapter provides an overview of two already published papers in the topic of G2V. For more information it is referred to the appendix addressing further content related papers. To enable a broad overview on relevant parameters all papers are discussed in a similar structure. First the most important parameters, which are used in the mentioned papers are prepared and discussed through an outline chart. Then a summary, which includes the content of the paper and the results, is given. Afterwards the methodologies presented in these papers are shown using a flowchart.

Based on these filtered parameters of papers and the founded methodologies the bottom up model of the thesis is prepared. In addition, the most important parameters of all edited studies are collected in chapter 2.2 and their necessity and usability for the bottom up model is verified.

2.1. Overview of papers

2.1.1. 1 – C. *Guille, G. Gross*: A conceptual framework for the Vehicle –to-Grid (V2G) implementation

Table 1 Paper 1 - A conceptual framework for the Vehicle-to-Grid implementation [21]

Used Parameter	Parameters for model region	Aim of Study/ Conclusion
• State of charge (S.O.C.) 60% • Difference between regulation up (provision of power) and regulation down services (absorption of power)	***Battery Vehicle (BV[2])***: Range: 32 miles/ 50km Idle Time: 22h ***Battery***: Capacity: 1-60kWh Recharging Time: 5h Life expectancy: 10 yr ***Producer Data***: NEISO (ISO New England) ***Model Framework***: low cost fast response extensive range flexibility high reliability security	***Aim:*** Development of a framework for the implementation of the V2G concept. ***Resume:*** An outline of how to design and structure the control system to enable the required data transfers between Aggregator-BVs and ESPs[3]. How to design an interactive scheme for the aggregator to attract and retain BV customers. ***Future Work:*** Enhance the life expectancy of Batteries. Governments have to promote BVs.

Content:

This paper develops a framework on how to move from a concept of the V2G technology to its real implementation. It is assumed that the BVs act aggregated and that they can be used as a generation source and as a load source when plugged-in if their State of Charge (SOC) is higher than 60%. Because one EV allocates too little capacity, an aggregator is introduced who adds the EVs to a cumulated fleet. The aggregator has the possibility to communicate with the BV owners, the Regional Transmission Organizations (*RTO*)/Independent System Operators (*ISO*) and the Independent Distribution Network Operators (IDSO). Thus advantages occur because the aggregator can make purchases like electricity, batteries or other services and will get better conditions and hence save costs. Figure 3 shows the interaction between the market players and the aggregator.

[2] In this paper a Battery Vehicle is an Electric Vehicle (EV) or a Plug-in Hybrid Electric Vehicle (PHEV)

[3] ESP… Electricity Service Provider

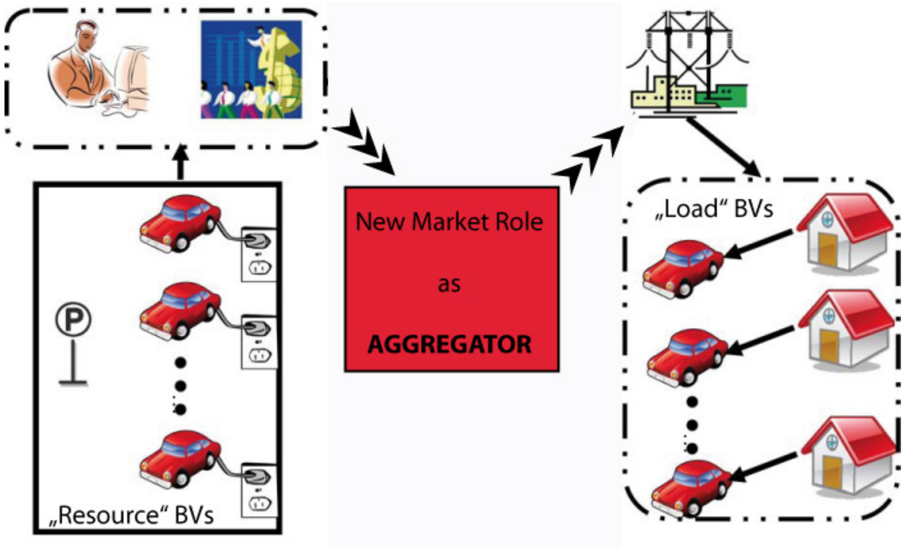

Figure 3 Market role of an aggregator, after [21]

A key assumption of this paper is that the BVs are only used for commuting purposes, so all customers have similar behaviors. Moreover, all SOCs of the batteries are tracked and the EVS are used as a resource and a load.

In a next the step the implementation of the framework is described which includes exact technical data for communication and the key basic requirements like costs of the communication network, the range of the battery, security and so on. Moreover a new business model, the aggregator package deal, is introduced. This package deal includes that the aggregator buys the needed batteries for the vehicles in big amounts and so owns all batteries. But of course the responsibility for the battery guarantees also lies with him. This leads to financial benefits at the preferential rates for operating and maintaining the battery for the EV owner.

2.1.2. 2 – *S.W.HADLEY, A. TSVETKOVA*: Potential impacts of plug-in hybrid electric vehicles on regional power generation

Table 2 Paper 2 - Potential impacts of Plug-In Hybrid Electric Vehicles on regional power generation [25]

Used Parameter	Parameters for model region	Aim of Study/ Conclusion
• ***Model Used***: ORCED[4] (for demand in 2020& 2030)=> output: average and marginal prices air emission generation adequacy • 25% market penetration starting by 2020 • CO_2, NO_x and SO_2 Emissions • S.O.C: 20-100% • Timing of plug-in • Estimation of demand (peak demand) • Estimation of supply (ordered by technology, fuel type and variable costs, outage time) • Electricity Price	***EV***: Range PHEV20 ***Used Data***:13 US regions by NERC[5] ***Battery***: S.O.C: 20-100% -Charging Rates: 120V/15A(1.4kW) 120V/20A(2kW) 220V/30A(6kW) - Lifetime: 10 yr two options: evening charges starts @5pm night charge starts @10pm	***Aim:*** An analysis of the potential impacts of PHEVs on electricity demand, supply, generation structure, prices, and associated emission levels in 2020 and 2030 in 13 American regions. ***Resume:*** The model predicts an increase in demand, generation, electricity prices and emissions from the utilities created by the introduction of PHEVs. Moreover it also suggests that by 2030 almost all regions have to add capacity to provide for charging PHEVs. ***Future Work:*** How to cope with owners who unplug the vehicles for travel before they are fully charged?

Content:

This paper forecasts the impacts of PHEVs on electricity demand, generation structure and emission levels for 2020 and 2030 in 13 US regions. Therefore the Oak Ridge Competitive Dispatch (ORCED) model is used to simulate the electricity demand and supply. Input factors for the model have been the number of vehicles, which were assumed to be 0% in 2010 and grow up to 25% by 2020. Another input value is the charging characteristic for a PHEV20, which has a 20-mile battery range and it is expected that the battery has to be recharged from a S.O.C. of 20% to a S.O.C. of 100%. The third important input factor for the model is the timing of the plug-in. Here, two options were modeled. For the evening charge half of the vehicles were plugged in at 5:00 pm and half at 6:00 pm, for the night charge half were plugged in at 10:00 pm and half at 11:00 pm.

[4] ORCED is the OAK RIDGE COMPETITIVE ELECTRICITY DISPATCH model.

[5] NERC is the shortcut for the *Natural Environment Research Council*

The ORCED model now shows the 13 NERC regions without transmission constraints within each region. To initiate the model each region has to have/needs:

- An Estimation of Demand
  With the hourly demands for every region, the data has to be converted into a load duration curve (LDC) for summer, winter and off-peak seasons. Due to adding PHEVs, the curve will rise. Thus the total energy demand increase from PHEVs is in the range of 1-5% and the peak capacity increase ranges from 0-28%.
- An Estimation of Supply,
  Therefore a list of all plants has to be made and then ordered by technology, fuel type and variable costs.
- A Dispatch Estimation
  The dispatch decisions of each region are based on variable costs (fuel, operations and Green House Gas (GHG) emissions)
-

Results:

For every region results are made with the model and, in general, the model predicts an increase in demand, generation, electricity prices and emissions through the introduction of PHEVs. Moreover the model predicts that generation electricity prices will increase for nearly every region, which is not linked to the used scenarios. Depending on the scenario, prices may increase by 1.2%-2.7% (WECC[6]-RMP[7]/ANM) and for evening recharge with 6kW almost 141% (FRCC[8]), 196% (WECC-CA) and 298% (SERC[9]).

Accessorily, the model predicts an increase in emissions from utilities. Of course this is linked to the generation mix in the different regions and that the evening charging scenario needs more oil based generation. So it is better to use the late night charging scenario, because therefore the use of renewable energies is more likely and this will help to decrease GHG emissions. Besides this, it is also suggested that by 2030, almost all regions have to add capacity to provide the needed demand for charging PHEVs.

In Figure 4 the fundamental methodology of this paper is shown. It includes the input parameters such as the electric generation system, the demand data and boundary conditions.

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[6] WECC is the Western Electricity Coordinating Council in the USA.

[7] RMP

[8] FRCC is the Florida Reliability Coordinating Council.

[9] The SERC Reliability Corporation is a nonprofit corporation.

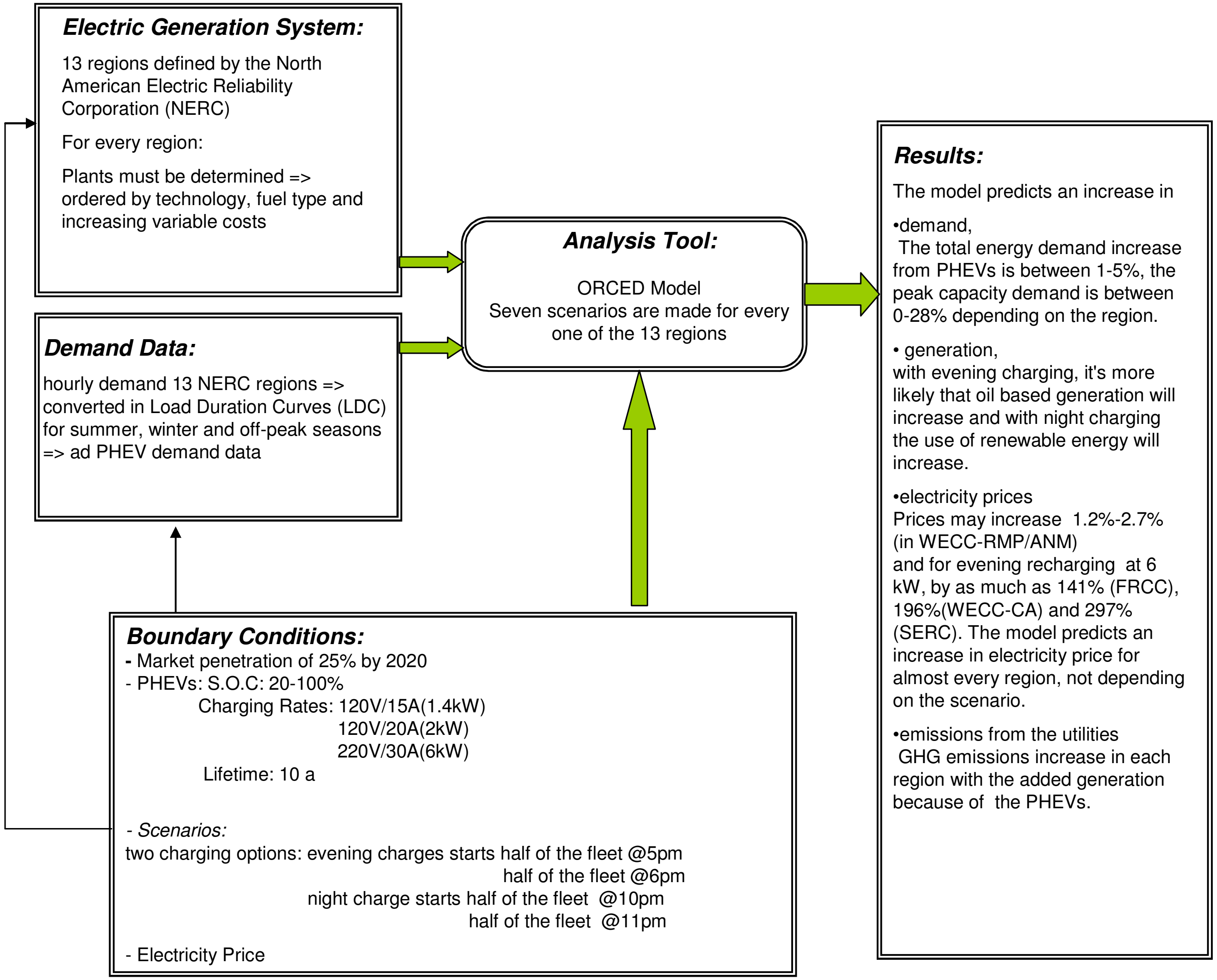

Figure 4 Conceptual function of paper 2

2.2. Parameters used in papers

Form the reviewed studies a couple of important parameters have been found which are necessary to build-up a bottom up e-mobility model. Therefore, a specification of the used parameters will be done and furthermore a discussion which reconsiders whether they are feasible for the expected model, or not.

At first, the parameters concerning the battery are described:

To model the battery, one basic information is the ***capacity of the battery***. In the papers a capacity bandwidth from 10 to 100 kWh is assumed, depending on which type of vehicle is used and which traffic groups are taken into account. A traffic group mainly consisting of commuter would be in the need of a higher battery capacity than a normal vehicle user in the city, because the commuters will have to overcome higher distances per day than the city driver. Even more, the battery capacity also depends on the different types of vehicles because due to various drive types, other battery sizes are needed. For example, a user of a PHEV does not need as big battery as the user of a BV or an EV because if the battery is empty, the PHEV user can switch to the conventional drive. In this thesis there is no determination between BEVS, PHEVS or other technologies. It is assumed that the battery of every electric mobility costumer has a Li-Ion technology at current standard and contains a charging capacity of 20kWh. Moreover the car types are solely electric vehicles (EVs).

Another important system characteristic is the appropriated ***range of the battery*** related to its capacity. It is assumed that the range of the battery is proportionate to its capacity. For example, according to [3] the range of a 20kWh battery as used in the thesis lies at approximately 100km.

A further important parameter of the battery is the **State of Charge** (***SOC)***. It describes the actual state of charge of the battery in %. Usually the actual capacity of the battery is taken into account for calculation, not the nominal capacity. But due to the fact that in this thesis no capacity decrease is considered, the nominal capacity is thus the actual capacity of the battery.

This leads to another fundamental parameter, the ***life expectancy of the battery***. Depending on the disposition of the battery, the life expectance of the battery varies. But in general, a distinction has to be made between the Gregorian dates life times and the circle life times. Thereby the Gregorian dates life times indicate how long the battery could be used for and the circle life how much charging and discharging acts the battery is feasible for, according to [6]. Here both life times are assumed to be long enough to not have to be taken into account for the made investigations.

Another often appearing parameter pertained to the battery is the ***charging time***. The charging time increases with the capacity of the battery. The exact calculation for a 20kWh Li-Ion battery is shown in chapter 4.3. Utilizing these calculations it can be assumed that charging a 20kWh battery from a SOC of 0% to 100%, will last about 8 hours, given that the battery is charged using common Austrian power socket with a connection power of 3,2kW. The ***Charging rates*** are even constrained to the used power sockets and for the amount of current these power sockets are assured (see Chapter 4.3).

In a next step the necessary parameters concerning the model buildup are described:

First of all, the ***number of vehicles*** in the observed area has to be constituted. In the different studies the sizes of the EV fleet ranges from a small amount to a few thousand EVs e.g. in the case of California. In this thesis the number of vehicles is correlated to the size of the area, as described in chapter 0

Furthermore, in the studies the EV fleet exists of different ***driving groups***. In [22] solely commuters are taken into account for modeling the EV fleet. Here, a distinction is made between a business driving group and a private driving group as shown in chapter 5.2.

In addition, an important factor for modeling the EV fleet is the ***timing of plug in***. To be cost efficient and to reduce the grid load at peak times, the main goal is to lower the necessary charging capacities for e-mobility during peak times, via demand ***valley filling***. This method aims at shifting additional energy use from peak times to times of lowest electricity demand. The implementation of this valley filling is shown in chapter 5.1.

Finally, the last parameter concerning the model creation is the market penetration rate of the electric vehicle fleet. A lot of researchers have worked on this topic and tried to predict the upcoming market penetration rates for the future. As there are no guaranteed values, this thesis assumes several market penetration rates to create different scenarios, shown in chapter 4.4.1.

In a last step, a variety of parameters concerning implementation costs have to be taken into account in order to accomplish the economic part of this thesis.

Different types of costs have been taken into account for calculation in the different papers. Capital costs for the EVs, the generation and demand actors. Moreover, maintenance costs for the grid and the communication network (if existing) are considered. Other parts are the costs for electricity purchases from the market and the costs occurring for electricity consumer at household level. These last two costs categories will also be analysed in detail in this thesis, as described in 0.

Figure 5 illustrates the concentrated Parameters needed for the G2V analysis for the bottom up model.

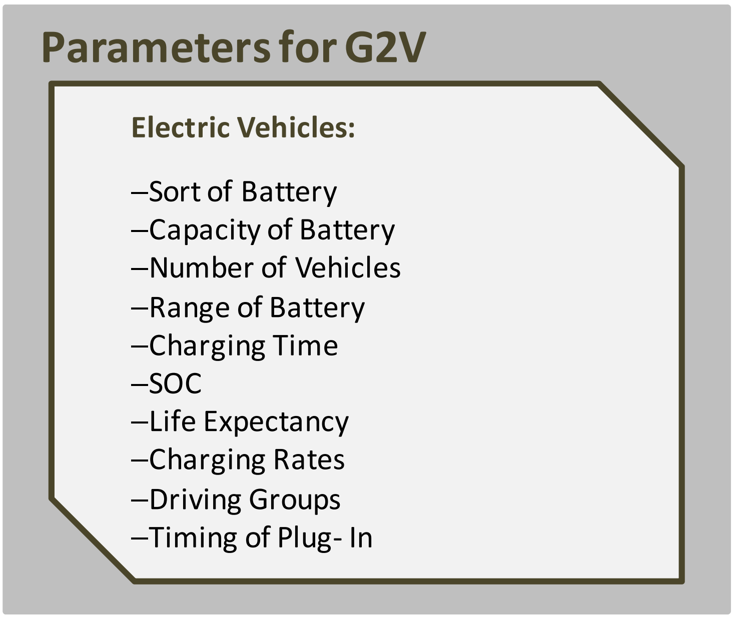

Figure 5 G2V parameters for the bottom up model

3. Data basis for bottom-up modeling of e-mobility case studies

This chapter is concerned with collecting the data basis for the bottom up model introduced in the following chapters of this thesis. Therefore data of several generation units, especially for biogas plants, wind power plants and photovoltaic technologies are described. Moreover, the demand units are delineated with the standard demand profiles, based on data records from [14].

3.1. Electric vehicle fleet and market penetration

In the year 2008, 5.9 million motor vehicles were registered in Austria. From this amount 4.3 million vehicles have been used as passenger cars (see [3]). Hence considering the approximately 8 million inhabitants of Austria, on average 50% of them possesses a passenger car. The same relationship between inhabitants and cars is consulted for this thesis. It is assumed that there is one passenger car per two people both in the urban area and within the rural area. The exact values for the rural and the urban case study are described in more detail in chapter 4.

To model different scenarios, various sizes of electric vehicle fleets, due to varying market penetration rates are introduced. In the modern literature a lot of approaches can be found which describe expected future market penetration rates, depending on political circumstances and the progress of battery technologies. As a consequence, market penetration rates are altering in a broad bandwidth (for an example see [3]). Hence, in this paper the amount of market penetration is freely estimated at four different rates. The first case is assumed with a market penetration rate of 0%. It corresponds to the current situation with evanescent minor to none EVs. It is called the Business as Usual (BAU) scenario. The other three scenarios, with 10, 30 and 50% are introduced as future assumptions.

3.2. Collected generation profiles for case study specific technologies

In this chapter the generation units for the bottom up model are arranged. Only generation units powered by renewable sources are used, on the one hand to decrease GHG emissions and on the other to control whether it is possible to use this generation units for a proper electricity supply.

In addition, it is distinguished for the generation of electricity between generation for base load and volatile production. The base load generation is produced from biogas plants, because these plants are continuously producing energy over the year, with just a few deviations.

For the volatile generation, on the other hand, wind power plants and photovoltaic cells are considered in the model. This kind of generation is highly unpredictable and it is thus difficult to integrate it in the common electric power supply, because minor to none storage capacity for this produced electricity is available in the common grid. But due to the used EVs in this thesis, there is the possibility to store the volatile energy when it is produced.

3.2.1.Biogas

A biogas plant is powered with natural gas, produced by agitation of different substances such as bio-waste, parts of plants and energy crops. In a first step the biogas is produced in special utilities out of the before mentioned substances. This biogas exists of methane, steam and carbon dioxide.

A major advantage of biogas is that it is produced using renewable energy sources and therefore is carbon dioxide neutral. This and the certainty that biogas has a nearly constant production over the year makes it perfect for the use in this thesis.

The development of conventional used biogas plants in Austria (really) started in the year 2002 due to a major demand coming from agricultural businesses to use the energy of biogas in terms of electricity and heat. [38] The historical development of biogas generation plants in Austria can be seen in Figure 6 below.

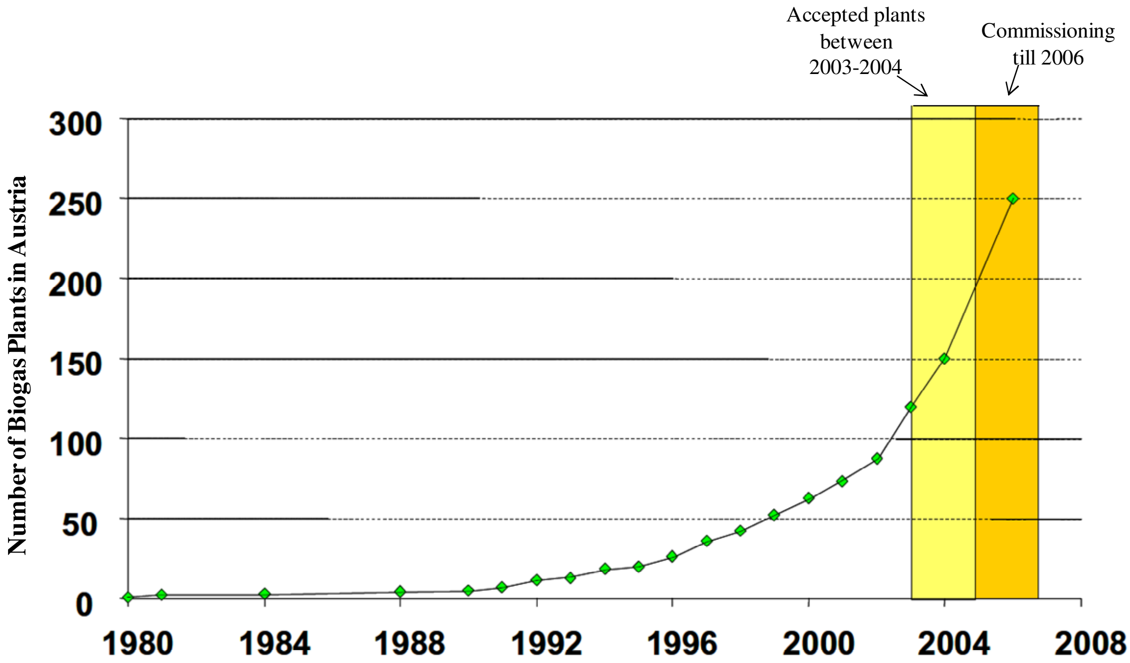

Figure 6 Chronological deployment of biogas plants in Austria, figure related to [38]

In Austria in the year 2002, mostly biogas plants with 80 kW_{el} were installed and the size of the plants grew subsequently. In the year 2004, plants with 180 kW_{el} were installed and plants with 240kW_{el} in 2007. [15] In total, until the end of June 2008 the number of biogas plants in Austria was 342 with a cumulative capacity of about 91,36 MW. [39]. This leads to an averaged plant size of 267 kW_{el} per biogas plant.

So in this assumption profiles of biogas plants with ***250 kW_{el}*** are taken for calculation owing to the averaged plant size in Austria. And due to the fact that the trend in Austria leads to bigger biogas plant sizes, in the thesis also ***500 kW_{el}*** plant and a plant with ***750 kW_{el}*** are taken into account for further calculations as well.

The calculation of the electricity generation of a biogas plant depends on the calorific value of the domestic gas. This calorific value is approached in literature (see e.g. [14]) with 8,1-11,2 kWh/m^3. Referring to [16] a calorific value of domestic gas of 11,11kWh/m^3 is used in this approach.

With this assumption the following calculation can be made to get a usable value.

$$P_{BG} = X * H * \eta \qquad (1)$$

X…Biogas generation (quarter of an hour data)
H… calorific value of domestic gas
η…Efficiency

The values resulting out of equation (1) are averaged over the underlying biogas generation data. This leads to 65 m^3/h for the 250 kW_{el} plant, 120m^3/h for the 500 kW_{el} plant and 195m^3/h for the 750 kW_{el} plant. This annual characteristic is shown for example for the biogas plant with 250 kW_{el} in Figure 7 with a percentage variation of 10%.

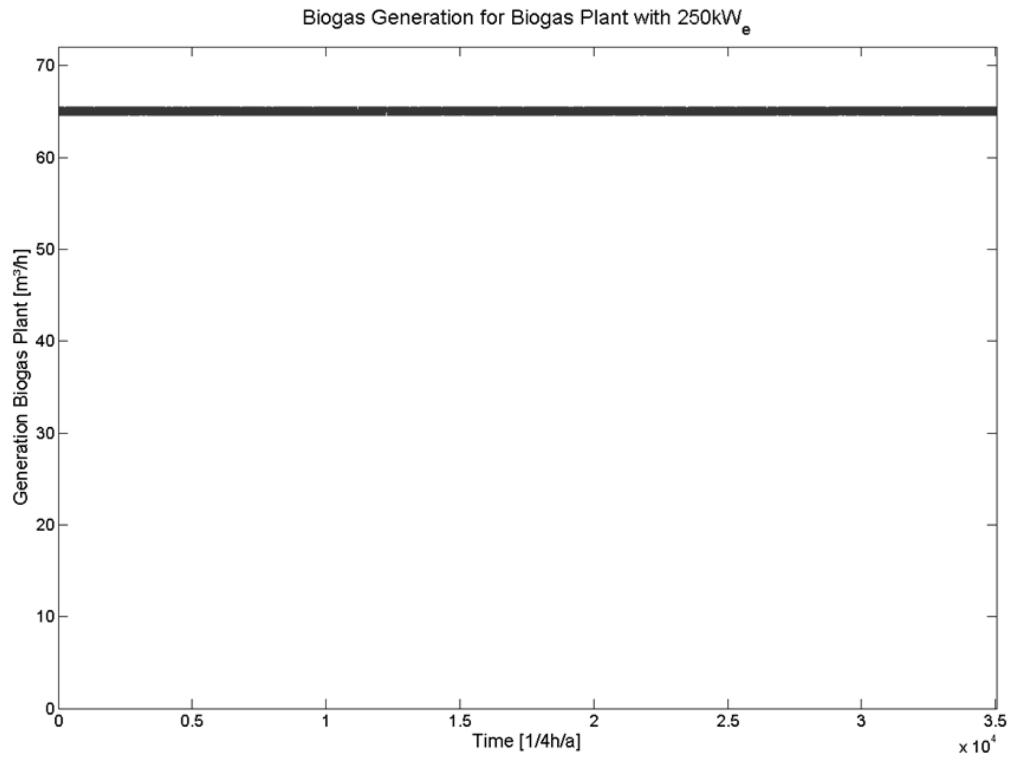

Figure 7 Annual biogas generation for biogas plant with 250kWel

In Figure 8 the electric production of this biogas plant with 250 kW_{el} is shown in representation for all three types of biogas plants.

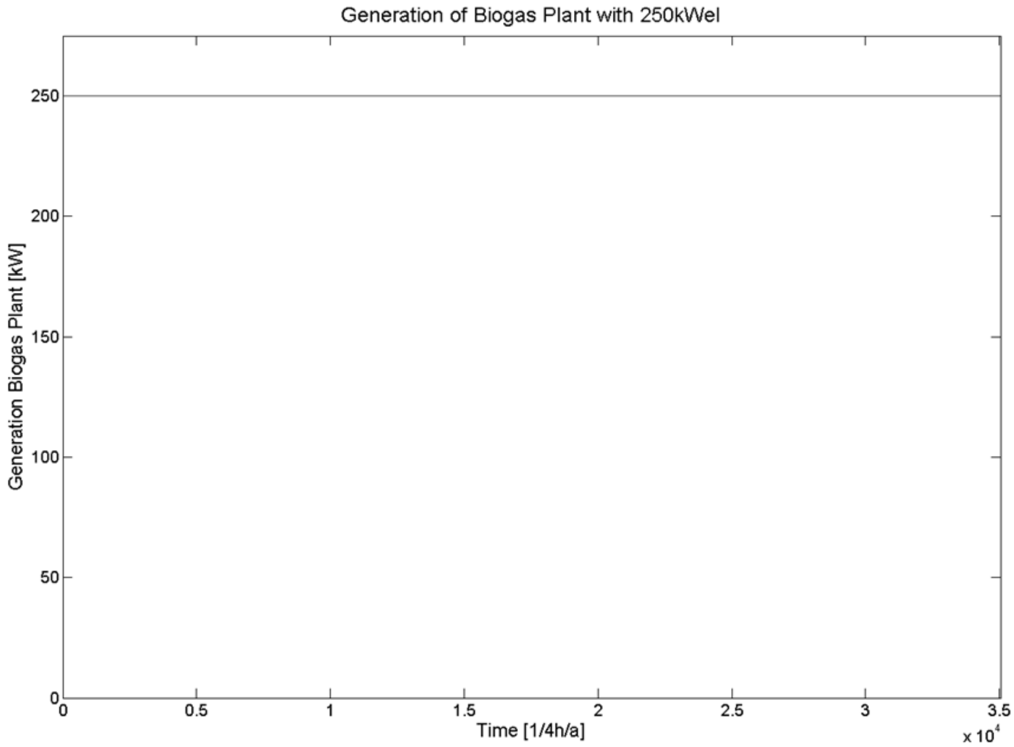

Figure 8 Annual generation profile of a biogas plant with $250kW_{peak}$

3.2.2. Wind power

In principle wind power plants can be installed in all climes, in the sea and on each landscape, provided that there are fitting wind conditions. But due to a volatile wind appearance the produced electricity can only be used if the electricity can be stored or in combination with other energy sources and if the grid capacity is sufficient to distribute the produced electricity.

By the end of 2008, there was a total installed wind capacity in Austria of 995MW, distributed on 607 generation units [40] . This leads to an average value of about 1.6 MW per wind power plant. Thus, in this thesis a 2 MW wind power plant is taken for further calculations.

As done in [14], based on empirical values, a standardized generation profile is made of a wind power plant. Therefore, the real generation values referred to the real values of a wind farm with accumulated generation values of 12MW. Hence the real generation profile is standardized on a profile with an annual generation of 5 GWh/a. This standardized profile is then up scaled on a profile for a 2MW wind power plant as needed for the analysis. Below this annual generation profile is shown in Figure 9.

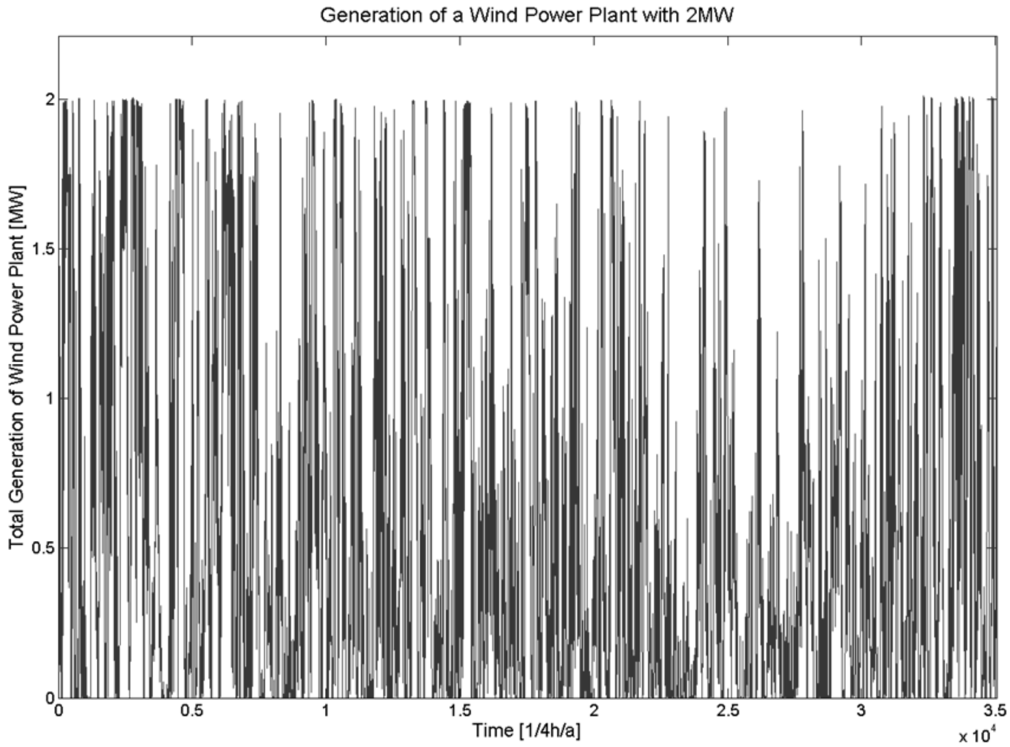

Figure 9 Annual generation of a wind power plant in Austria (standardized to the year 2007)

3.2.3.Photovoltaic

In addition to the used wind power plants for modeling volatile generation, volatile energy out of photovoltaic cells is also assumed in this thesis. Like the electricity from wind power, the photovoltaic technology is renewable and forward looking, because thereby the solar power is altered direct into electricity via the solar cells. A major advantage, especially in urban areas, is that photovoltaic cells are noiseless and do not produce any greenhouse gas emissions when working.

In this thesis, the solar radiation of Austria is taken for calculation. Due to a measured solar radiation in Austria, photovoltaic cells allocate approximately 800kWh generation with a cell size of $10m^2$ in one year. Moreover, a peak generation of 1kWp can be reached [18].

The annual generation of a $10m^2$ cell with a peak production of 1kW is shown in Figure 10.

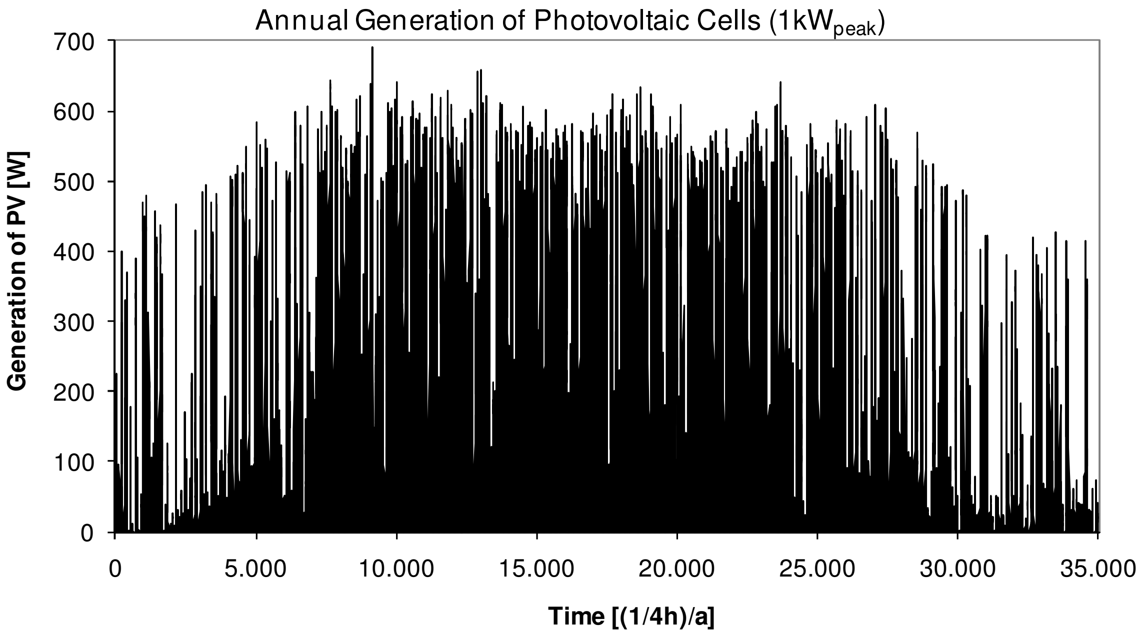

Figure 10 Annual generation of a $10m^2$ photovoltaic cell with 1kW peak production

3.1. Standard demand profiles for different demand groups

In this chapter the different demand profiles are introduced. These profiles can be distinguished into three main groups, households, businesses and farms, whereas the business profiles are separately classified in different profiles. This depends on the various consumption bearings of the business types. Such distinctions are also made for the farming profiles. In Table 3 all of these profiles are described.

Table 3 Standardized business, agricultural and household groups (source [14])

Profile	Description
G0	Business (average of G1-G6)
G1	Business on weekdays from 8 am till 6 pm
G2	Business with major demand in the nights
G3	Business permanent
G4	Shop/Hairdresser
G5	Bakery with bake house
G6	Business just at weekends
L0	Farms
L1	Farm with cattle-breeding
L2	Other farms
H0	Household

In the thesis the business groups G0 and G3, the household profile H0 and the farm profile L0 are used and therefore explained in more detail in the following chapters.

3.1.1.Business profiles

Business Group G0

The customer group G0 is an averaged value of all business groups G1-G6. It is used when a characteristic assignment to the other profiles cannot be found. Figure 11 shows one weekly profile of the base year 2007. The load peaks occur due to different demand behavior on workdays, Saturdays and Sundays. The peak times at workdays are at 09.15 am until 12.15 pm and at 04.00 pm until 06.00 pm. On Saturdays the peak times occur just at one specific time period at 18.00 am until 20.30 pm. Figure 12 shows the annual standardized profile of business group G0. It is illustrated that a slightly different behavior occurs linked to the seasons, because in winter (time) more electricity demand is evident due to heating and increased light necessity.

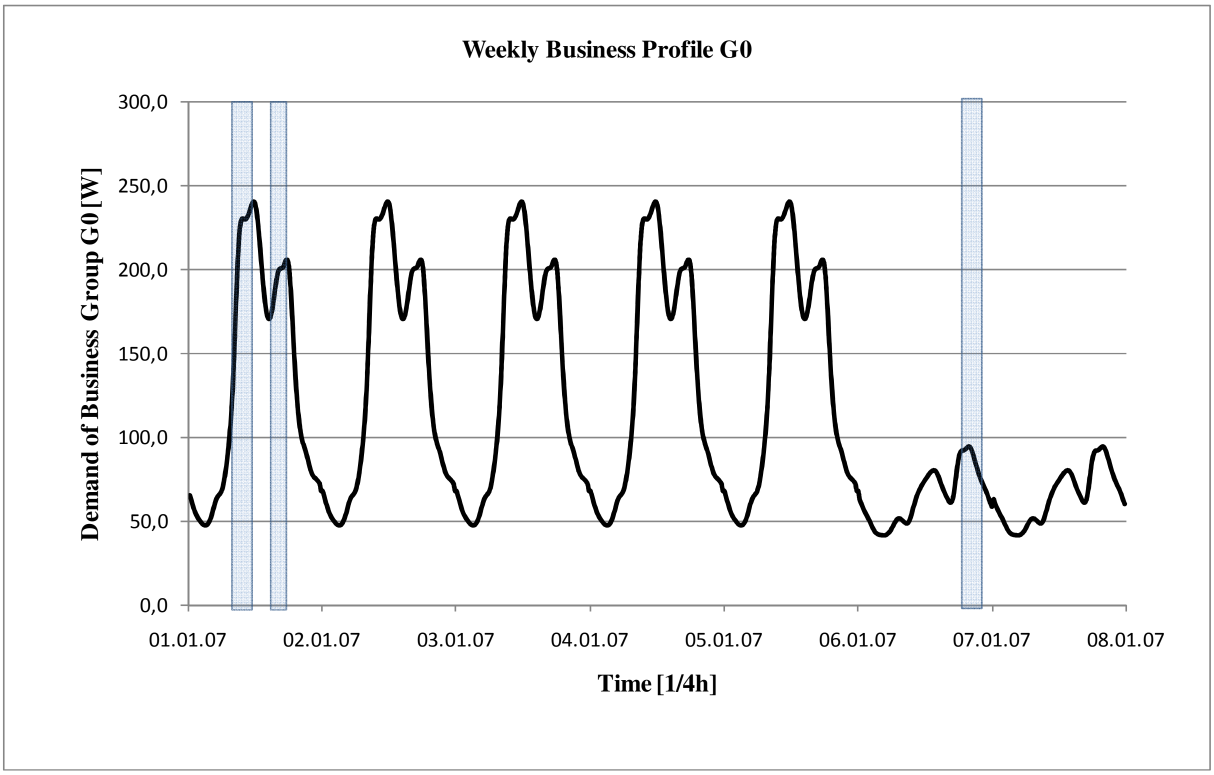

Figure 11 Weekly business profile G0 [14],

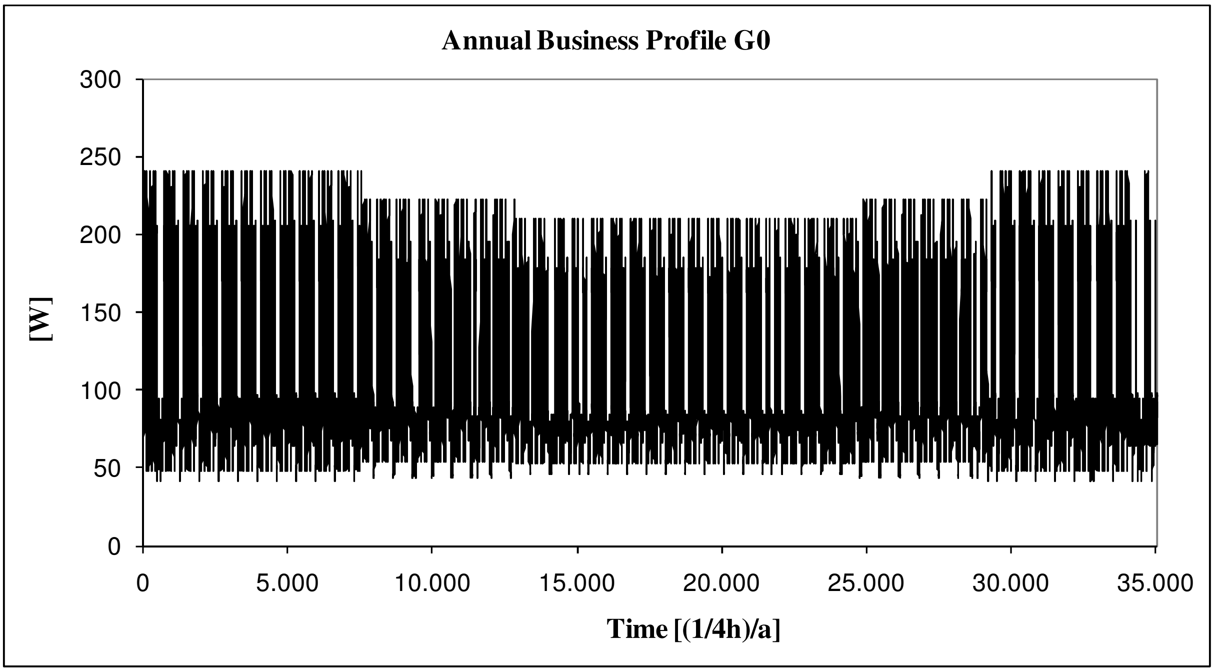

Figure 12 Business profile G0, [14]

Business group G3

The standardized load profile G3 includes business locations, which have a nearly constant electricity demand over time, which is viewable as a demand basement. This basement can be seen in the weekly profile in Figure 13 and is illustrated in the annual profile in Figure 14. Locations which belong to this profile are sewage plants, drinking water pumps, communal facilities in housing areas, car parks and shops with air conditioning.

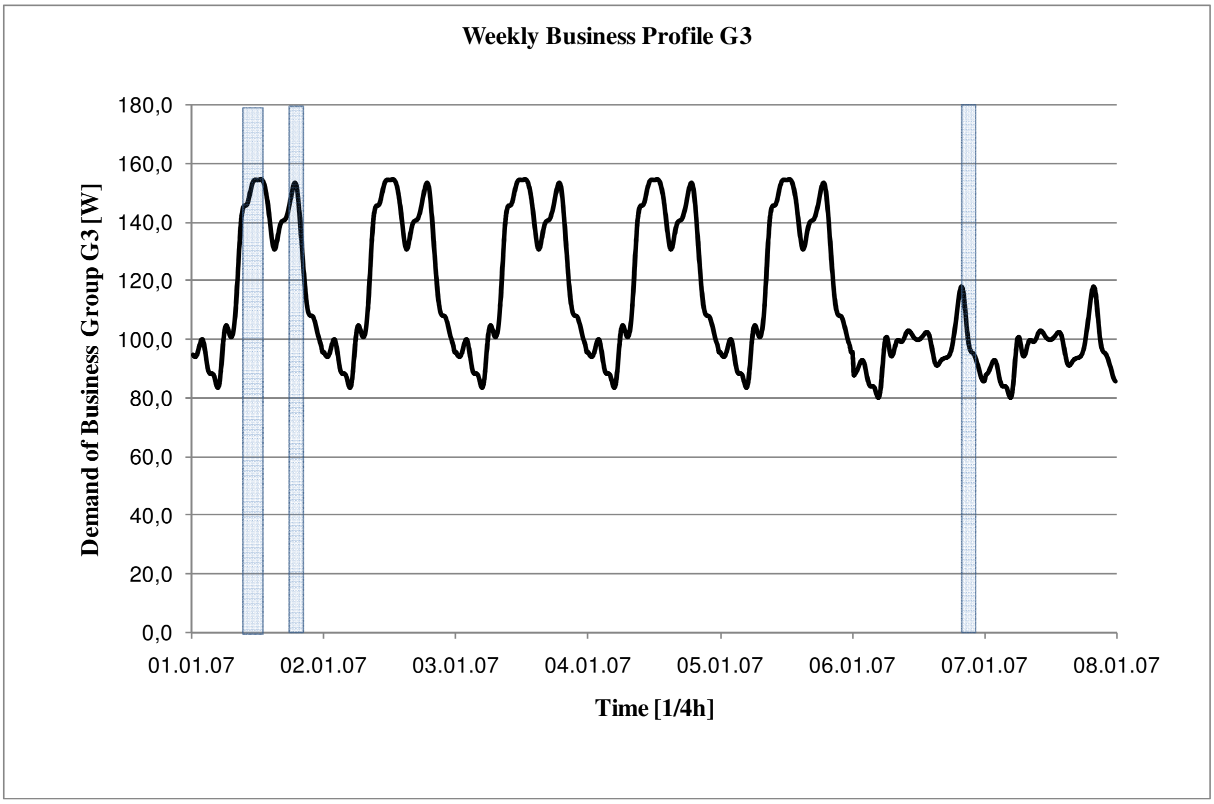

Figure 13 Weekly business profile G3, [14]

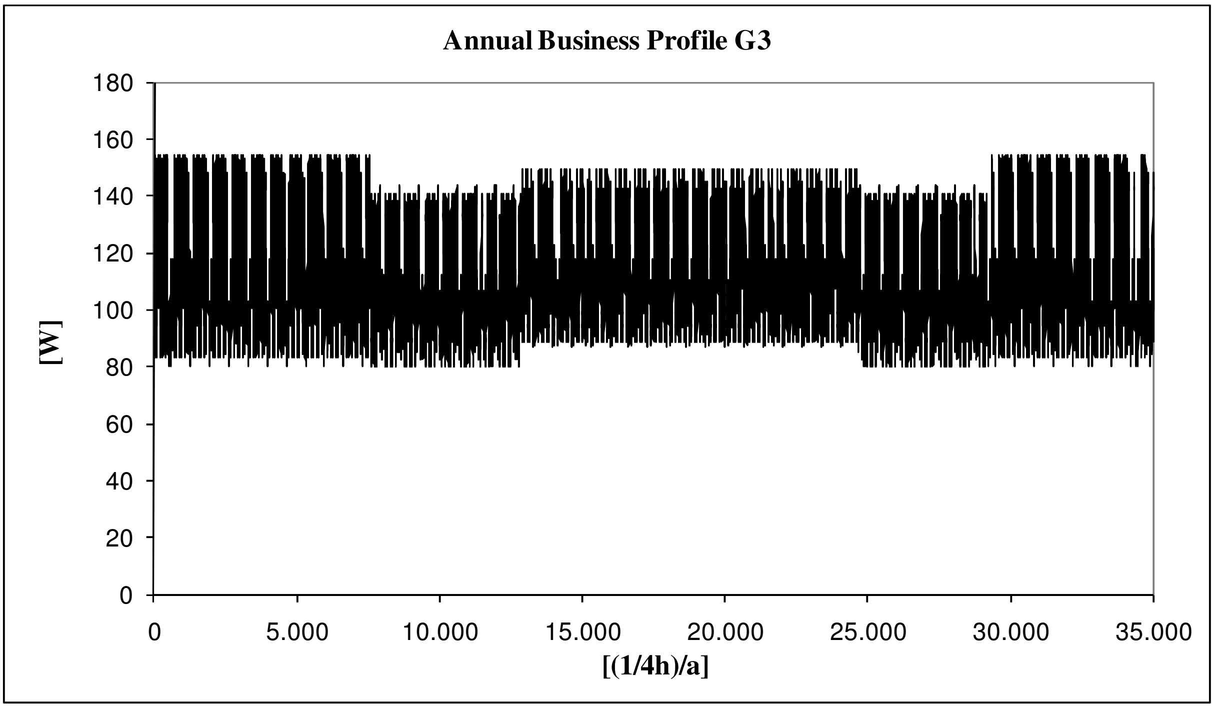

Figure 14 Annual business profile G3, [14]

3.1.2. Household Profiles

The household profile H0 includes households with mainly private demand. If there are special assets such as electric thermal storage based heating technologies or heat pumps, the profile H0 cannot be used anymore.

The weekly profile, shown in Figure 15, illustrates the typical demand of a household. This profile is characterized by smaller peaks of demand in the morning and on midday and the main peak in the evening at about 6 pm. In general, the consumption is higher on weekends because people are at home, which leads to higher electricity consumption in the households.

Examining Figure 16, the annual profile of households, one can see that in general the demand decreases in the summer time. This is caused by less use of illumination and no heating. Nevertheless, the peaks of demand on weekends occur over the whole year.

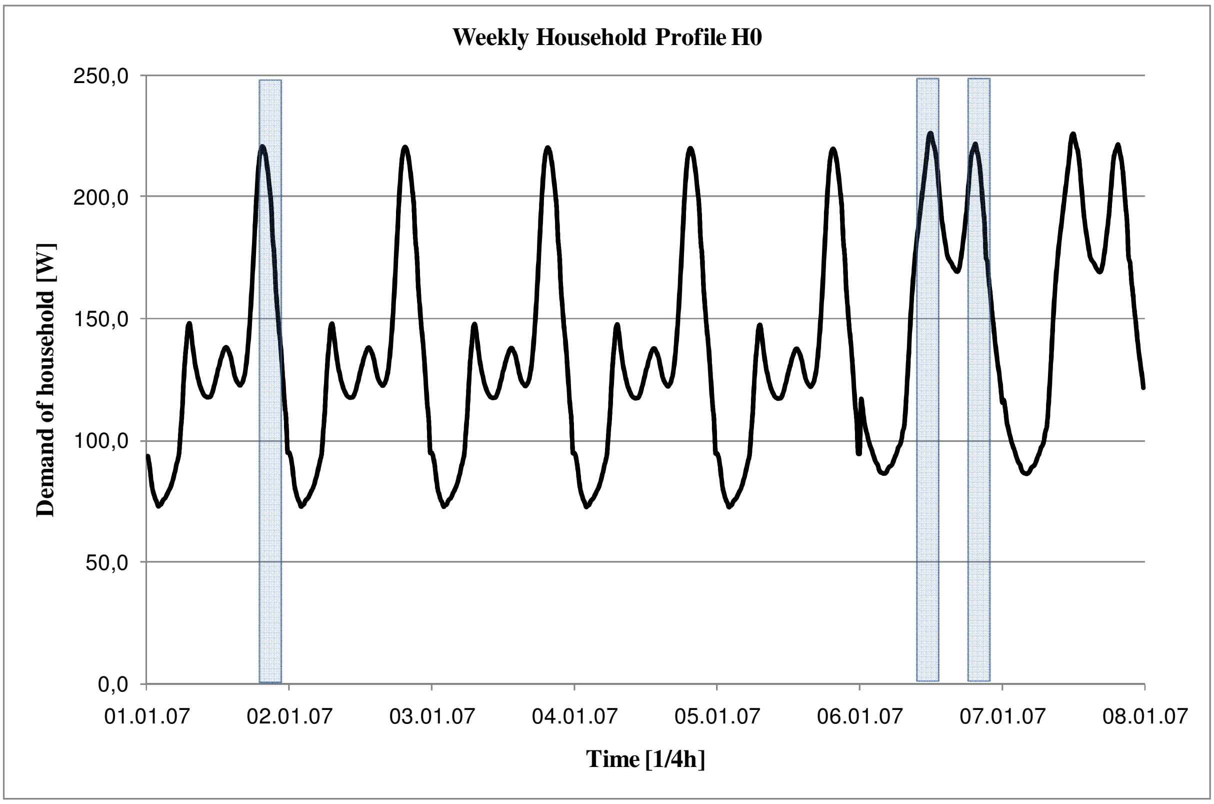

Figure 15 Weekly household profile, [14]

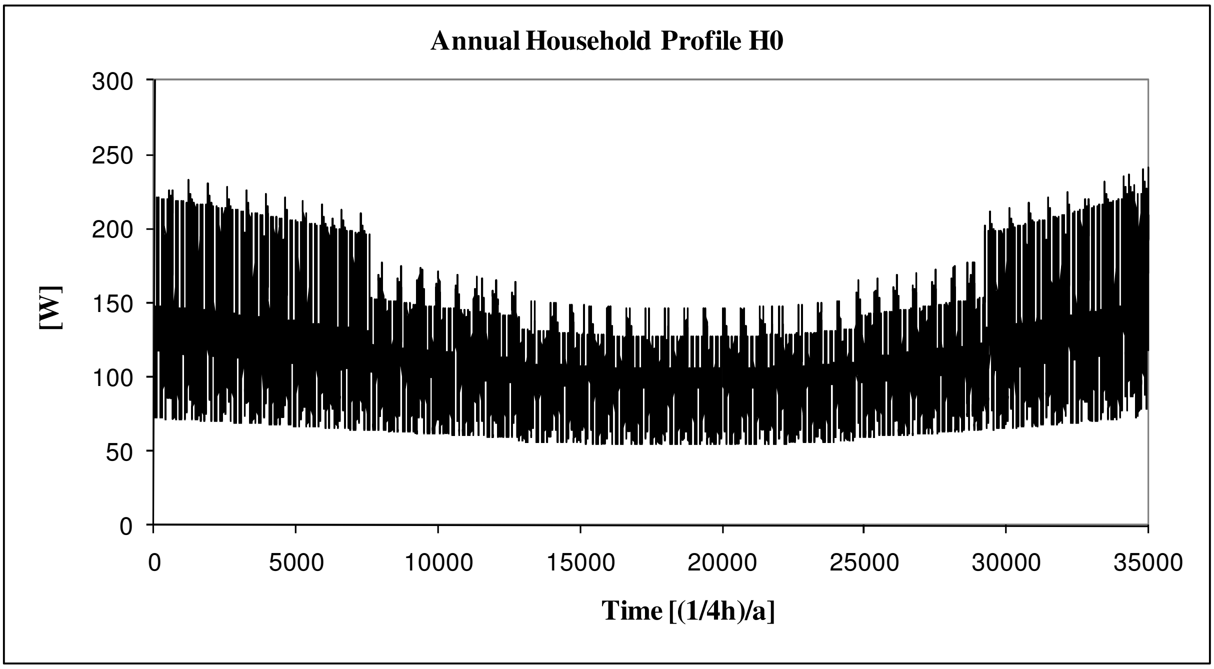

Figure 16 Annual household profile H0, [14]

Farming Profiles

The profile L0 reflects a weighted average of all agricultural profiles (L1 and L2). The load profile L1 consists of farming businesses with cattle breeding and dairy farming and load profile L2 consists of traditional farms.

This profile has demand peaks in the morning at 8 am and then later in the afternoon at 7 pm, caused by the use of milking machines when the cattle is fed. The higher demand peaks on weekends occur because the part time farmers have more time to do farm work. The weekly profile L0, which shows this characteristic, is shown in Figure 17

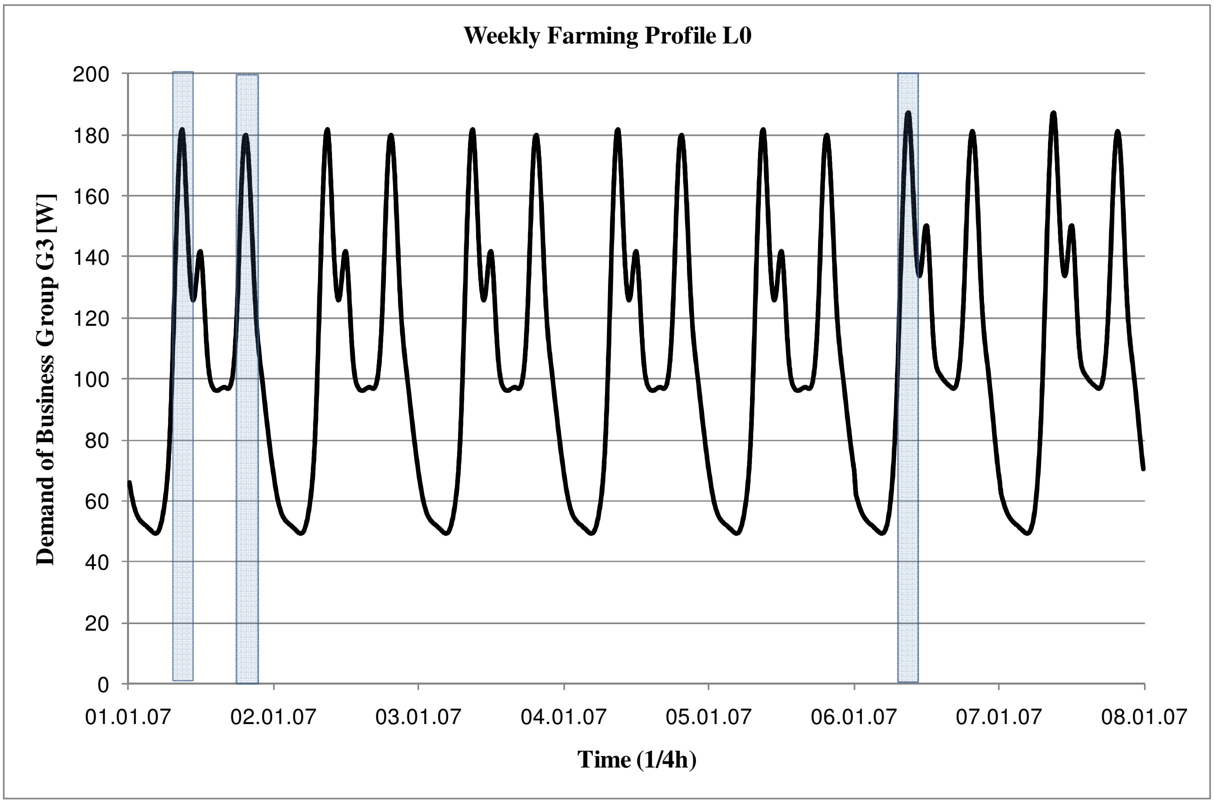

Figure 17 Weekly farming profile L0, [14]

3.2. Compendium of all business as usual parameters

Here with Figure 18 all parameters for the base case scenario are described and a compendium is made.

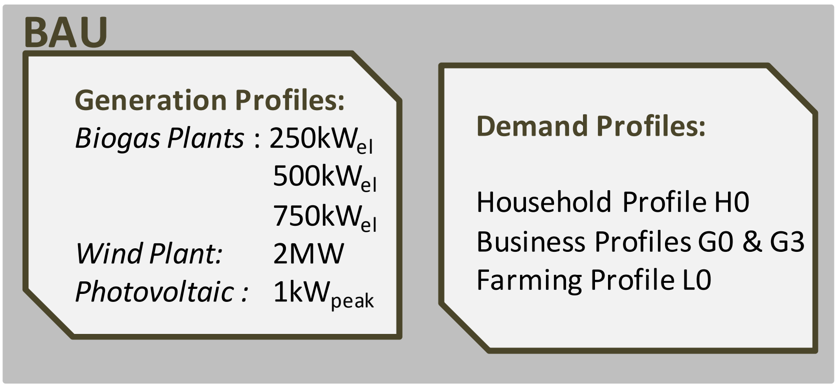

Figure 18 Input parameters of generation and demand for the BAU scenario without EVs

4. Methodology I: Overview of model creation

This chapter describes how the model creation in the thesis works. It shows how two different areas - a rural area and an urban one - are defined, and where the ideas for them come from. Therefore typical Austrian areas have been considered to create case studies which should reflect possible generation and demand mixes in reality. Moreover, the methodology for implementing a Li Ion battery is described in detail.

4.1. The rural case

4.1.1. Definition of the rural case study layout

In literature the definition for a rural area from the Council of Europe's approach can be cited as follows: [11]

The European Charter for Rural Areas defines a rural area as "a stretch of inland or coastal countryside, including small towns and villages, where the main part of the area is used for:

- *agriculture, forestry, aquaculture and fisheries,*
- *economic and cultural activities of country-dwellers (crafts, industry, services, etc),*
- *non-urban recreation and leisure areas [or natural reserves],*
- *other purposes, such as for housing."*

The definition concludes by comparing urban and rural areas*: "The agricultural (including forestry, aquaculture and fisheries) and non-agricultural parts of a rural area form a whole distinguishable from an urban area, which is characterized by a high concentration of inhabitants and of vertical or horizontal structures[11]."*

Consequently, the main criterion used to distinguish rural communities from urban ones, is the population density, with the dividing line set at 150 inhabitants per square kilometer [12]. To check this finding, the size and inhabitants of five rural areas in Lower Austria are shown in Table 4:

Table 4 Different rural areas in Lower Austria [18]

Rural Area	Area [km²]	Inhabitants	Population Density [inhabitants/km²]
Hohe Wand	24,6	1319	53,6
Winzendorf-Muthmannsdorf	16,6	1812	109,2
Bad Fischau Brunn	20,6	2807	136,3
Wismath	38,6	1564	40,6
Lichtenegg	35,4	1082	30,6
Average	**27,1**	**1716,8**	**74,0**

To find the data necessary for the areas, the average of the inhabitants, the size of the areas and the population density of these Austrian villages are taken in order to appoint these values for the case study areas in the thesis. Thus with the calculated averaged population density of 74 inhabitants per square kilometer and an estimated ***area size of 27 km²***, a total of ***1998 inhabitants*** is calculated for the rural area.

4.1.2. Generation mix in the rural area

Based on the introduced generation possibilities in chapter 3.2, a generation mix, optimized for the rural area, is configured. This generation mix is based on volatile wind generation and on a biogas plant with 250kW$_p$ for the base consumption.

Table 5 Generation mix in the rural area

Generation Profiles	Rural Area
Biogas 250 kW$_p$	1
Wind 2MW	1

Table 5 shows the annual generation in the rural area for the before mentioned accumulated generation profiles in chapter 3.2. Due to the implemented wind power plant the generation is volatile and the peaks of generation are dependent on the season and are not predictable as shown in Figure 19. Caused by the used biogas plant, a constant generation offset of 250kW through the whole year can be modeled.

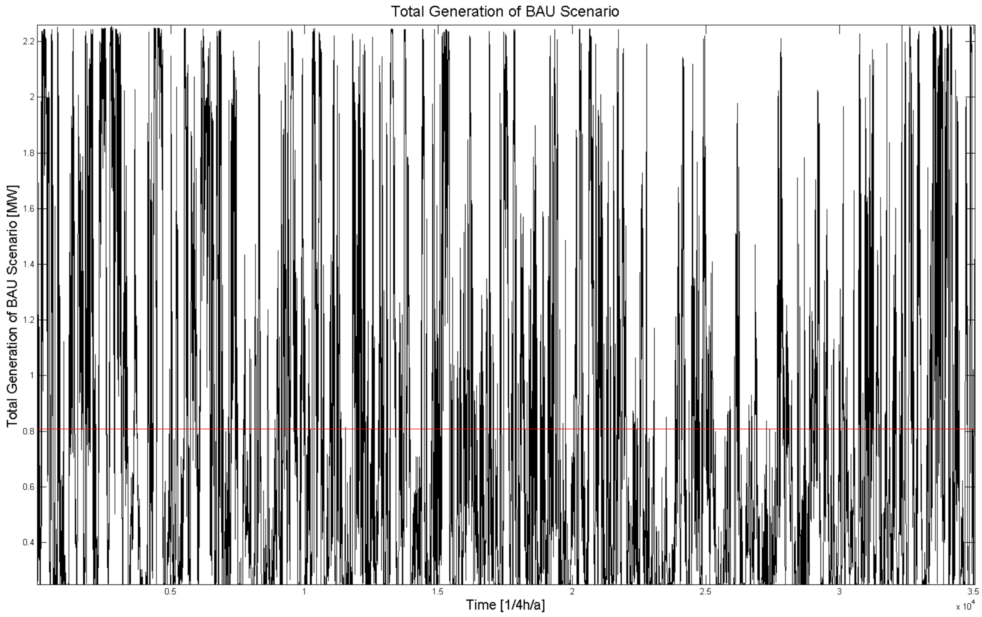

Figure 19 Annual generation mix for the rural area

4.1.3.Demand mix in the rural area

The used H0 profiles (compare chapter 3.1.2) for the demand mix in the rural area are calculated by the inhabitants of the area. It is assumed that 70 % of the inhabitants live in a four person household, 20% in a two person household and 10% in a single household. Out of this the H0 profiles are computed as shown in Table 6.

Table 6 Shares of households in rural area

Rural Area		
Inhabitants	1998	
Shares of Households		
%	Persons	Household- Profiles
70	4	350
20	2	200
10	1	200
	Total of	**750**

Table 7 Demand mix in the rural area

Demand Profiles	**Number of Profiles**
Household H0	750
Business G0	30
Business G3	0
Farming L0	50

The rural area is modeled as a region with households and business units and moreover profiles of farms are taken into account. To reproduce this, 30 G0 (compare chapter 3.1.1) profiles are used which show the weighted average of all other business groups. Alongside 50 farming profiles and 750 household profiles as described in chapter 3.1.1 are calculated.

Figure 20 shows the accumulated demand profile of the rural area which is similar to the annual demand profile H0, illustrated in Figure 16. This happens because the H0 profiles have the biggest part of the whole demand. The pink curve illustrates the average capacity for the accumulated demand, which lies at 950 kW.

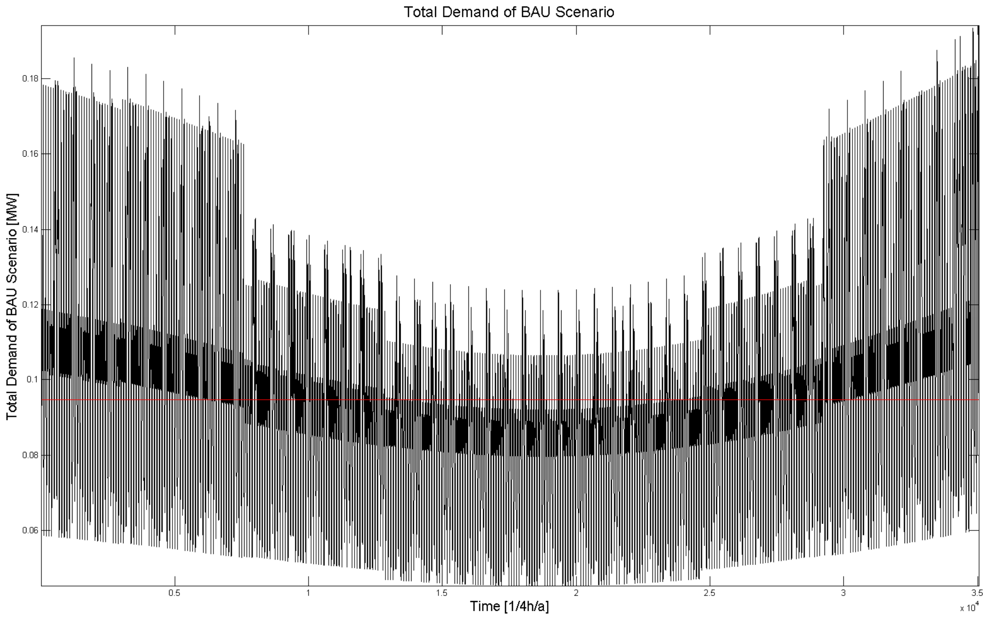

Figure 20 Demand of BAU scenario of the rural area

4.2. Urban case

4.2.1. Definition of the urban layout

For the urban area, different cities in lower Austria are compared in Table 8. The average area of the chosen cities is 58,7 km². Corresponding to this, an average of 30276 inhabitants are given, which leads to a population density of ~ 530 inhabitants per km² for urban areas.

Therefore, an area with a ***size of 60 km²*** is chosen, and according to the before calculated population density of 530 inhabitants per square kilometer, a total of ***31800 inhabitants*** are taken for further modeling.

Table 8 Urban areas in Lower Austria [18]

Urban Areas	Area [km²]	Inhabitants	Population Density [inhabitants/km²]
Wiener Neustadt	61,0	40600	666,0
Sankt Pölten	108,5	51543	475,1
Neunkirchen	20,3	12251	604,1
Krems	51,6	23898	463,0
Amstetten	52,2	23092	442,2
Average	**58,7**	**30276,8**	**530,1**

4.2.2.Generation mix in the urban area

For the urban area a generation mix, optimal for the circumstances of this area, is introduced with the help of the generation units described in chapter 3.2. The generation mix is based on volatile solar generation and on biogas plants with 250kW$_p$, 500kW$_p$ and 750kW$_p$ for the base consumption, combined in Table 9. These biogas plants are provided from beyond the city boundary, but are counted among the urban area record.

Table 9 Generation mix in the urban area

Generation Profiles	Number of Profiles
Biogas 250 kW$_p$	5
Biogas 500 kW$_p$	8
Biogas 750 kW$_p$	10
Solar 1kW$_{peak}$	190

Figure 21 shows the accumulated generation of the before described generation mix in the urban area. In the annual profile the used photovoltaic cells have an increased generation in summer time, due to more solar irradiation. The base demand generation of 1.5 MW can be assigned to the three biogas plants. In addition, the blue line shows the averaged value for the accumulated generation which is at 1.6MW.

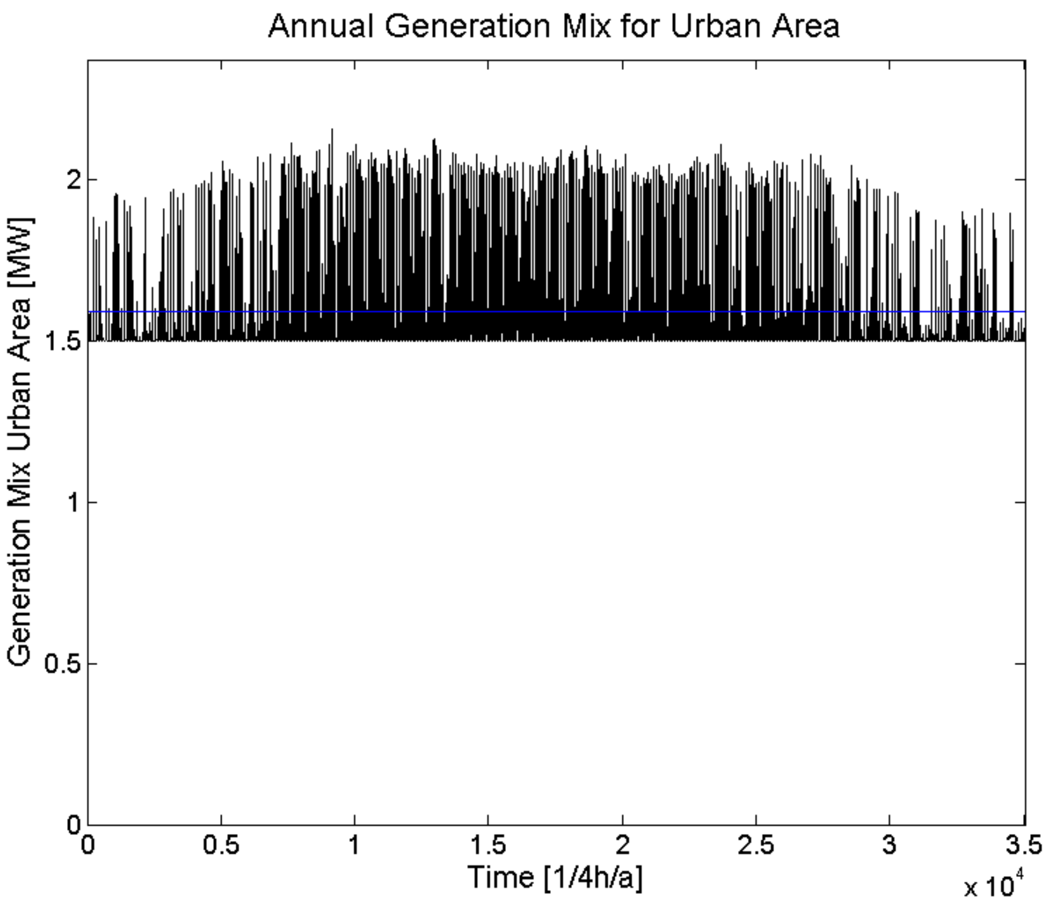

Figure 21 Total annual generation in the urban area

4.2.3.Demand mix in the urban area

The used H0 profiles for the demand mix in the urban area are equally calculated due to the inhabitants of the area as shown for the rural area. It is assumed that 70 % of the inhabitants live in a four person household, 20% in a two person household and 10% in a single household. Out of this the H0 profiles are computed as shown in Table 10.

Table 10 Shares of households in urban area

Urban Area		
Inhabitants	31800	
Shares of Households		
%	Persons	Household- Profiles
70	4	5565
20	2	3180
10	1	3180
	Total of	**11925**

Table 11 Demand mix in the urban area

Demand Profiles	Number of Profiles
Household H0	11925
Business G0	0
Business G1	0
Business G2	0
Business G3	70
Business G4	0
Business G5	0
Business G6	0
Farming L0	0

In the urban area on the demand side, only Household Profiles and Business Profiles G3 are considered. These profiles cover houses and housing areas with a few supermarkets and shopping possibilities without industry or big shops and stores (see Table 11).

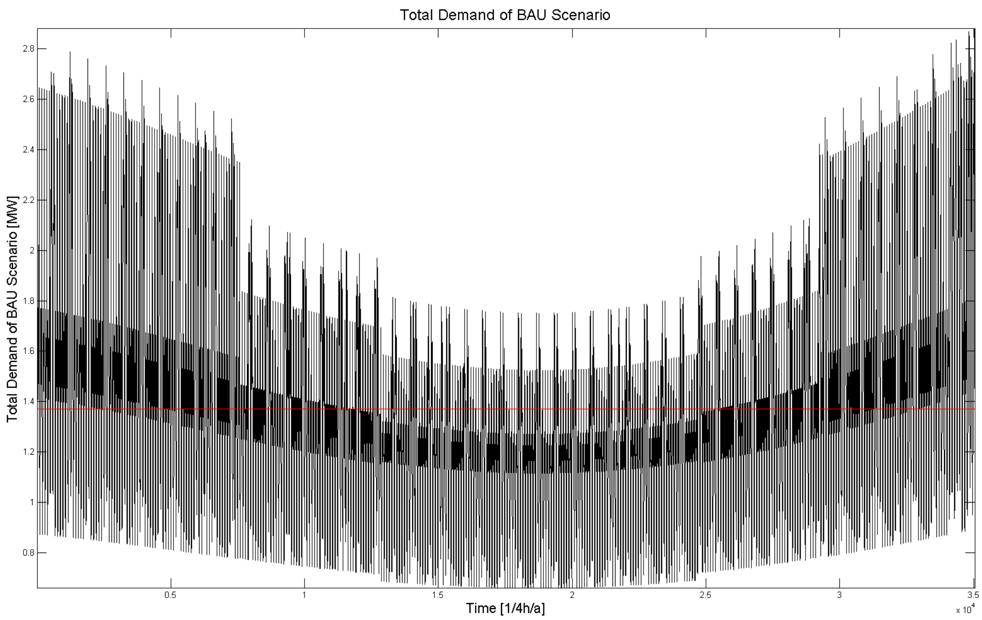

Figure 22 Total annual demand in the urban area

Figure 22 shows the annual demand in the urban area caused by H0 profiles and G3 business profiles, whereas again like in the rural area, the H0 profiles have the major part. The average value, shown as a pink line, has the value 1.3 MW, taken for the whole year.

4.3. Battery modeling

Although today most of the existing HEVs and PHEVs work with NiMH batteries, in this thesis Li Ion batteries are used, because the Li Ion batteries are actually replacing the NiMH batteries more and more.

Nowadays the biggest field of application for Li-Ion batteries is the mobile communication area. At the moment, this area takes 30% of the whole worldwide production [13], but there is already a glut on the market. The remaining 70% of the cells are built for laptops and more and more for the power tool market as for EVs or PHEVs

Li Ion cells can be used even for energy intensive and for high-capacity applications. But regardless of the technology used, the theoretical reachable energy density of 410Wh/kg cannot be exceeded. Prevailing Li Ion cells have a power to energy ratio of about 3-40W/Wh, depending on the cell type [4]. It is best to charge the battery in a temperature band of 0 to 40° Celsius, (otherwise) with lower temperature the internal resistance increases and thus a higher charging time results [4].

When modeling the battery for the Matlab Model, the IUa-charging approach is used.

Thereby in the current phase (I-Phase), the charging current is constant and the voltage is just slightly differing. That is why this phase is called constant power phase. This kind of charging is used until the charging switch over point is reached.

Then the voltage is set on the charging end voltage and the current is exponentially decreasing, called voltage-phase (U-phase). It is over when I_{LS} (charging shut down current) in C-rate is reached, resulting in a fully charged battery [4].

The current for charging and discharging is measured in the before mentioned C-rate. Thereby *1C* means that a 1000mAh battery would provide 1000mA for one hour if discharged at 1C rate. If the same battery is discharged with a 0,5 C-rate, that means that the battery provides 500mA for two hours[36].

In addition, it is assumed that the battery is charged only at common one-phase power sockets, which manage a maximum voltage value of 230V and a maximum current of 16A[4]. Here it is calculated with 230V and 14A so that the maximum value of the current is not exceeded.

Another possibility would have been to charge the battery over a high voltage power socket with 400V and 16A, 32A or 63A. This would lead to shorter charging times, but there won't be these kinds of power sockets everywhere, so this thesis works with the common one-phase power sockets which cope with a power of 3,2kW.

Now, to deduce the characteristic of the charging process, the basic values needed are as follows:

$P_{const} = 3{,}2\ kW$ [10]

$s = 80\%$[11]

$U_N = 3{,}6V$[12]

$U_{LS} = 4{,}2$[13]V

$I_{LS} = 0{,}03 * C - Rate$[14]

$E_{Batt} = 20kWh$[15]

First of all the charging shut-off power has to be calculated (equation (2)) and in a next step the charging correction coefficient (is calculated) (equation (3)). Now it is possible to calculate the constant charging power in the I-phase on the one hand, which lies constant at 3,2kW, and the decreasing charging power of the U-phase on the other hand, as shown in equation (4).

$$P_{LS} = \frac{U_{LS}}{U_N} * I_{LS} * E_{Batt} \qquad (2)$$

$$k_L = \frac{100 - s}{\ln\left(\frac{P_{const}}{P_{LS}}\right)} \qquad (3)$$

$$P = P_{const} * e^{\frac{s-SOC}{k_L}} \qquad (4)$$

Figure 23 shows the total charging process of a 20kWh battery, assembled of the constant I- phase and the U- phase as described before. [4]

---

[10] P_{const}…Constant Charging Power during a SOC from 1-80%

[11] S… Charging Switch over Point

[12] U_N … Nominal voltage

[13] U_{LS}…Charging Shut down Voltage (for all types of Li-ion batteries the same)

[14] I_{LS}… Charging Shut down Current

[15] E_{Batt}… Capacity of battery

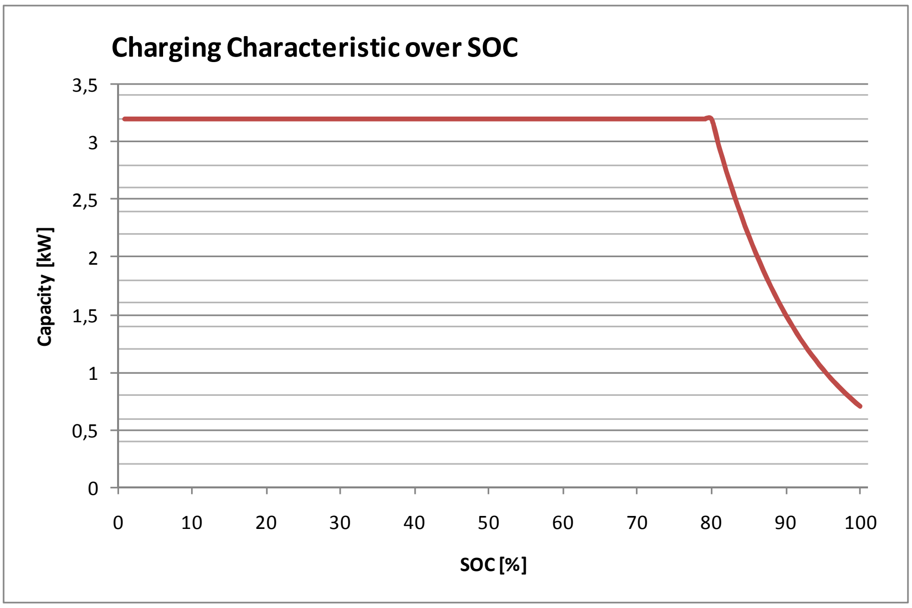

Figure 23 IUa charging of a 20kWH battery

But due to the used load and generation profiles (chapters 3.2 and3.1), the battery cannot be implemented in the Matlab model as charging power over SOC. The power values over the quarter of an hour data are needed. So in a next step, the SOC is converted in a corresponding energy entity. (compare description in Figure 24)

$$\Delta E_{Batt} = SOC = \frac{E_{Batt}}{100} \qquad (5)$$

For the first phase, the constant current-phase, the timeslots corresponding to the ΔE_{Batt} are calculated over the constant power P_{const}.

$$\Delta t = \frac{\Delta E_{Batt}}{P_{const}} \qquad (6)$$

For the second phase, the constant voltage phase, the timeslots corresponding to the ΔE_{Batt}, are calculated over the prevailing valid power value, as shown in equation 3.[16]

$$\Delta t = \frac{\Delta E_{Batt}}{P_{(SOC)}} \qquad (7)$$

[16] $P_{(SOC)}$ ..Charging power against SOC

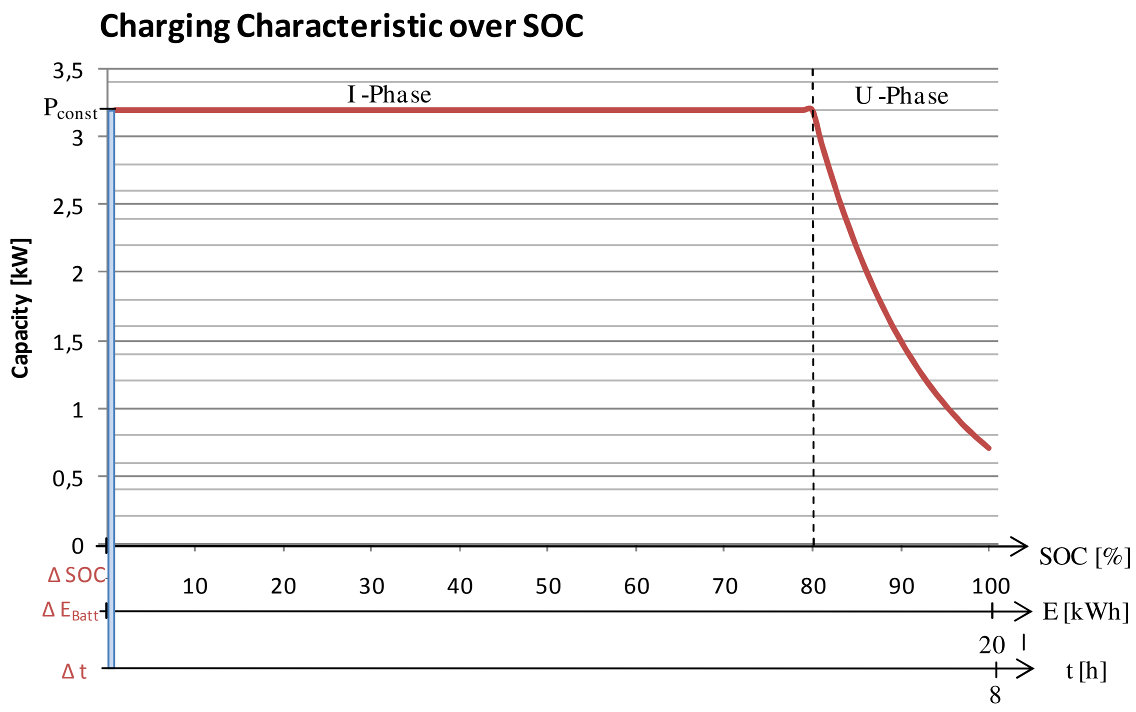

Figure 24 Calculation for the charging over time using the example of a 20kWH Li Ion battery

Then, the Δt values are cumulated until a quarter of an hour is reached. Furthermore, the corresponding power values are added and subsequently divided through the number of Δt values to get the mean value. Figure 25 shows the resulting graph for a 20kWh Li ion battery.

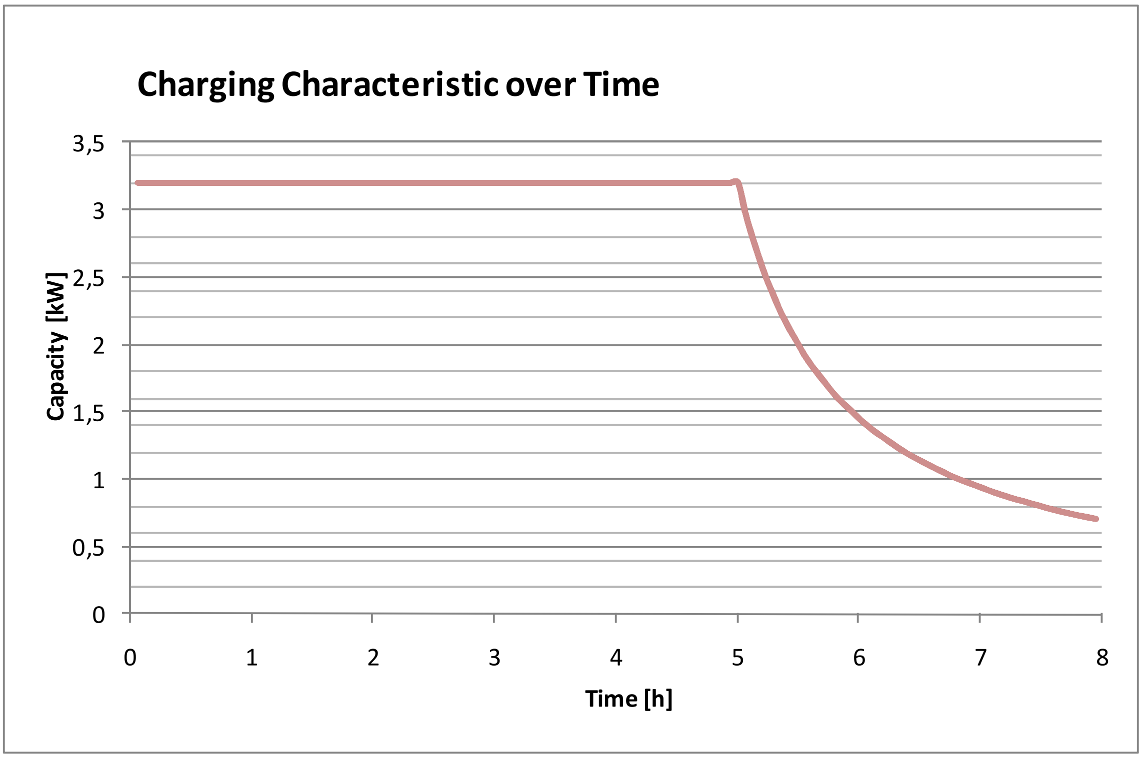

Figure 25 Charging characteristic of a 20kWh battery over time

4.4. Further model parameters

In this chapter, further parameters for the model creation, in particular the parameters for modeling the G2V scenarios are introduced. These parameters are a matter of market penetration rates of the EV fleet for the certain areas and an assumption of the starting times.

4.4.1.Market penetration rates

Table 12 shows the market penetration rates for the rural and urban areas described before in chapter 4.1 and chapter 4.2. Therefore the assumption has been made that there is one car for two persons in the areas, which is usual in Austria. An accurate explanation to this assumption can be found in chapter 3.1.

Table 12 Electric Vehicle fleet with different market penetration rates

Market Penetration [%]	Rural Area [EVs]	Urban Area [EVs]
0	0	0
10	100	1590
30	300	4770
50	500	7950

4.4.2.Assumptions for starting times

Generally, the EV fleet is separated in two business groups. On the one hand the private business group, which consist of private traffic, leisure traffic and others and on the other hand the business traffic group which consists of commuter traffic, education traffic and business traffic. The proportion of the business traffic group is 52% of the whole automobile fleet and the group private shares 48%, according to [31] and described in Figure 26 and Figure 27.

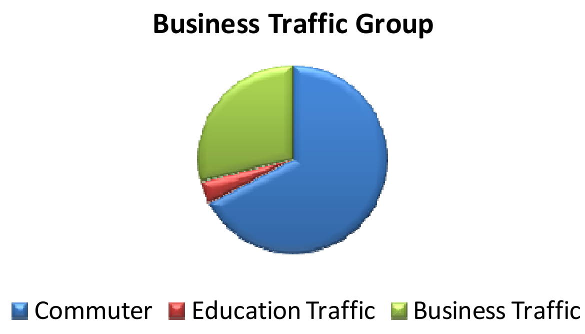

Figure 26 Distribution of the business traffic group

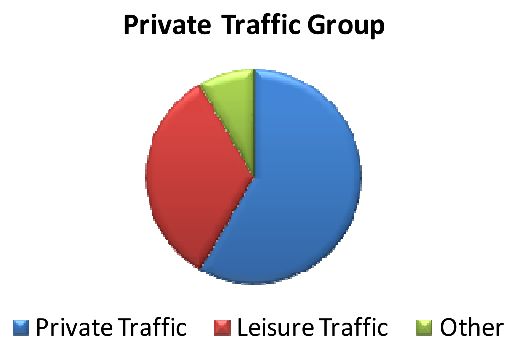

Figure 27 Distribution of the private traffic group

Persons in the private traffic group on average cover a distance of 6,65 km per day, and in the business traffic group a distance of 13,83km is typical [31]. This leads to the confirmation that the range provided by a 20kWH battery, as introduced before, is sufficient because the State of Charge (SOC) never undergoes a level of 82%, if calculated a 20kWh battery reaches for 100km.

In a next step a distinction between individual and controlled charging is made, to perform the key analysis of this thesis.

In the case of individual charging, the EV fleet is charged at midday and at 5.30 pm. This time slots for charging occur, because this would be the most common times for people to come back and charge their vehicle, either after some shopping or coming home from work. With these assumptions customers charge their vehicles at a bad case for the electricity supplier. If the electricity supplier has to purchase electricity at peak times, then the energy is just available at the market for peak prices, which can be more than twice the prices in off-peak times. Moreover the grid is already working to capacity at peak times, and it is hard for the electricity supplier to handle addition grid load.

A way to overcome these problems is the introduction of demand characteristics valley filling methodology. There it is tried to shift demand peaks into off peak times. The peak demands occur in the introduced areas owing to the peaks of the household profiles, since they take the biggest part of consumption. So for finding the best starting times for the controlled charging scenario, the H0 profiles are used with to apply for valley filling method mentioned above.

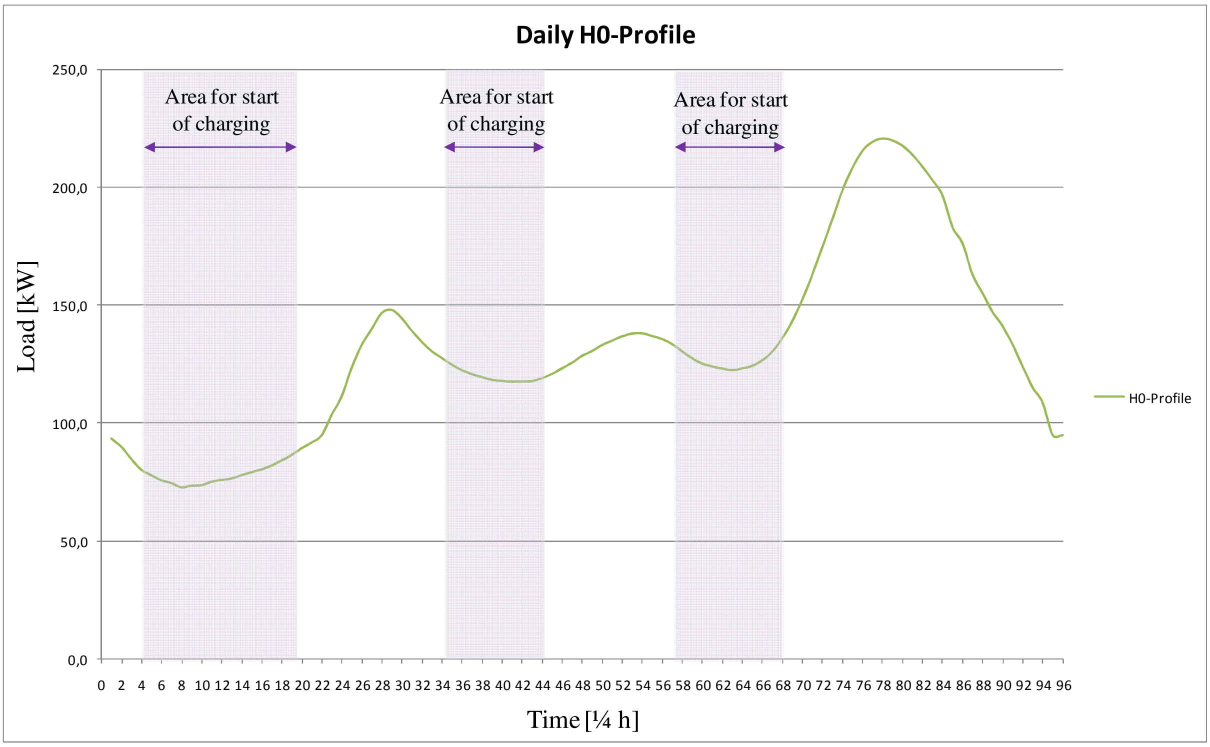

Figure 28 Areas for valley filling in the daily H0 profile

Possible EV charging times therefore emerge in the night, from 1 o'clock in the morning until 5 am, from 8.30 am until midday and in the afternoon, before the mean peak from 2.30pm until 5 pm. But except the off peak time in the night, the other valleys fall in peak times for purchasing electricity on the market. Hence in this thesis charging times for starting are set at 3 am, due to valley filling and at 9 pm. The second time is chosen because then the grid load is already retreated and electricity is cheap to purchase. Additional it is no problem to start charging the EV fleet in the late evening, because due to the reason that the SOC never undergoes 80% of SOC, the cars are fully recharged until the morning when customers need them

5. Methodology II: The MATLAB model

This chapter declares how the by now introduced parameters are technically implemented into the calculated model, and how the programming code is constructed. The model is programmed with MATLAB, the Matrix Laboratory. MATLAB is platform free software for solving numerical problems with the help of matrices. More information can be found at [41].

5.1. The implementation of the battery

Chapter 4.3 describes the exact methodology of how the battery is modeled. The most import step therefore is to alter the charging power over the SOC, shown in Figure 24, into charging power over time, shown in Figure 25. So it is possible to put together the different generation and demand profiles with the demand profile of the battery. With this knowledge now it is possible to principal implement the battery in the MATLAB model. But therefore some additional assumptions have to be made which are shown in Figure 29 underneath where the exact process is depicted.

First P_{LS} and k_L are computed and with this values then the power has to be calculated. Therefore iteration from 1 to 100 is made. If the iteration value is lower or equal to 80 a constant power of 3,2kW will be saved, otherwise the power is calculated with equation (4) and afterwards also saved in matrix A.

Then ΔE_{Batt} values are calculated, whereas one ΔE_{Bat} conforms to 1% of SOC. Thereafter the ΔE_{Batt} steps are divided through the related power value out of matrix A, always for the same SOC, from 1-100%. Now the Δt values belonging to the ΔE_{Batt} steps are found and saved in matrix B.

This leads to the last step where iteration over the whole matrix B is made. In this iteration the Δt values and simultaneously the corresponding power values are summated and if 15 minutes (quarter of an hour) at summing up the Δt values are reached, the mean value of the power values is done and afterwards the results are saved to matrix P.

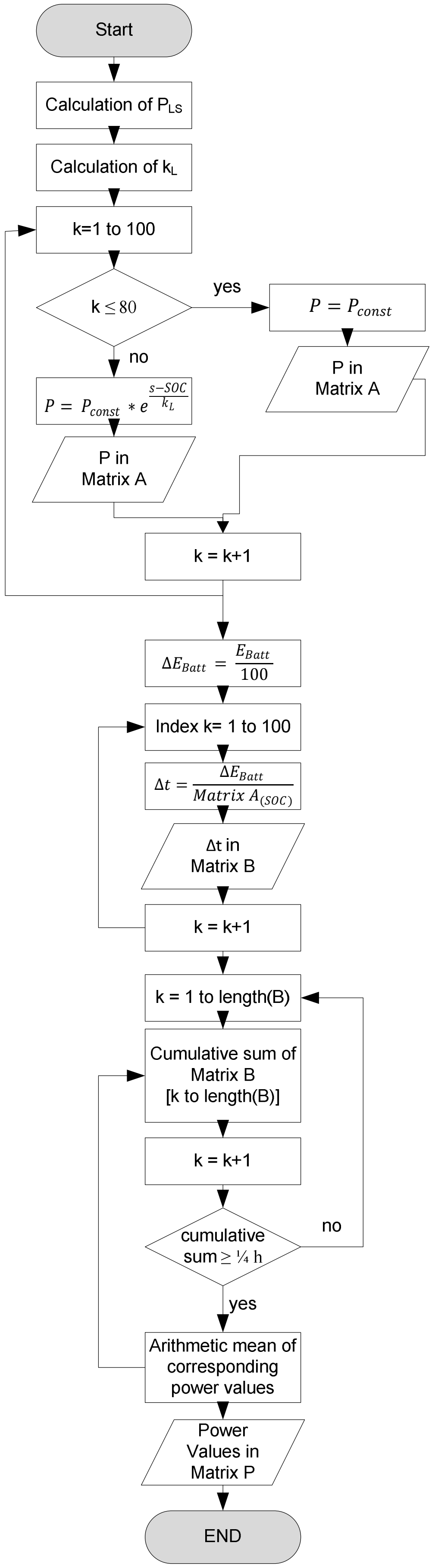

Figure 29 Flowchart of how the battery is modeled

5.2. Modeling the whole fleet

On the terms of the before found data from chapter 5.1, now the whole EV fleet can be implemented with certain starting times and the previously shown charging characteristics. Therefore the input parameters as the number of cars, the different starting times and the range of the different business groups (chapter 4.4) are necessary. The accurate procedure for this is illustrated in Figure 30.

First a starting time vector, which has the length of the size of the vehicle fleet, in this example 5000, is applied. In Figure 30 a starting time of 40 (1/4) h which is equal to 10 am is assumed. To get a Gaussian distribution for the starting times a vector with 5000 random Gaussian numbers between 0-3 is done with an automatic MATLAB function. With this distribution between 0-3, starting times can vary plus/minus an hour of the exact starting time. This data then are saved in vector *Z*.

In a next step an iteration loop is executed over vector *Z* and every second element is multiplied with minus one. After each iteration step the values are saved to vector *X*. Then this vector *X* is subtracted from the starting time vector *S* and the results are saved to vector *D*, which now contains the different starting times. Subsequently the same starting times in vector *D* are summarized to get the exact quantity of starting EVs at certain starting times.

Next to that the *ΔSOC* value for the maximum range of the driving groups is calculated with $Range_{Battery}$ and Δs, as shown in equation (8).

$$\Delta SOC = \frac{100}{Range_{Battery}} * \Delta s \qquad (8)$$

- ΔSOC… SOC for maximum way per day of traffic group
- $Range_{Battery}$… Range of battery (100km for 20kWh)
- Δs… Maximum way of traffic group
- P_{SOC} …Power value over SOC

Now this calculated *ΔSOC* is subtracted from the maximum SOC of 100% and so the minimum occurring SOC for the traffic group is computed. Then the accessory power value in matrix A is searched and with this founded power value P_{SOC} the belonging time and power value of matrix P are selected. Hereafter, from the selected value until the end of the matrix the data are saved into Matrix *E*.

In a last step this Matrix *E* is multiplied with the vector *SA* and so the starting times and profiles for the whole EV fleet in the area are calculated and implemented.

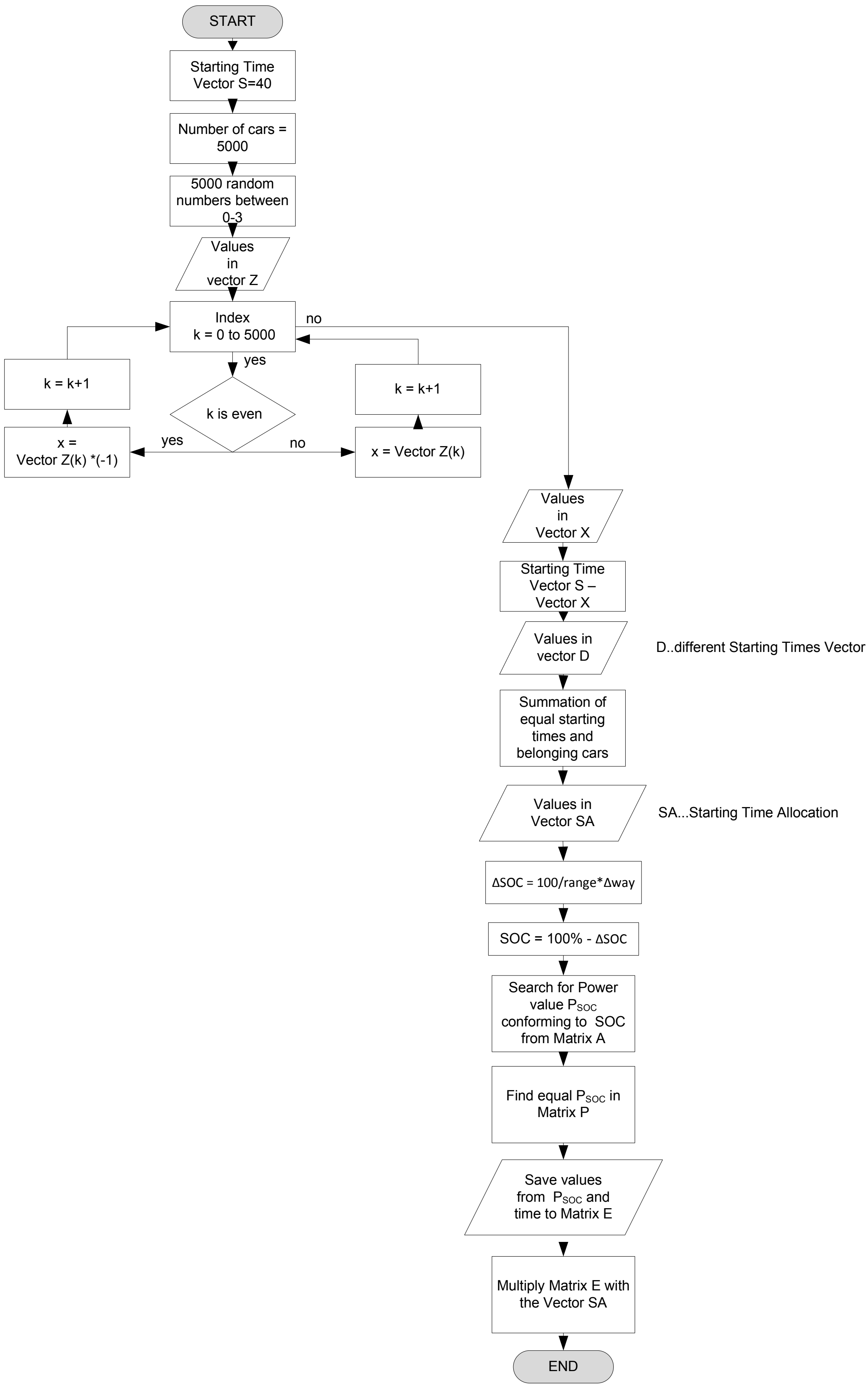

Figure 30 Flow Chart of the modeling of different starting times with Gaussian distribution

5.3. The graphical user interface

A Graphical User Interface (GUI) with MATLAB was developed, which works with the before mentioned input parameter and implements the bottom up model. It allows calculating various different scenarios for different input parameter and so it is possible to create optional areas. Figure 31 shows this unfilled GUI. Figure 32 shows the filled GUI with all possible graphic outputs.

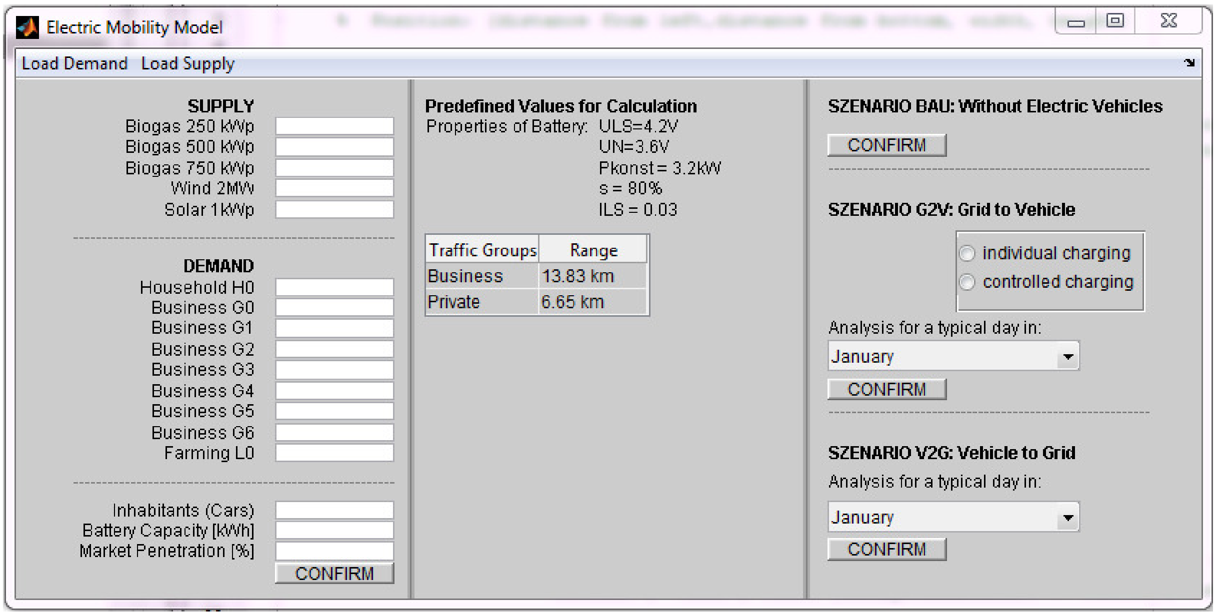

Figure 31 Graphic user interface for the MATLAB model

In the first Column in the first part the numbers of generation profiles can be inserted. This inserted data must be positive integers, if not an error occurs. The same is valid for the second part of the column where the numbers of demand profiles can be entered. Here too, only positive integers are valid.

The third part of column one is necessary for the different market penetration scenarios. The user there has to input the number of inhabitants of an area. From this value, the half is conform to the conventional vehicle fleet as described in chapter 3.1. Also the battery capacity and the value for the market penetration rate has to be entered.

If the user activates the Confirm button in the first column, figures of the daily accumulated generation, demand and import/export for different times in the year pop up. In addition appears in the second column, in the GUI, a figure which describes the charging of the battery over time for the inserted battery capacity. At the moment this function is just implemented for a 20kWH battery as used in the thesis. For further investigations it is possible to create these figures also for other battery capacities.

In the third column the user can theoretically chose between three different scenarios, whereas the V2G scenario is not conducted in this thesis, but could be similar implemented for further investigations.

The first confirm button is appropriate for the BAU scenario. Therefore the data concerning the battery are not needed because in the BAU scenario no EVs appear. The exact function of this scenario is described in 5.4.

In column 3 in part 2 the confirm button is proper for the G2V scenario. For it the user first has to decide whether he wants to investigate individual or controlled charging. Then a month for the analysis has to be chosen. If afterwards the G2V confirm button is pressed, figures of generation, demand, demand of the EVs and the total IMP/Exp energy occurs. For the exact implementation of this scenario see chapter 5.5.

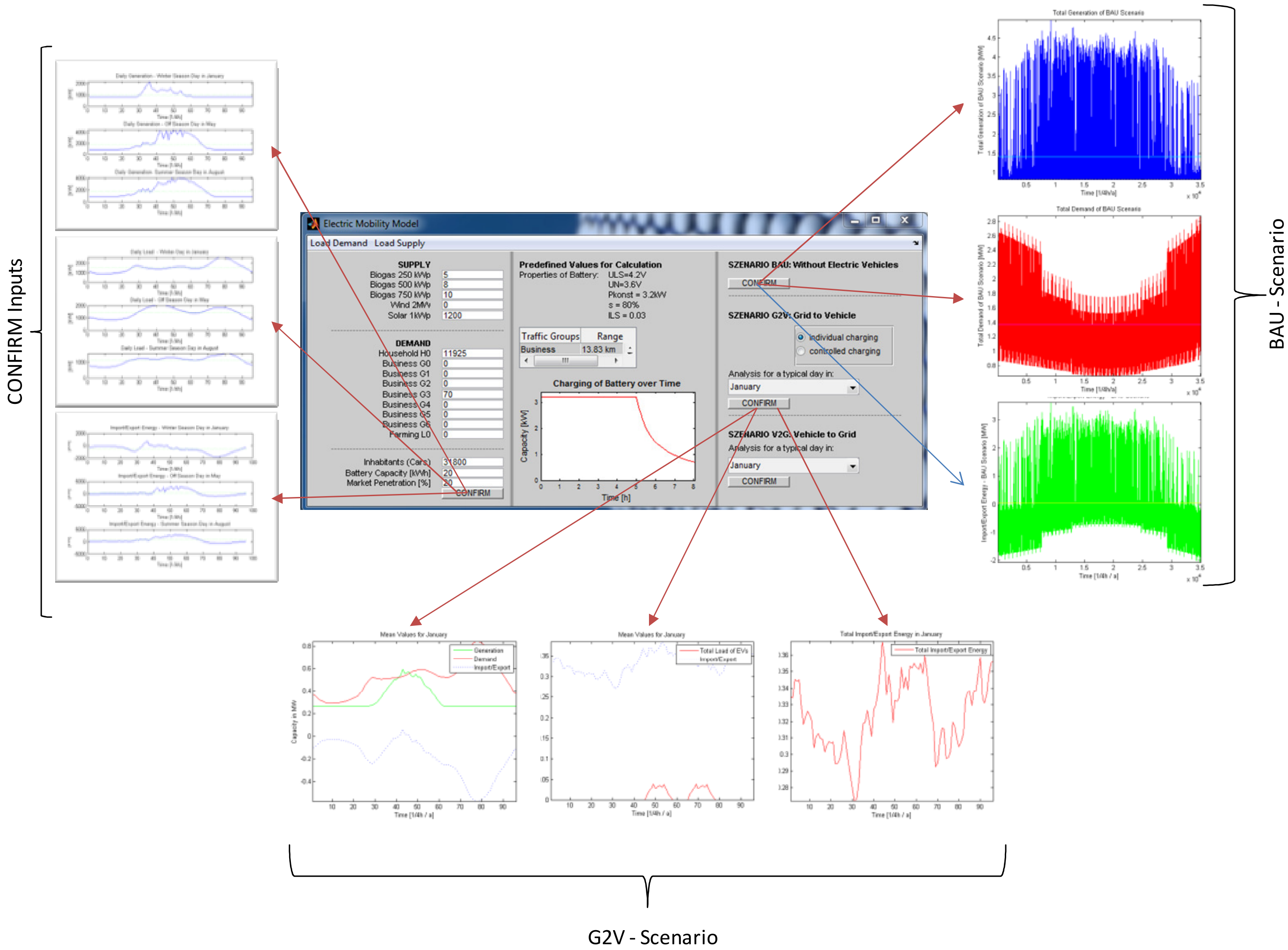

Figure 32 Schematic representation of outputs of the MATLAB model

5.4. The business as usual scenario

For the BAU scenario, the initiated generation and demand profiles from chapter 3.2 and chapter 3.1 are used. The user can enter any numbers of profiles into the GUI and afterwards press the button Confirm BAU. The MATLAB program executes the BAU algorithms which work off the following steps.

On the one hand the annual generation profiles and on the other hand the annual demand profiles are summed up. Then the import/export energy, resulting of total generation minus total demand is calculated. To get a good idea of these findings, MATLAB figures are made of the annual generation, the annual demand and the annual import/export proportion. Figure 33 Function of the BAU scenario shows the exact function.

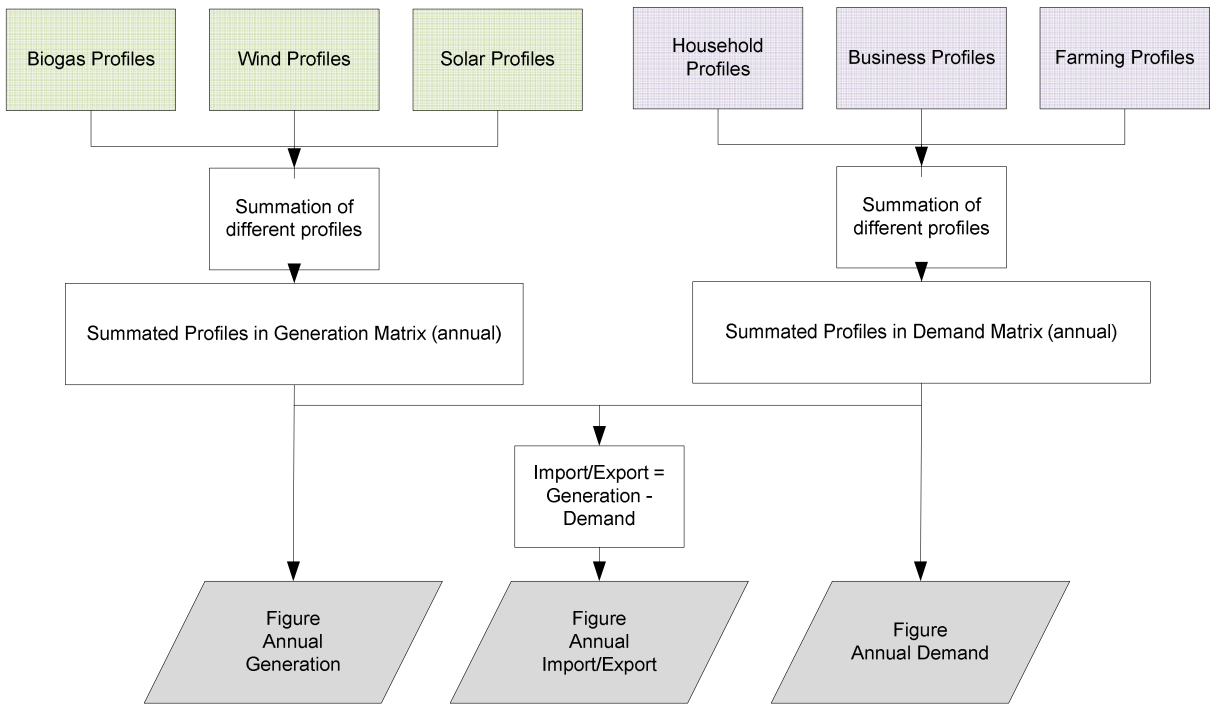

Figure 33 Function of the BAU scenario

5.5. The Grid to Vehicle Scenario

In the G2V scenario, in contrast to the BAU scenario, instead of the annual profiles   the daily mean values are used. For one daily profile the data for one month is averaged at each quarter of an hour of the summated generation and demand profiles. The mix of the generation and demand profiles has to be entered by the user into the GUI before. In addition the modeled EV fleet, as described in chapter 5.2is considered for calculations. The accumulated load profile of the EV fleet is summated to the basic demand and therefore a total demand is made.

As an output the GUI provides a figure with daily generation, demand and import/export energy, additionally a figure with the load of the EV fleet over time and finally a figure which contains the total load, and the total generation, which is equal to the BAU generation and a curve which displays import/export proportion.

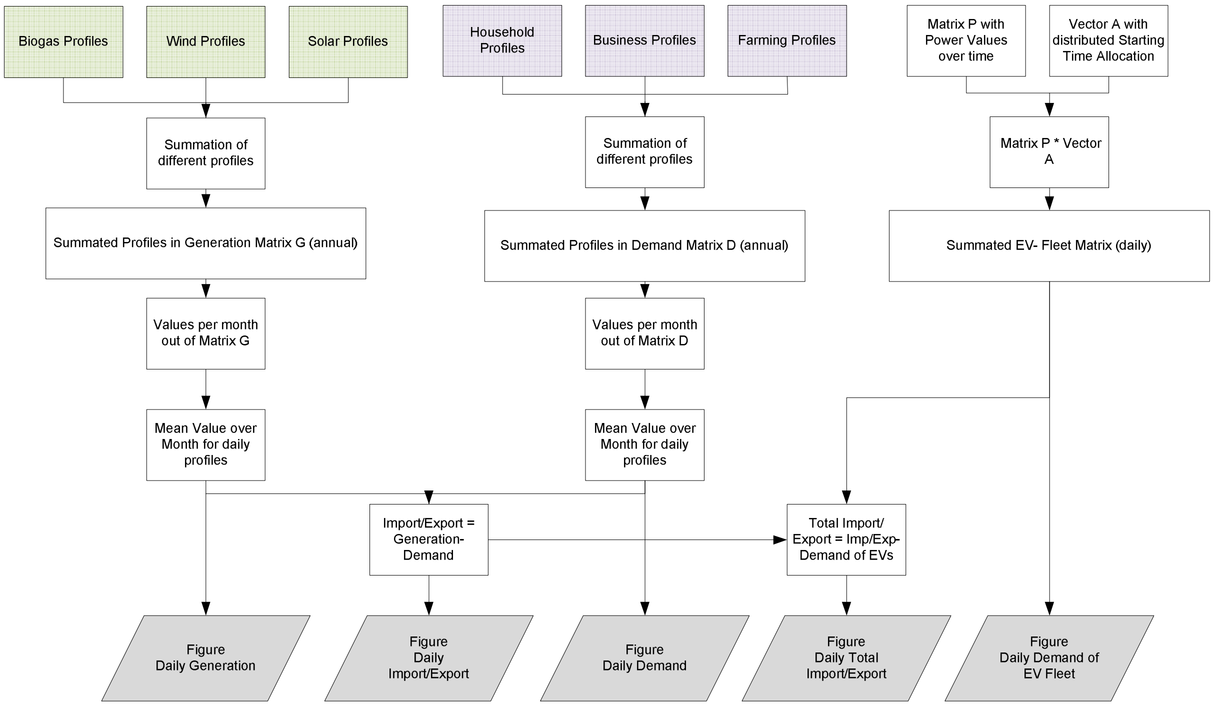

Figure 34 Function of the G2V scenario´

6. Methodology III: Economic evaluation

For the economic evaluation the generation and the demand utilities in the areas, described in chapter 4.1 and chapter 4.2, are summed up to generation units and demand units. Moreover an additional own entity within the economic analysis is the Electricity Supplier.

Figure 35 illustrates that on the one hand this electricity supplier is in interaction with the generation and demand units and on the other hand the electricity supplier has the possibility to trade electricity at the market. So if there is too much generation in the area, the electricity supplier has the feasibility to sell the dispensable energy to the market and if there is not enough generation, it is possible for him to purchase energy from the market, to market conditions. And in general it is assumed that the grid can bear the additional load of the EV fleet, for all investigated market penetration rates.

In addition there is also accessory demand caused by the EV fleet. It is the assumption that for the electricity supplier no additional costs occur for purchasing batteries or doing services. These costs are financed by the customers, respectively the EV owners. The electricity supplier just obtains more revenues due to the increased demand.

For the economic evaluation the costs of the generation units are not taken into account, because it is the assumption that the feed-in tariffs are not taken into account and their capital costs are already amortized.

Figure 35 shows the interaction between these market players and in the remaining chapter, the exact methodology for this interaction is introduced.

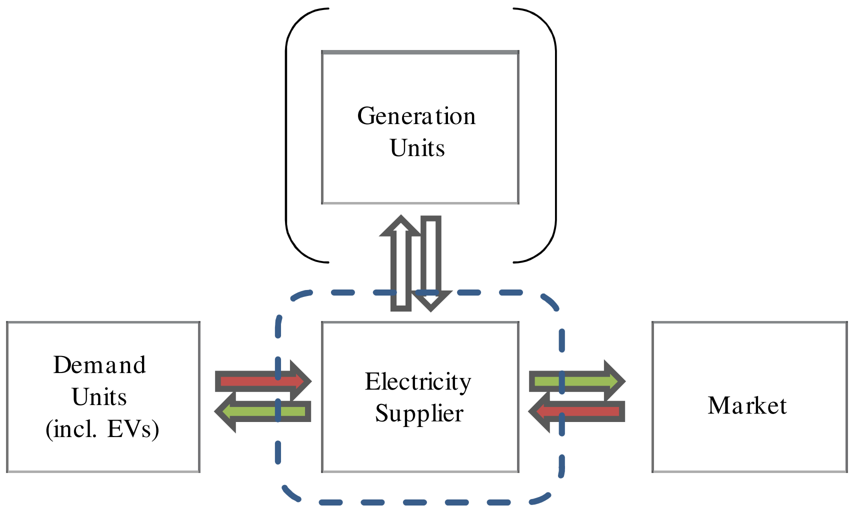

Figure 35 Market players in bottom up model

After the economic evaluation of the interaction of the market player the grid load caused by the EV fleet is rated, and it is examined how controlled charging could lead to less grid load than individual charging. Further results of this examination are given in chapter 6.2.

Afterwards, in chapter 7 the found results for that economic evaluation are derived.

6.1. Interaction with the energy market

Hence the main focus in this subchapter lies on the revenues an electricity supplier can expect for certain input parameters in the defined regions. These total revenues are calculated as shown in equation (12) but therefore first the revenues at demand have to be calculated, based on the demand of the different annual consumption profiles and the demand of the EV fleet. The demand over time is multiplied with a constant electricity tariff, which an Austrian customer would have to pay. As an example this electricity tariff are 86,3 €/MWh in Vienna for the year 2010. [21].

$$R_{Demand} = \frac{(P_{Demand} + P_{EV})}{t} * T_C * n \qquad (9)$$

- R_{Demand} ... revenues gained at demand [€]
- P_{Demand}...Capacity of demand [MW]
- n ...Number of days of the month
- P_{EV} Capacity of EV fleet [MW]
- T_C Electricity tariff [€/MWh]
- t in [(1/4)h]

In a next step, also the revenues and costs for selling or purchasing electricity on the market are calculated. For it the Import –Export (IMP/EXP) balance has to be calculated, whereby the demand consists of the standardized load profiles combined with the load caused by the EV fleet. The resulting $P_{IMP/EXP}$ power is calculated for every quarter of an hour for a year and is therefore varying over time.

$$P_{IMP/EXP(t)} = P_{Generation}(t) - P_{Demand}(t) \qquad (10)$$

- $P_{IMP/EXP}$ total Import/Export Power [MW]
- $P_{Generation}$... Capacity of generation

Then this IMP/EXP power is multiplied with historical Austrian market prices of the year 2009 [20]. These market prices have been averaged, over a month deliberately for each hour and the annual characteristic of them for the year 2008 is shown in Figure 36.

$$R/C_{Market} = \frac{P_{IMP/EXP}}{t} * T_M * n \qquad (11)$$

- R/C_{Market} ...Costs/Revenues for selling/purchasing electricity to the market [€]
- T_{Market} ... prices for energy as shown in Figure 36

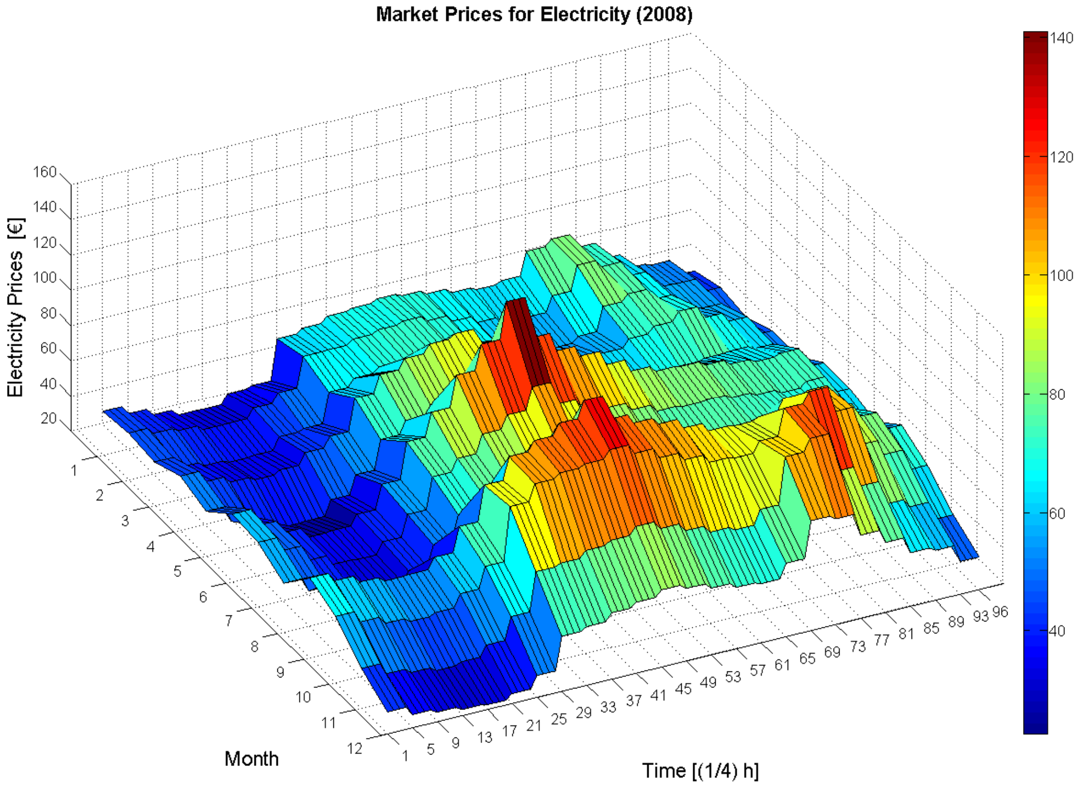

Figure 36 Averaged market prices for the year 2008 in Austria

Emerging positive values of equation (11)are ascribed to revenues for the electricity supplier, because this amount of power has been sold to the market. If there is a negative return, then the energy supplier had to invest money to cover the exalted demand in the specific area.

Now for the total revenues of the electricity supplier the revenues at demand, the revenues yield at the market and the costs occurring at the market have to be combined. The result is shown in equation (12).

$$R_{Energy\ Supplier} = R_{Demand} + R_{Market} - C_{Market} \qquad (12)$$

- $R_{Energy\ Supplier}$ Revenues of energy supplier [€]
- R_{Market} Revenues caused by sold energy to the market [€]
- C_{Market} Costs caused by purchased energy from the market [€]

6.2. Grid evaluation

Next, the additional load caused by the EV fleet on the grid is examined and it is rated whether there is an advantage concerning the maximum grid load due to controlled charging. Therefore the maximum load values of generation and demand (incl. EV fleet) are considered in the following:

$$P_{Peak} = \max\{P_{Demand_{(t)}} + P_{EV_{(t)}}, P_{Generation_{(t)}}\} \qquad (13)$$

- P_{Peak} Maximum load in grid [MW]

In equation (13) the power values are given for each quarter of an hour, thus four values per each hour. Out of this data for a whole year, the maximum grid load is sought.

This peak value, reduced by the maximum grid value in the BAU case, shows then the additional load for the grid caused by the EV fleet compared to the BAU scenario with 0% market penetration, calculated in equation(7).

$$P_{add} = P_{Peak} - P_{BAU_{max}} \qquad (14)$$

- P_{add} additional grid load due to EV fleet [MW]
- $P_{BAU_{max}}$ maximum grid load in BAU case [MW]

7. Case study: Specific results

In this chapter the results of the before described arithmetic procedures are shown for the different analyzed areas and scenarios, the controlled charging case and the individual charging case.

7.1. Analysis of possible revenues from point of view of the electricity supplier

The economic analyses show the possible higher revenues due to the controlled charging strategy using a valley filling methodology as described in chapter 4.4.2. In general, higher revenues are mainly developed because of a higher electricity demand caused by the EV fleet in the controlled charging and the individual charging case.

7.1.1. Rural area

First of all Figure 37 shows that categorically controlled charging yields to higher revenues than individual charging. Moreover it is illustrated that the difference between controlled and individual charging is getting bigger for higher market penetration rates.

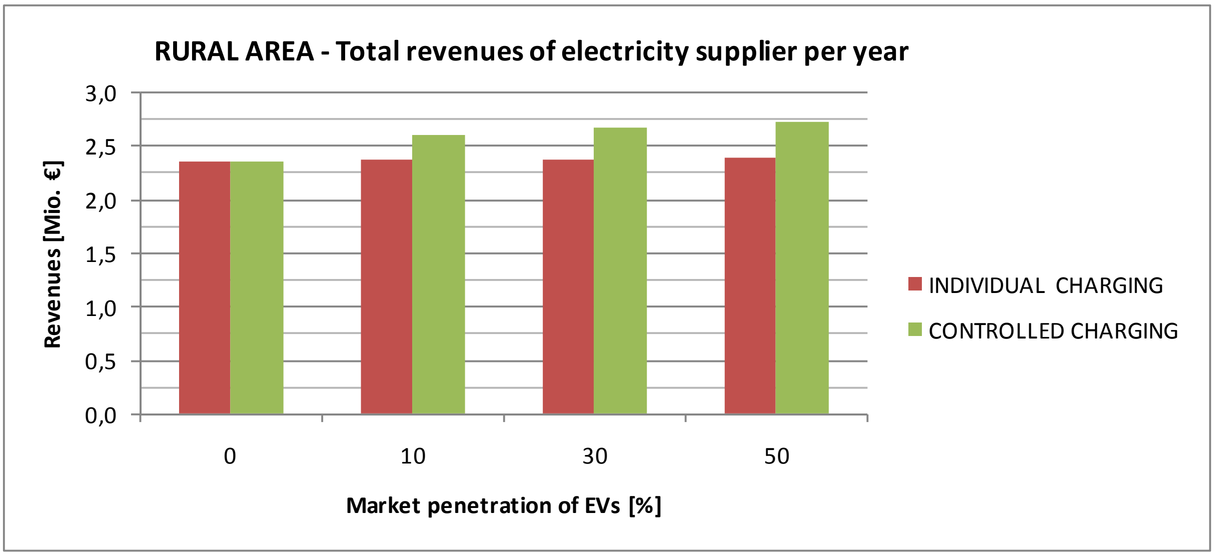

Figure 37 Total revenues of electricity supplier in the rural area

In the BAU scenario, naturally there is no distinction between the two charging methods, because no EVs are taken for calculation. At the 10% market penetration case, controlled charging leads to € 240.700 more revenues than individual charging, and at the 30% case, the revenues even amount to €293.180. As told before, the highest extra revenues of the four calculated cases result for 50% market penetration and lie at € 345.900 per year

These delta revenues converted on the housholds in the rural area show Figure 38.For 10% market penetration, revenues per year of € 321 are gained, at 30% even € 391and the biggest gain is can be found at 50% market penetration with €461 per household.

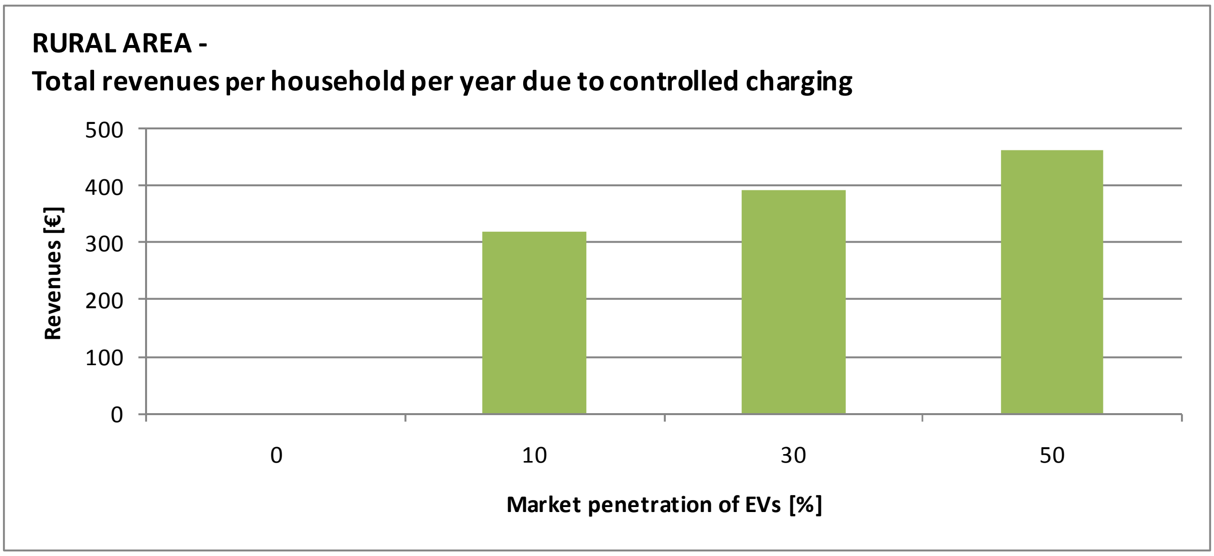

Figure 38 Total Revenues of Electricity Supplier in the Rural Area per Household due to controlled charging

Now it is possible to assume occurring delta revenues for higher market penetrations due to a linear approximation of the before found results. It is possible to do this approximation because the EV fleet is increasing linear and so the revenues are too This linear approximation is described by equation (15) and the characteristic therefore is shown in Figure 39.

$$R_{Energy\ Supplier} = 3{,}5 * MP + 286 \qquad (15)$$

- MP… Market penetration [%]

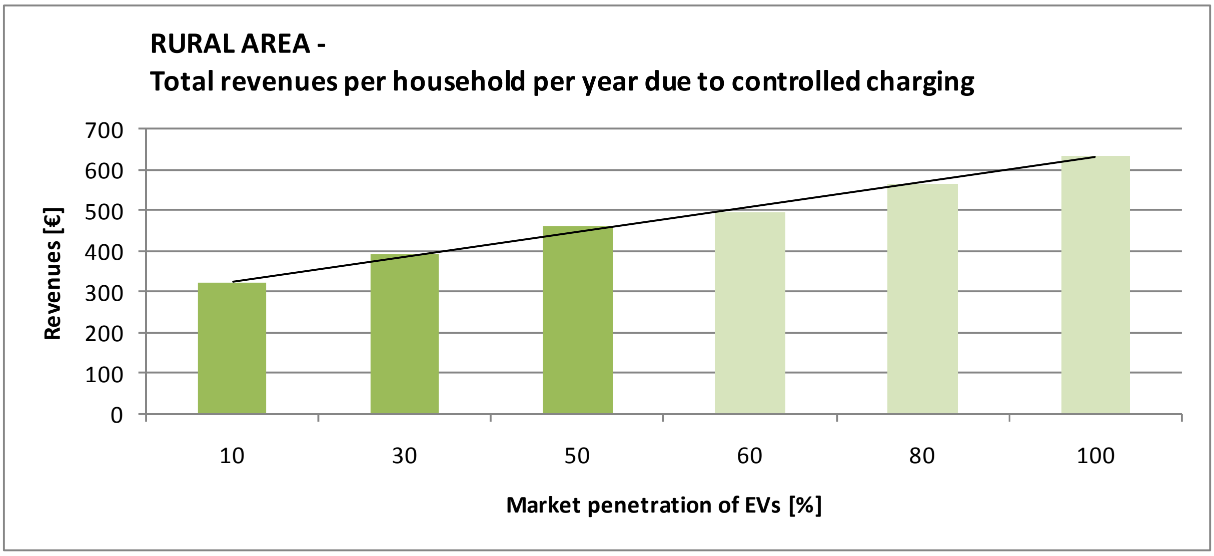

Figure 39 Linear approximation of revenues per households for further market penetration rates

This assumption leads to maximum delta revenues in the 100% market penetration case of 636€ per household and year.

Installation needs for G2V concept

With the delta revenues gained at the various market penetration rates makes it now possible for the electricity supplier to purchase components which are necessary to adopt the controlled charging. Hence one possibility is to install a home terminal for each household, where customers can plug in their EV when they are at home. So the electricity supplier knows how much EVs are online and has the possibility to communicate with the EVs. Therefore these home terminals have to consist of a few important components. On the one hand a computer is needed where the executing software is running. This computer needs nonstop connection to the internet to be updated constantly and to receive commands from the electricity supplier. On the other hand the terminal needs a single-phase power socket for 230 V (16A) where the EVs can be charged. The meter for measure the used electricity is in the EVs, so the electricity supplier does not have to take this into account.

For the intelligence of the home terminal a tablet pc is chosen which can be served via a pen. This tablet pc has an USB interface to communicate with the EV, has a memory, it is possible to run a system software there and costs € 224 according to [42]. Additionally, further costs are estimated for the power sockets and the housing of the home terminal with €150,-.

Moreover an internet connection is needed from the home terminals to the electricity supplier, for the home terminal to receive commands. Table 13 shows the chosen internet connection.

Table 13 Costs for internet connection [43]

	Costs [€/month]	Costs [€/a]
Internet	18,6	
WLAN	1,90	
Total costs	20,5	246

So total capital costs of 620€ occur for the home terminal with a constant internet connection in the first year. Because the electricity supplier has no guarantee that customers will stay with him, it is important that the costs of the home terminals are amortized in the first year, as it is assumed here, that customers are tied to the contract with the electricity supplier for one year. For other business models it is possible for the electricity supplier to gain fixed revenues over a couple of years and so he has more capital to spend on infrastructure, respectively less market penetration is needed to fit the costs.

In this case, a market penetration of 95 %, which accord to 950 EVs, is necessary to yield enough revenues to finance the infrastructure for controlled charging, according to equation (15).

Another possibility occurs if the customer provides the internet connection himself. Then only costs for the home terminal occur, which lie at € 374,-. And these costs can be already covered at a market penetration rate of 25%.

7.1.2. Urban area

Like in the rural area, Figure 40 shows that in the urban area in principal the total revenues for the electricity supplier are increasing with an escalating market penetration rate. And moreover it is illustrated that in all analyzed cases controlled charging yields to higher revenues than individual charging.

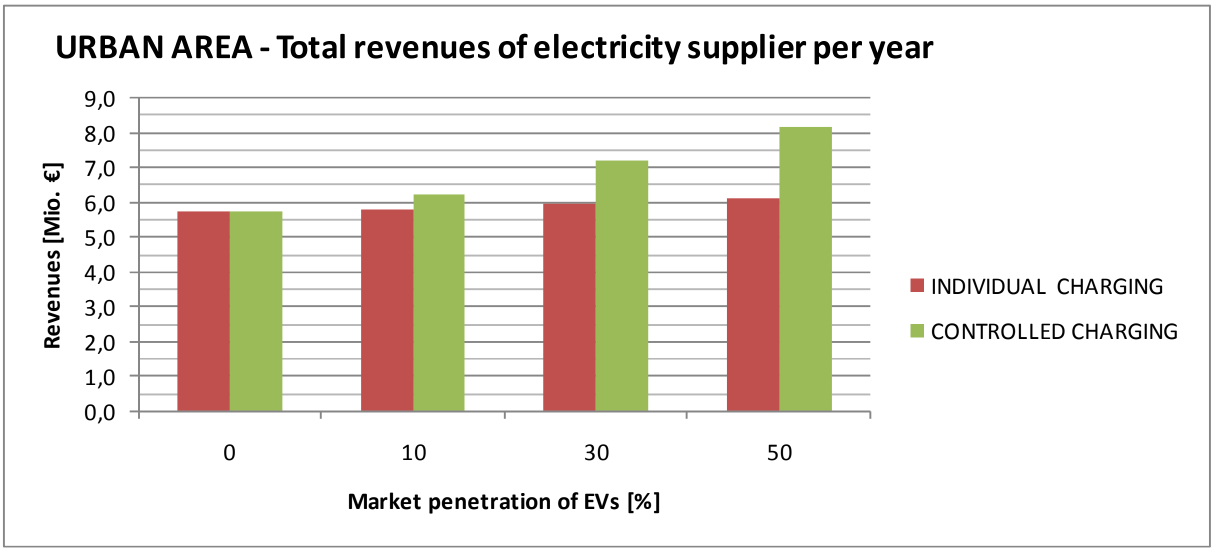

Figure 40 Total revenues of electricity supplier in the urban area

In detail, € 419.200 more revenues due to controlled charging for a 10% market penetration and € 1.258.000 for the 30% market penetration case are yield. The highest delta revenues of the four calculated cases are occurring at 50% market penetration with € 2.095.400. These findings are now broken down on the 11925 households in the urban area, as shown in Figure 41. Caused by the increasing delta revenues due to controlled charging, the revenues per household get bigger too.

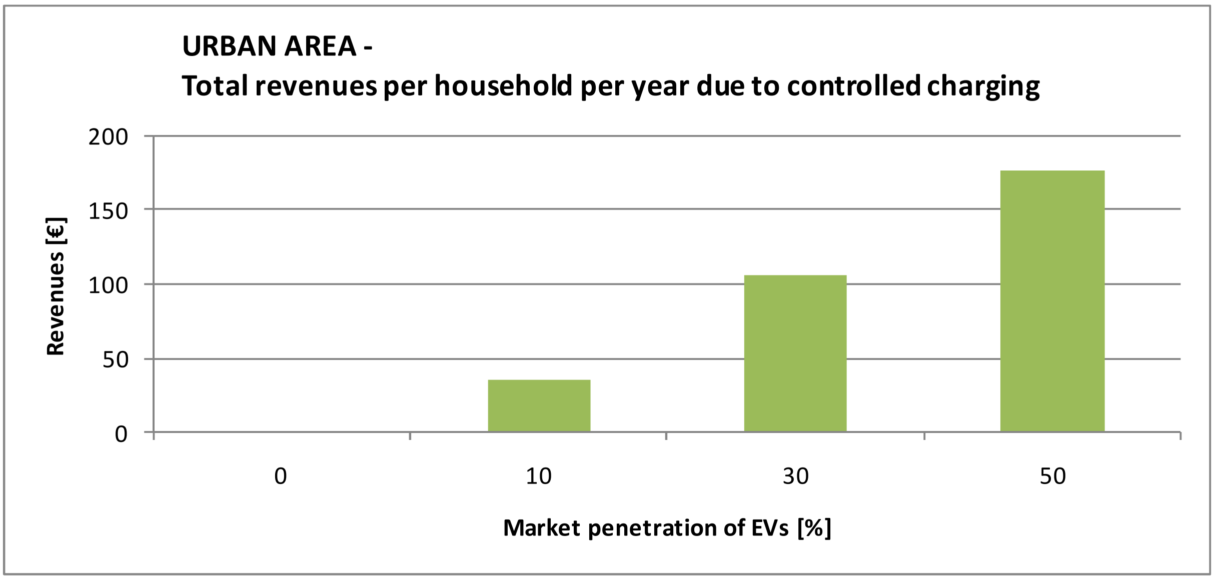

Figure 41 Total revenues of electricity supplier in the urban area per household

The revenues due to controlled charging are increasing for higher rates of market penetration and to get an idea of further occurring market penetration rates, a linear approximation of the results like before in chapter 7.1.1 is made.

$$R_{Energy\ Supplier} = 3{,}53 * MP + 0{,}25 \qquad (16)$$

This linear approximation, described in equation (16) shows maximum revenues at the 100% market penetration rate of € 353. This is almost just the half of the results for the urban area, but this caused by the higher generation in the rural area than in the urban one, the import/export energy in the rural area is higher than in the urban one, already for the BAU scenario. Therefore in the urban are more electricity has to purchase to balance the demand in area. The appropriate characteristic of further market penetration rates illustrates Figure 42.

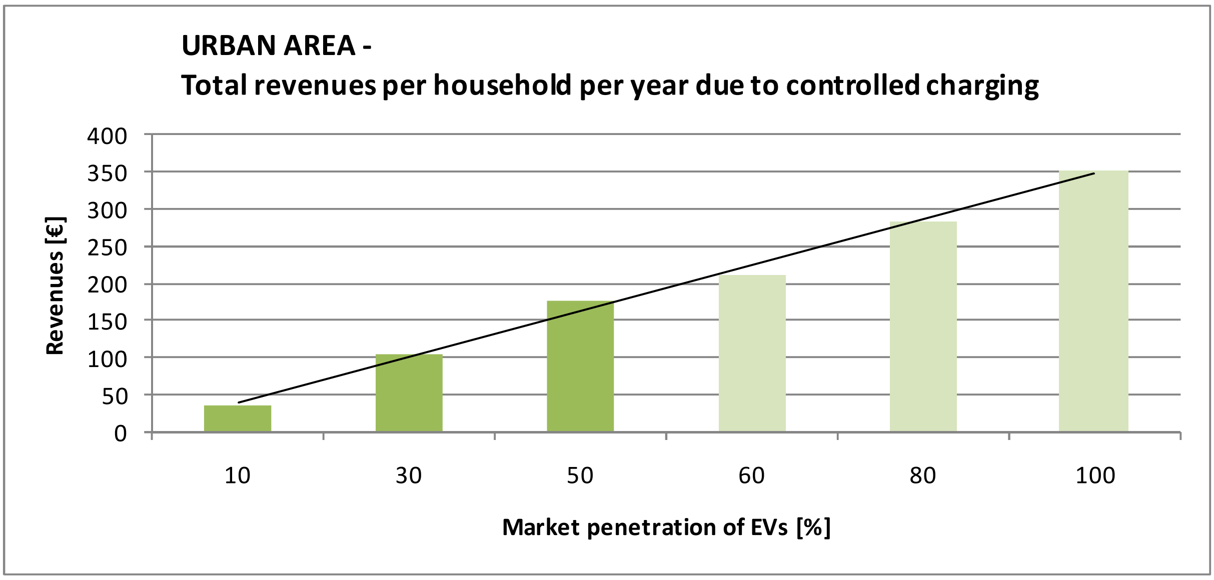

Figure 42 Linear approximation of revenues per household for further market penetration rates

With the maximum revenues of € 353 at the 100% market penetration rate, no high economic incentives to invest in the controlled charging infrastructure are given for the electricity supplier, if the home stations cost € 620 per piece. (Chapter 7.1.1. - Installation needs for G2V concept)

In the urban case it is not even economic for the electricity supplier to invest in these home terminals when the customer himself provides the internet connection. Therefore costs cannot be covered until a theoretical market penetration rate of 106%. This means an increase of the EV fleet would be necessary with the current business model.

7.1.3.Identified differences

In Table 14 the identified differences concerning revenues and market penetration rates in the two different areas can be seen. Generally it is to say that in the rural area the home terminals can be financed with the existing EV fleet. With the described linear approximation in equation(15, the exact market penetration rates for the terminals can be calculated. Only for the home terminals a founding is already feasible at 25% market penetration, for the home terminals including an internet connection a market penetration rate of 95% is needed to be economic in the first year.

Contrariwise, in the urban area the revenues of the maximum existing EV fleet are not enough to cover the costs of the home terminals in one year. The reason therefore lies in the smaller revenues gained in the urban area than in the rural one, caused by the cost occurring on the electricity market. For the home terminals without an internet connection 106% market penetration would be necessary and for the home terminals with internet connection even 175% market penetration would be needful.

Table 14 Necessary market penetration rates to cover the costs of home terminals

	Market Penetration Rate [%]	
	Rural Area	Urban Area
home terminal incl. internet	95%	175%
home terminal excl. internet	25%	106%

7.2. Grid evaluation results

In this chapter the maximum founded capacity values appearing in the different market penetration scenarios in the grid are going to be assessed.

7.2.1. Rural area

The maximum grid capacity is constrained to the developing demand including the demand of EVs and the power of generation. Here in the rural case the generation shows in total always a higher grid capacity needs than the demand including the demand of the EV fleet for all market penetration scenarios. So the calculated maximum grid load of 430kW in the BAU scenario is also valid for all other market penetration scenarios like shown in Figure 43. Therefore no advantages can be found due to controlled charging in the rural area.

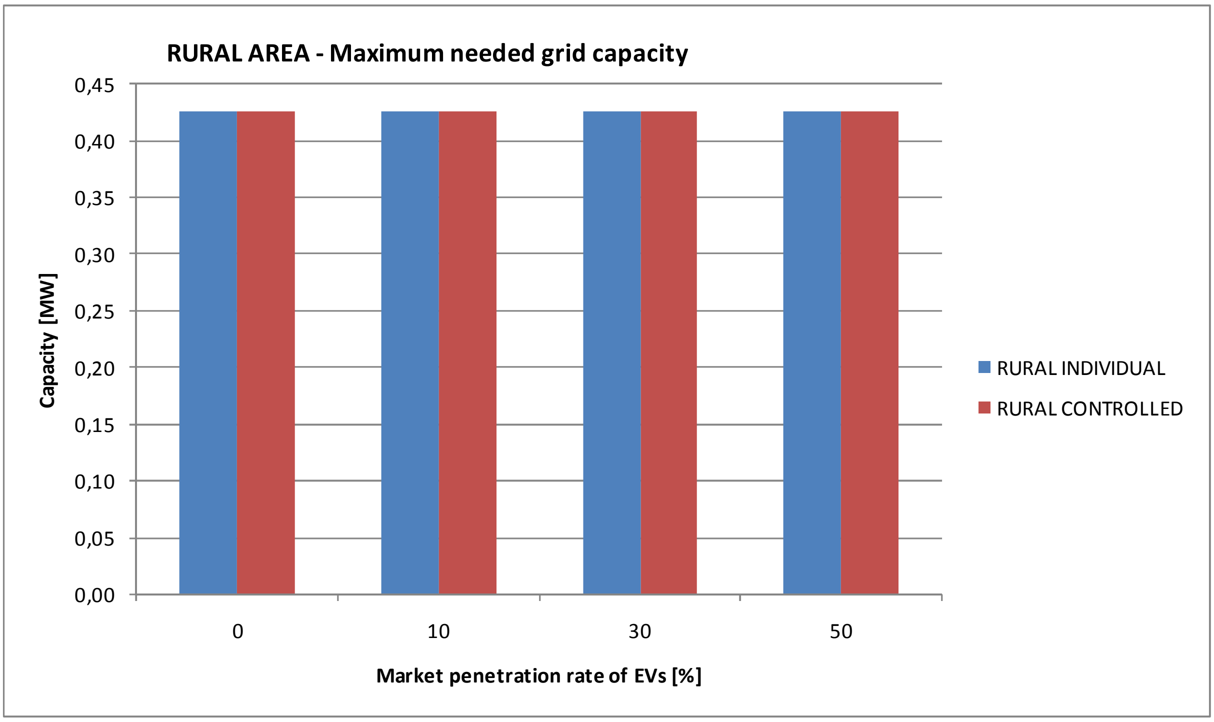

Figure 43 Maximum needed grid capacity in the rural area

7.2.2. Urban area

In a first step the grid load for the urban area is calculated without an additional load caused by EVs. As it can be seen in Figure 44 this general maximum grid load lies at 850kW per quarter of an hour. Then the grid load is increasing with the escalating market penetration rate until the maximum value of 3,9 MW at 50% market penetration is found.

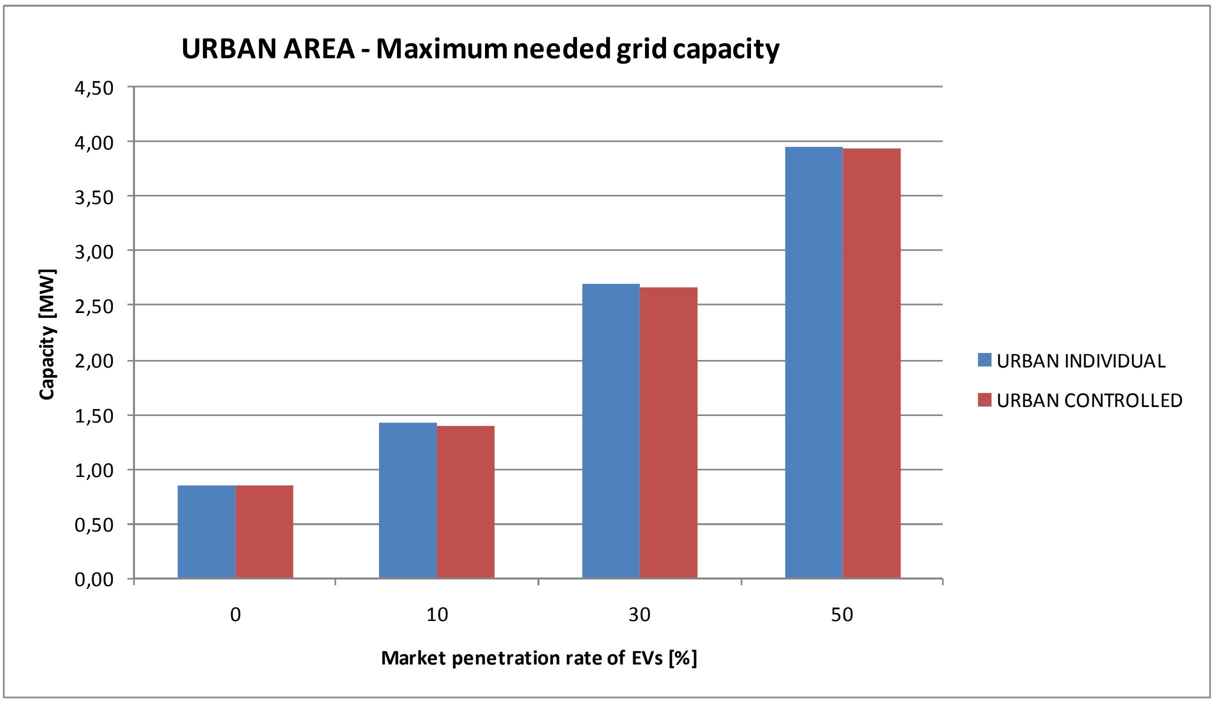

Figure 44 Maximum needed grid capacity in the urban area

The maximum values of the grid load is in the urban area always caused by the total demand implying the general demand and the demand of the EV fleet. This is valid for both, the individual and the controlled charging case.

Moreover it is illustrated in Figure 44 that there are not big advantages occurring due to the controlled charging case compared to the individual charging case. Although the controlled charging is modeled with the valley filling method, the maximum grid load of the EV fleet is for the various market penetration rates fairly equal and the averaged diminished grid load due to controlled charging lies at about 26kW. An explanation therefore can be found in the chosen starting times for both charging strategies. In the individual charging strategy the second charging date is at 5.30 pm shortly before the main demand peak in the H0 profiles occur. Because of the briefly lasting charging times not much overlapping of these two demand peaks happen. On the other side, the controlled charging strategy has its second starting date at 9.00 pm, where purchasing energy is cheap. But this date is shortly after the demand peak of the H0 profiles (Figure 28), and so an equal situation like in the individual charging case occur. So the before mentioned difference of 26kW emerges.

Charging at best and worst case

Since these chosen starting times do not image the worst and the best possible case for the grid, an additional analysis has been made. Therefore the generation and demand mix in the urban case for an average day in January has been used. It is assumed that in the best case, all EVs user plug in their cars at 2.00 am, when the gird load of the H0 profiles is smallest. On the opposite, for the worst case it is assumed that all EVs are plugged in at 7.30 pm when the grid is already used to the maximum. The characteristics for these examinations are shown in Figure 47 - Figure 49 for the best charging case, and in Figure 50 - Figure 52 for the worst charging case. For both cases, a linear approximation of the grid load is done and the belonging characteristic show Figure 45.

For the best case the following equation for the linear approximation is found:

$$P_{Burden_{BEST}} = 0{,}12 \, * MP + 0{,}29 \qquad (17)$$

$P_{Burden_{BEST}}$ ... Maximum grid load at the best charging case [MW]

And for the worst charging case the approximation in equation (18) is valid:

$$P_{Burden_{WORST}} = 0{,}12 \, * MP + 0{,}8 \qquad (18)$$

$P_{Burden_{WORST}}$... Maximum grid load at the worst charging case [MW]

In both cases the gradient of the straight lines are the same size, the linear functions are just differing through the offset at the beginning. How this offset emerges show Figure 46. So it is clear that the delta grid load (load of worst case minus the load of the best case) is more or less the same for all market penetration rates. Small deviations are occurring only because of the nominal distributed starting time allocation. So an average over the founded delta grid load values for the market penetration of 10%, 30% and 50% is made. This leads to an averaged delta grid load between the worst and the best case of 483kW.

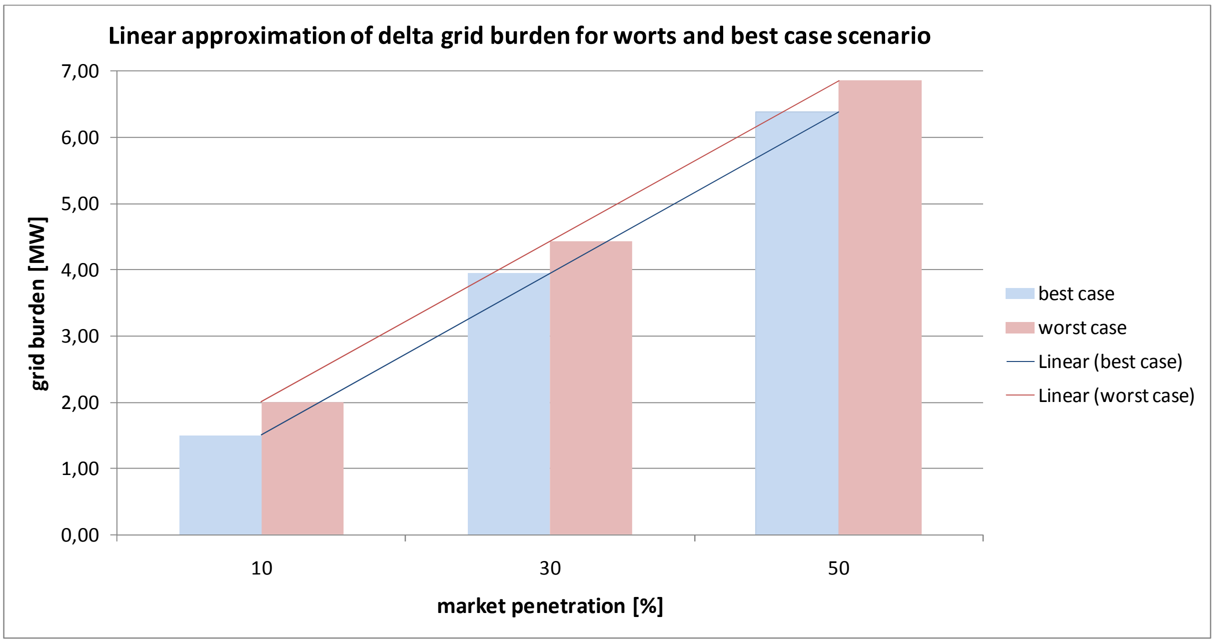

Figure 45 Grid load of worst and best case scenario for a typical day in January

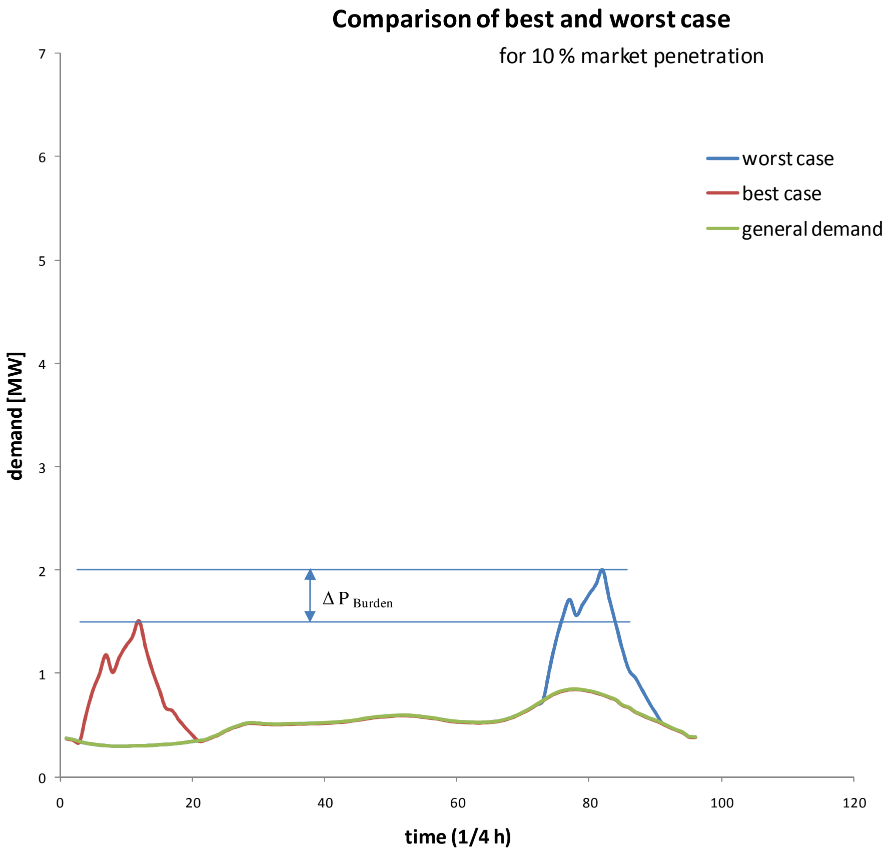

Figure 46 Comparison of best and worst case for one starting time of the EV fleet

It is important to consider the necessity to expand the grid so the additional load can be covered. The grid expansion costs therefore can be evaluated with 160 €/kW, according to [2]. Hence for the worst case scenario additional averaged costs, based on the averaged 483kW for the extra delta grid load are calculated. This leads to € 77.331, - valid for all market penetration rates.

Best charging case for one starting time

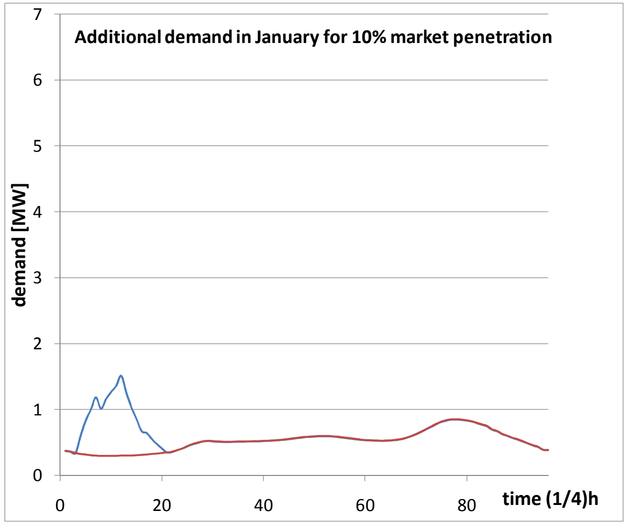

Figure 47 Best Case for charging with 10% market penetration

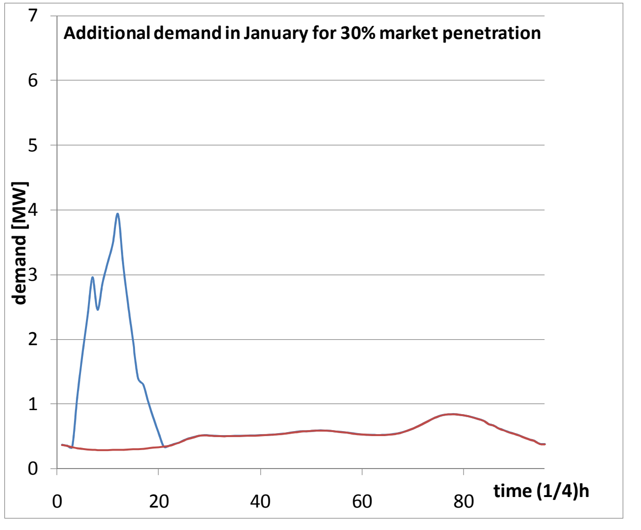

Figure 48 Best Case for charging with 30% market penetration

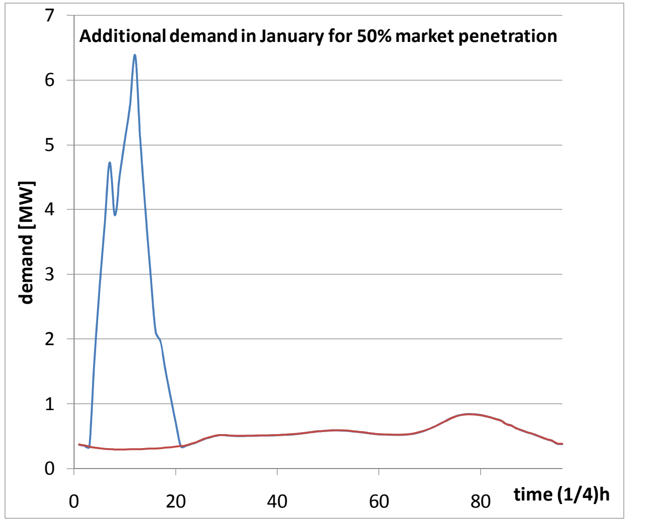

Figure 49 Best Case for charging with 50% market penetration

Worst charging case for one starting time

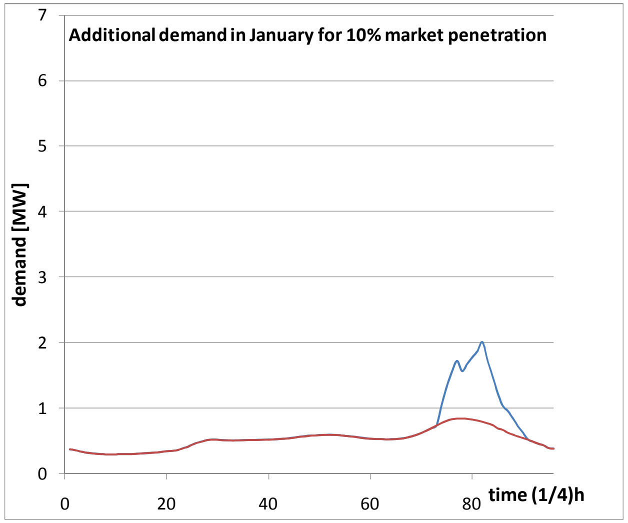

Figure 50 Worst Case for charging with 10% market penetration

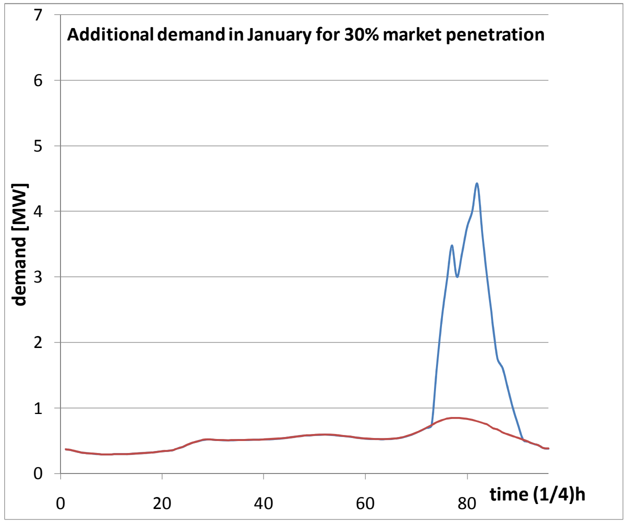

Figure 51 Worst Case for charging with 30% market penetration

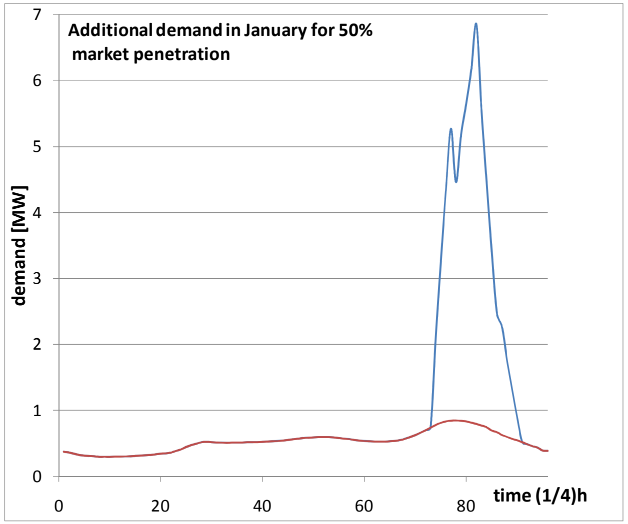

Figure 52 Worst Case for charging with 50% market penetration

3.1.1.Identified Differences

For the rural areas no profits can be found regarding the controlled charging strategy. Since the maximum grid load is only affected from the generation, which is mainly influenced by the wind power plant, the same maximum grid load for all market penetration cases accrue. So the generation is always higher than the demand in this area and this leads to a maximum grid load of 430kW.

On the opposite in the urban area another situation occurs. In this area, the maximum grid load is not caused by the generation, instead the demand inclusive the demand of the EVs is responsible. Thus different maximum grid load values occur for the various market penetration rates, the general demand in the BAU scenario lies at 850kW.

During the evaluation advantages due to controlled charging has been emphasized with the chosen starting times of chapter 4.4.2. But these benefits are quiet small, with 26kW. So a best and a worst charging case has been introduced for the urban area to show the greatest possible distinction concerning the grid load. Therewith bigger advantages caused by the best charging case have been proved. And due to the reason that the grid loads, of the best and the worst case expand linear, a difference grid load of averaged 483kW for all market penetration rates can be found.

4. Conclusions and outlook

The main objective of this thesis has been to identify economic benefits of controlled charging in comparison to individual charging of a selected EV fleet from an electricity suppliers' point.

The major conclusion from the technological perspective is that a battery size of 20kWh is mostly unnecessary for usual Austrian driving habits, the results prove. That is to say in virtually no case more than 20% charge are exceeded. This allows the opportunity of lower battery capacities in future applications (if applicable for customers), which could lead to lower investment cost as well as lower charging times. Another opportunity would be to use the remaining battery capacity for Vehicle to Grid strategies.

This leads to a different point-of-view for the utility and the user:

- In a continuative vehicle to grid strategy this "overcapacity" of the EV would be beneficial for the utility (especially if the battery is fully purchased by the vehicle owner), because it gets storage capacity for free.
- There is actually no advantage for the vehicle owner and in principal there is no incentive for him to purchase such large batteries.

Moreover, the starting times for charging the EV fleet have been derived as important criterions. As the extreme assumption of starting the charging of all EVs at one starting time has been implemented in an urban area even at an early EV market penetration rate of 10% an additional grid load occur. Thus, in the urban area given that there is no significant grid overcapacity, the grid has to be expanded already at 10% market penetration rate of the EV fleet, which will lead to grid expansion costs for the electricity supplier which are not considered in this work.

The economic evaluation shows that in the rural area the yield revenues split on households are for 10% market penetration €320, for 30% market penetration 390€ and € 460 for the 50% case. These revenues are increasing linearly until revenues of € 640 at 100% market penetration rate are reached. So in the rural area enough revenues can be gathered already in the first year to invest in the necessary infrastructure for the G2V strategy. These revenues are caused by the high domestic generation of the wind power plant in the area, which leads to revenues at the electricity market for sold energy. As a market penetration rate of 25% enables the supplier to purchase the before mentioned infrastructure, this G2V concept could be economic in the near future for the underlying assumptions of the thesis.

In the urban area a different situation occurs. At a market penetration rate of 10% revenues of € 35 are gained, for 30% market penetration revenues of €105 and €176 for 50% market penetration are possible per household. Due to a linear approximation, further maximum revenues of € 353 in the 100% market penetration rate are calculated. But in this case the yield revenues per household are too low to guarantee secure investments into a G2V infrastructure in the first year.

These findings are also very important to be considered for a next level of the analysis. Constructing on the already developed MATLAB model, an additional V2G analysis could be done. The necessary fields and arrays are already implemented in the graphical user interface. Additional to receiving electricity from the grid, with the V2G scenario it should be possible to deliver electricity to the grid, if needed at peak demand times.

Regarding the development in the near future the situation is as follows:

Several projects and studies are already ongoing in Austria on the G2V and V2G topic. Even model regions in Austrian cities are already introduced respectively are going to be introduced, using EV fleet. With these finding then it would be possible to compare the model findings with real results of the areas and to adopt the input parameter to make them useable for further more realistic investigations.

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Appendix

Table 15 Paper 3: Vehicle-to-Grid power implementation: From stabilizing the grid to supporting large-scale renewable energy *[1]*

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
Vehicle-to-Grid power implementation: From stabilizing the grid to supporting large-scale renewable energy	• capital costs • costs of electricity • number of units	***EV***: idle time: 23,04h per day ***Battery***: capacity: 15 kW lifetime: >3000h ***Renewable Energy***: Photovoltaic & Wind ***Concerning Utility, EV and Light Vehicle Fleet (LVF):*** number of units average unit power total system power time of in-use response time capital cost cost of electricity	***Aim:*** The aim is to calculate the amount of V2G necessary to stabilize large-scale solar electricity for peak power and large-scale wind base load power. ***Resume:*** In short terms EVs should be tapped for regulation and spinning reserves (3% of the fleet can serve it). Later EVs can serve markets for peak power and storage for renewable electric generation. ***Future Work:*** The prospects of V2G are to function as storage for renewable energy, for low pollution and to get more independent from petroleum.

Content:

The paper assumes that there is a hypothetical fleet of EVs, which is 25% of the today's light vehicle fleet in America. (44.000.000 EVs). On the one hand it is operated with the Plug in Hybrids (PHEV) which have a connection to the grid and therefore are important for the vehicle to grid (V2G) concept. On the other hand there is the power market concerning V2G, which is divided into base load peak, spinning reserve and regulation and for the future, not now formalized, is storage and backup power for renewable energy. Now the paper introduces different business models to cope with different V2G possibilities.

1) In the first one the electric utilities would buy V2G energy from hundreds of individual PHEV owners and then sells the energy in 1MW blocks back to the regional power market).

2) An independent party serves as the aggregator of individual vehicles (e.g. an automobile manufacture or a battery manufacturer/distributer).

The most import renewable sources are photovoltaic (PV) and wind turbines, whereas PV has a fairly predictable daily cycle, but wind turbines are more complicate to handle.

Results:

It's suggested by the study, "*that optimal vehicle support for the pattern of shortfall events would be storage from battery or hybrid in battery mode for the most frequent and low-energy shortfalls and back up form the fuel cell or hybrid in motor-generator mode."* So V2G can be the missing piece of the system that enables renewable energy sources to provide the needed energy.

Moreover it is assumed that in near future EVs should be used for high-value, time critical services (regulation and spinning reserves), which can be maintained by 3% of the fleet. Later V2G can serve markets for peak power and can be used as storage for renewable energy.

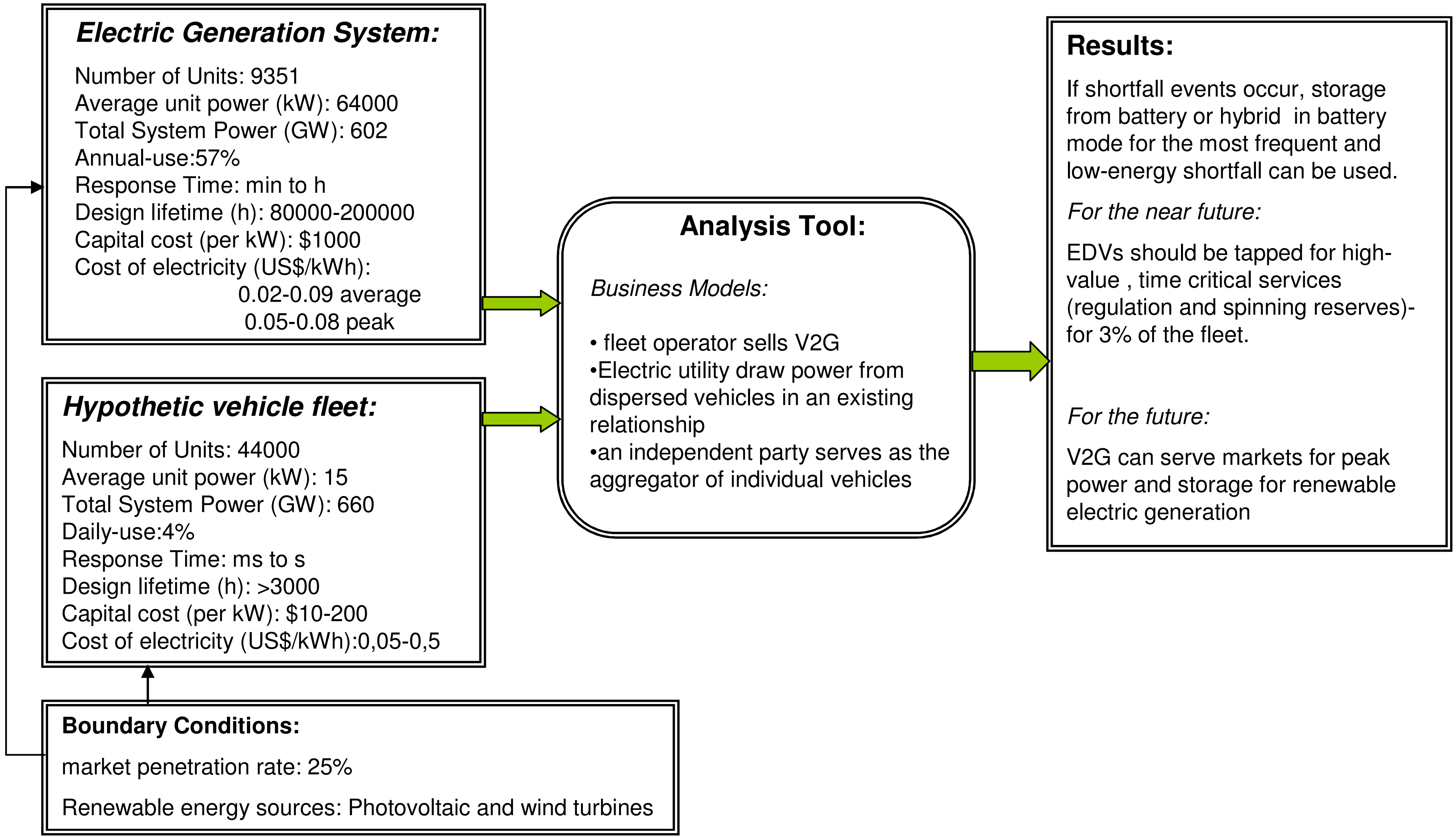

Figure 53 Conceptual function of paper

Table 16 Paper 4: Plug-in hybrid electric vehicles and environmental beneficial load building: Implications on California's revenue adjustment mechanism [24]

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
Plug-in hybrid electric vehicles and environmental beneficial load building: Implications on California's revenue adjustment mechanism	• Greenhouse gas emission (GHG)	***EV***: range PHEV20 & PHEV40[17] ***Producer data***: California	***Aim:*** What's the best way to reconcile the increase in electricity demand and subsequent increase in power-sector GHG emissions due to PHEV penetration in the utility sector under California's regulatory structure? ***Resume:*** PHEVs will result in lower system-wide greenhouse gas emission in California but there are policies and regulations, which discourage the PHEV penetration. ***Future work:*** The State of California has to examine possible mechanisms for providing incentives to the utility sector. (e.g. creating a separate rate class for PHEVs)

[17] Plug in Hybrid electric vehicle (PHEV): a vehicle with an internal combustion engine (ICE) and significant battery capacity

Vehicle to Grid capability (V2G): the possibility for PHEVs to get electricity from the grid

Content:

The advantage in using PHEVs are the

- System benefits, electricity is a more efficient fuel than gasoline or diesel
- Consumer benefits, spending on gasoline can be reduced by $800 per year
- Electric utility benefits, with a market penetration of 50% the total required energy for fleet charging will be about 10-20% of regional electricity generation.
- Mobile storage, PHEVs with V2G capability represent distributed mobile energy storage that is financed by the vehicle owner
- Load flattening, thereby the demand created by PHEVs will help to fill in the overnight valleys in the load curve
- Firming intermittent renewables and ancillary services, the storage capability of PHEVs could help balance the normal fluctuation of demand and intermittent renewable supply.

In California are laws and regulations that impact utility benefits from PHEVs and V2G, like

- Greenhouse gas emission reduction policies
- Investor-owned utility and transportation GHG regulations (low-carbon fuel standard - 10% reduction in the carbon intensity of vehicle fuels by 2020)
- Electricity efficiency policy

Results:

However, assuming a 30 % penetration rate of PHEVs by 2020, the transportation sector's GHG emissions are reduced by 22 million metric tons, but the electric sector's emissions are increased by 6 million metric tons. PHEVs will guide to lower GHG emissions in California, but existing California policies and regulations may discourage the electric utility sector from supporting the implementation of PHEVs, so there has to be a change in the Californian law.

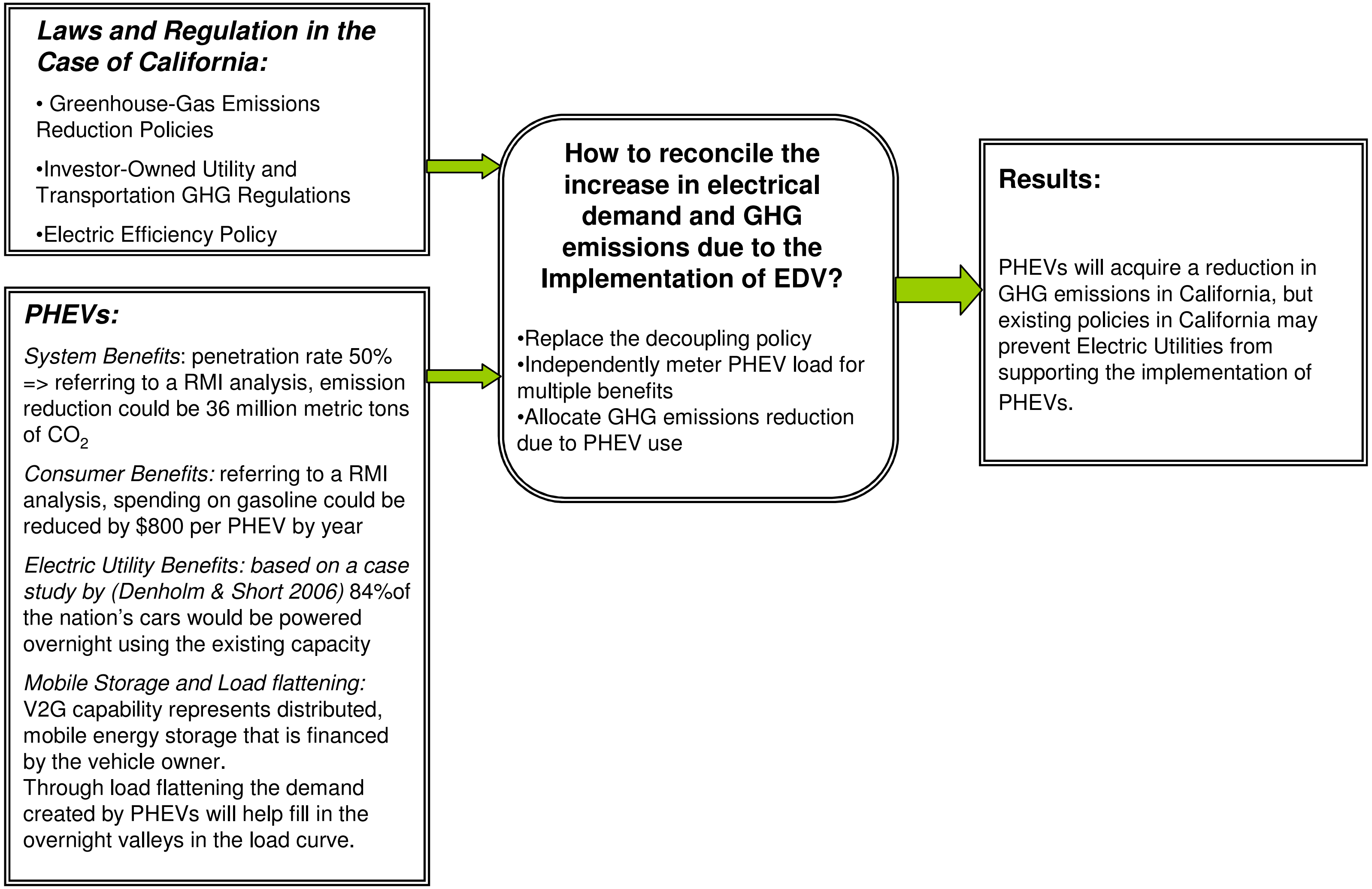

Figure 54 Conceptual function of paper

Table 17 Paper 5: Potential impacts of plug-in hybrid electric vehicles on regional power generation [26]

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
An evaluation of utility system impacts and benefits of optimally dispatches plug-in hybrid electric vehicles	• LDC • ***Model used***: PHEV-load Tool • average capacity factor (PPL) 60% • load serving capacity • battery capacity • PHEV plug-in factor • maximum circuit capacity • discharge time • market penetration 40-50% • reliably plugged in at planning time • average battery SOC at peak • discharged time required for dependable capacity • base dependable capacity (kW per PHEV)	***EV***: range: PHEV20-PHEV40 ***Demand data***: Midwestern US utility ***Supply data***: Utilities in America	***Aim:*** To evaluate the effects of optimal PHEV charging under the assumption that utilities will indirectly or directly control, when charging takes place, providing consumers with the absolute lowest cost of driving energy. ***Resume:*** Large-scaled deployment of PHEVs just has a small impact on the electrical power system in terms of additional generation requirements. ***Future work:*** Analysis of the synergism between distributed PHEV energy storage and intermittent renewables.

Content:

The paper evaluates the effects of optimal PHEV charging under the assumption that utilities will indirectly or directly control, when charging takes place, providing consumers with the absolute lowest cost of driving energy. Therefore six American regions are reviewed. In these six regions the electricity demand of hypothetical fleet is added to the given load duration curve under an optimal charging strategy. Dependent on the case, PHEVs are between a range of 20-40 miles.

The base case assumption comprises overnight charging during periods of least-cost electricity. The PHEV load tool uses a valley-filling algorithm, which adds load when the demand is lowest.

Results:

The impacts of PHEV charging are concluded as follows; with 50% penetration rate the optimized charging has increased the minimum overnight load and flattened the load curve during this time period. PHEVs are just addressable for traditional peaking capacity, but only if it’s cheaper for utilities to pay for vehicles instead of a conventional generator.

For each of the six American regions occur an increased electricity demand (5-10%), due to differing base demand and per capital transportation demand.

Moreover PHEVS can be used for “super-peaks”, and therefore reduce the adoption of older peaking units with high emissions and low efficiency.

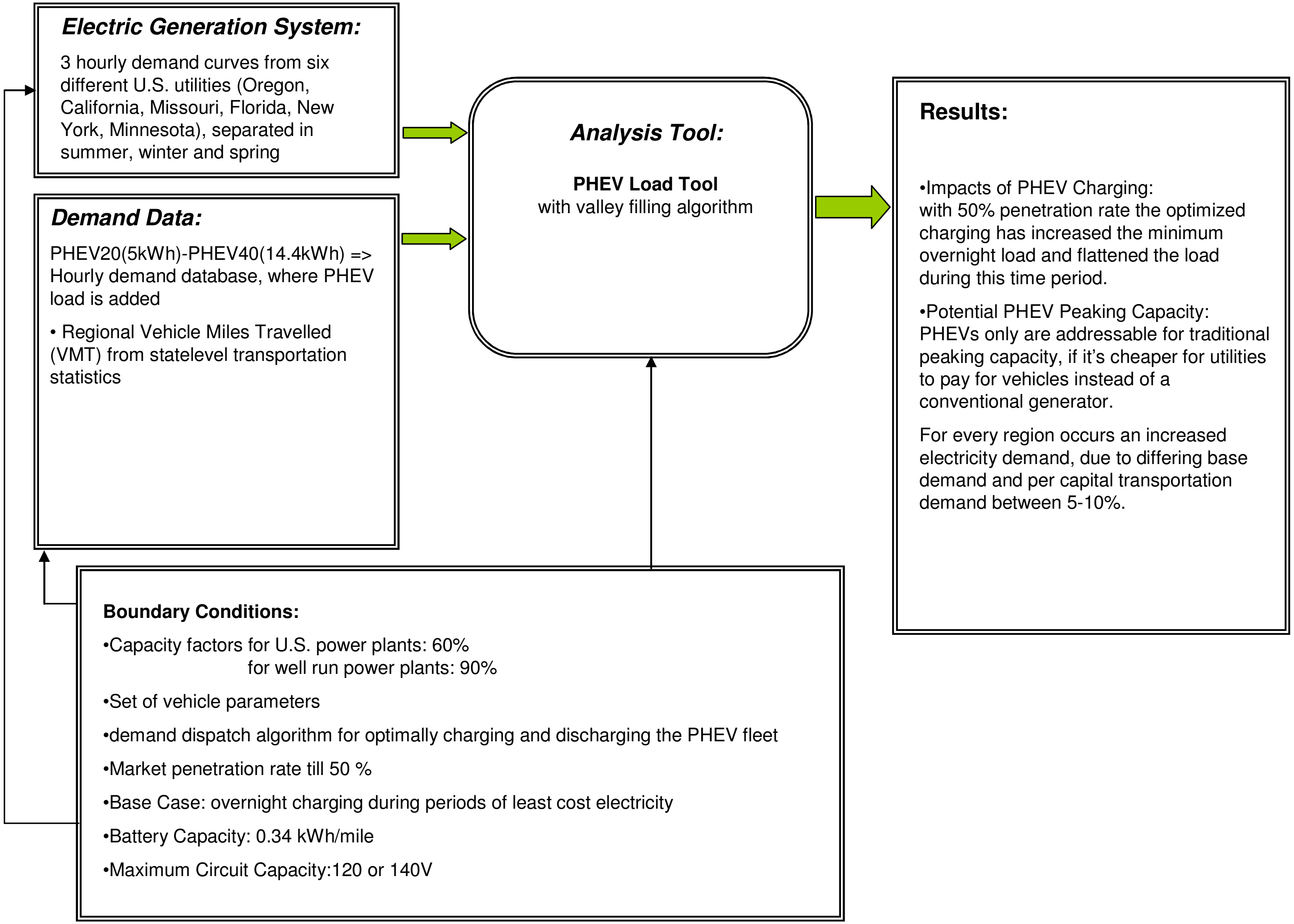

Figure 55 Conceptual function of paper

Table 18 Paper 6: A preliminary assessment of plug-in hybrid electric vehicles on wind energy market [27]

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
A preliminary assessment of plug-in hybrid electric vehicles on wind energy market	• ***Model used***. WinDS Model (Wind Deployment System) • market penetration (50% by 2050) • PHEV plug in factor • maximum circuit capacity • energy constraint • S.O.C • *financial data:* Inflation rate 3% real discount rate 8.5% tax rate 40% debt ratio 0 real interest rate 0 nominal interest rate during construction 10% • load growth • capacity requirement • wind resources • emission rates • fuel prices • outage rates	***EV***: range: PHEV20 (5.9 kWh battery) PHEV60 (17.7 kWh battery) idle time: 19,2h per day drive efficiency: 0,29kWH/mile charging efficiency: 85% ***Supply data***: 136 PowerControlArea	***Aim:*** The paper shows the synergism between plug-in hybrid electric vehicles and wind energy. ***Resume:*** PHEVS could be a significant enabling factor for increased penetration of wind energy, but only with higher capacity than with PHEV20. The PHEV60 case results in more than a doubled installed wind capacity, as well as decreasing electric sector carbon emission. ***Future work:*** A better representation of driving profiles for LDVs, better driving profiles for PHEV charging profiles and an estimation of regulation reserve benefits provided by PHEVs

Content:

First of all the study oppose the state of the art of wind technology to PHEVs. It's shown that the optimal solution for wind could be to couple it with PHEVs, which will work as low cost source of energy storage. A base case scenario is made, where valid energy policies of the year 2005, in America, has been taken into account. The WinDS model uses data from the U.S. Energy Information Administration's Annual Energy Outlook without PHEV penetration. This base case is later used for comparison. The next step is the introduction of PHEVs with a market penetration (up to 50% till 2050), a plug-in factor of 50%, and a maximum circuit capacity of 9.6kW. So the capacity value can be calculated as follows:

"Vehicle capacity = The minimum of line capacity or battery energy (kWh)*S.O.C. * plugged-in/discharge time required (h)"

So in the first case PHEV20 s are used and in the second case PHEV60s are used.

Conclusion:

The paper doesn't take the economics of the PHEVs into account, so the conclusions are restricted, but through the different cases, several findings can be drawn:
First in the PHEV20 scenario, wind installation increase up to 235GW by 2050 and the 50% penetration rate results in at least 25% reduction in oil based consumption for the U.S. LDV fleet. So with higher storage capacity than in the PHEV20 case, PHEVs can be used for increased wind supply.

Besides in the PHEV60 case the wind installation increases up to 443GW by 2050, but because of the reserve capacity provided by the PHEVs, there is hardly no need for conventional storage capacity anymore. Moreover the PHEV60 fleet is nearly carbon neutral. With the lager batteries in the PHEV60 case, there will be more per-vehicle reserve capacity

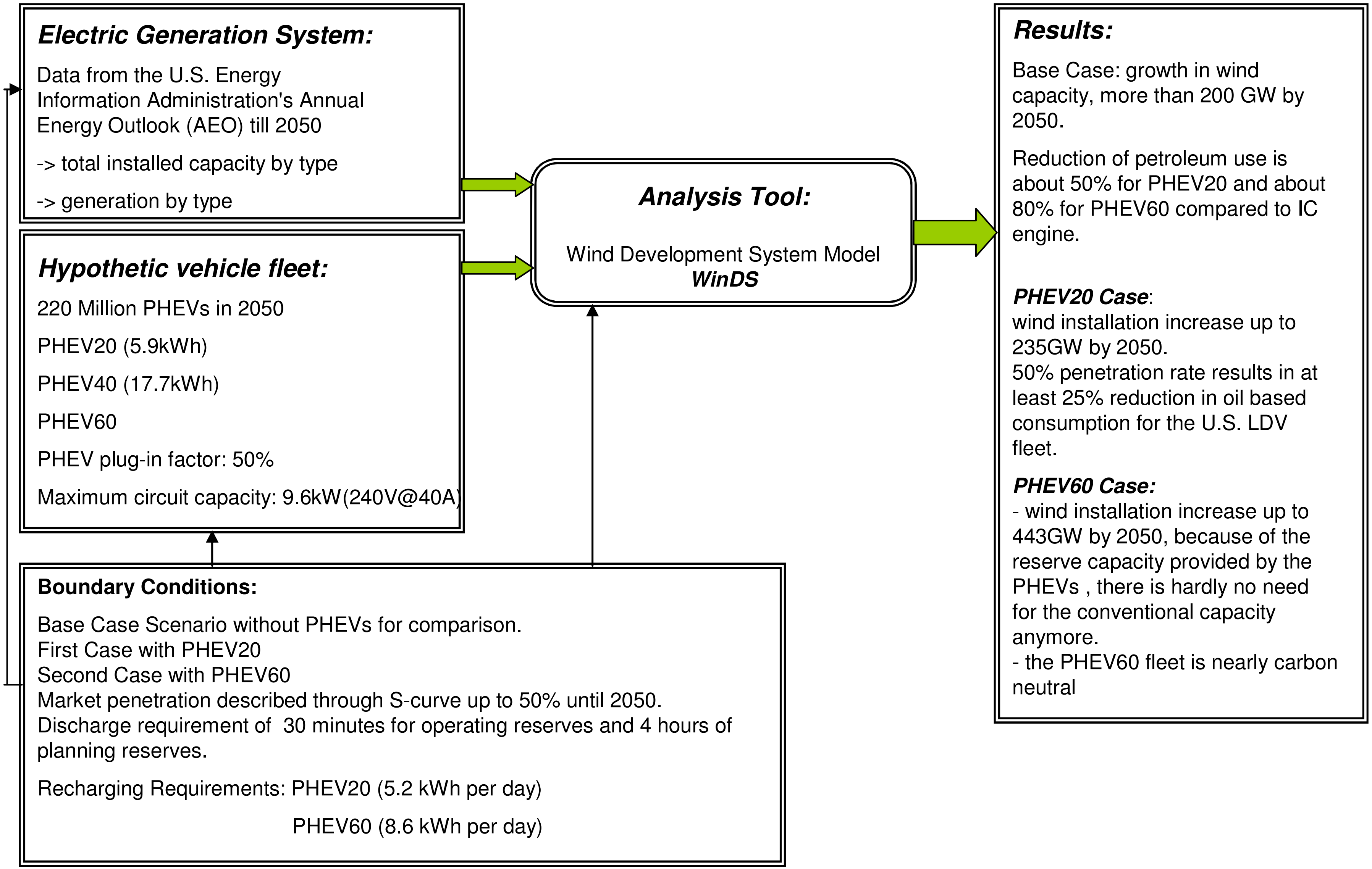

Figure 56 Conceptual function of paper

Table 19 Paper 7: Impact assessments of plug-in hybrid vehicles on electric utilities and regional U.S. power grids: Part1: Technical analysis [28]

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
Impact assessments of plug-in hybrid vehicles on electric utilities and regional U.S. power grids: Part 1: Technical analysis	• ***Model used***. GREET plant types/generation mix generation dispatch vehicle types • summer day • winter day • average load shape • "valley-filling" Methodology	***EV***: range: 33miles ***Battery***: capacity: 8,6-15,2 kWh ***System Load:*** 9 NERC Regions (2002) 3 WECC[18] Regions	***Aim:*** To estimate the regional percentages of the energy requirements for the U.S: LDV stock that could potentially be supported by the existing infrastructure. ***Resume:*** The existing electricity infrastructure has enough capacity to fuel up to 84% of the nation's cars or 73% of the LDV fleet for 33 miles per day. GHG emissions and some criteria emissions would be reduced based on total emission figures. Particular emissions would increase because of coal fired power plants. The gasoline consumption will be reduced by up to 6.5 MMBpd.

[18] WECC Western Electricity Coordinating Council

Content:

In this study, two different approaches have been made; first a life cycle cost-analysis which takes a variety of electricity prices, gasoline prices and alternative conventional vehicle efficiencies into account and second an analysis of the impacts concerning the costs of electricity as a response to a large scale market penetration of PHEVs without new investments (T&D).

1. *LCC Analysis*

The premium for the purchase of a PHEV in comparison to conventional cars as a Honda Civic with 35 mpg, a conventional vehicle with 27,5 mpg and a Toyota Prius HEV with 56 mpg is made. The price of gasoline varies between $2.5-$3.5 per gallon. The ***results*** for the above mentioned assumptions are now shown for the case of California and Ohio.

Case 1: PHEV versus a Honda Civic

- In California with an electricity price of 12 cent/kW and a gasoline price of $2.50 per gallon, the break-even point for the purchasing premium is $2000.
- In Ohio with lower electricity rates but with the same gasoline price as in California, is the purchasing premium $3000.

Case 2: PHEV versus a conventional vehicle

- In California with a electricity price of 12 cent/kW and a gasoline price of $2.50 per gallon, the break-even point for the purchasing premium is $3500
- In Ohio with lower electricity rates but with the same gasoline price as in California, is the purchasing premium $4600.

Case 3: PHEV versus a Toyota Prius

- In California with an electricity price of 12 cent/kW and a gasoline price of $2.50 per gallon, the break-even point for the purchasing premium is $0.
- In Ohio with lower electricity rates but with the same gasoline price as in California, is the purchasing premium $1000.

2. *Utility Analysis*

The revenues and cost effects of a 100% market penetration of PHEVs (charging at night – valley feeling) are investigated concerning the grid for 2003-2004. On two utilities is thrown light on, the Cincinnati Gas and Electric Company (CGE) and the San Diego Gas and Electric Company (SDG&E). Therefore it's important to know, that CGE generates more power than is needed, so the not needed energy is sold on a broader market. For CGE the power is supplied by steam electric power plants (coal or gas) and the generation profile of SDG&E only exist due to nuclear power plants.

Therefore three scenarios are made:

1) First a short run scenario where no changes occur in the two areas.

-2) Second a short run scenario with higher variable costs because of increased fuel costs is done. As to say doubled averaged costs in the CGE area and 50% rise of the averaged variable costs in the SDG&E area.

3) In a last step a long run scenario including investments in generation is made. In the CGE are a 600MW coal fired power plant of $750 million is build and in the SDG&E area a gas fired plant of $350 million is introduced

To sum up, it's to say that PHEVs can improve the efficiency for fixed capital and provide significant average cost savings for a wide variety of electric utilities. So the best condition for a successful introduction of PHEVs are on the one hand high fixed unit costs and low variable unit costs of generation and on the other hand spare off-peak capacity or the possibility to buy cheap purchased power.

1. LCC ANALYSIS:

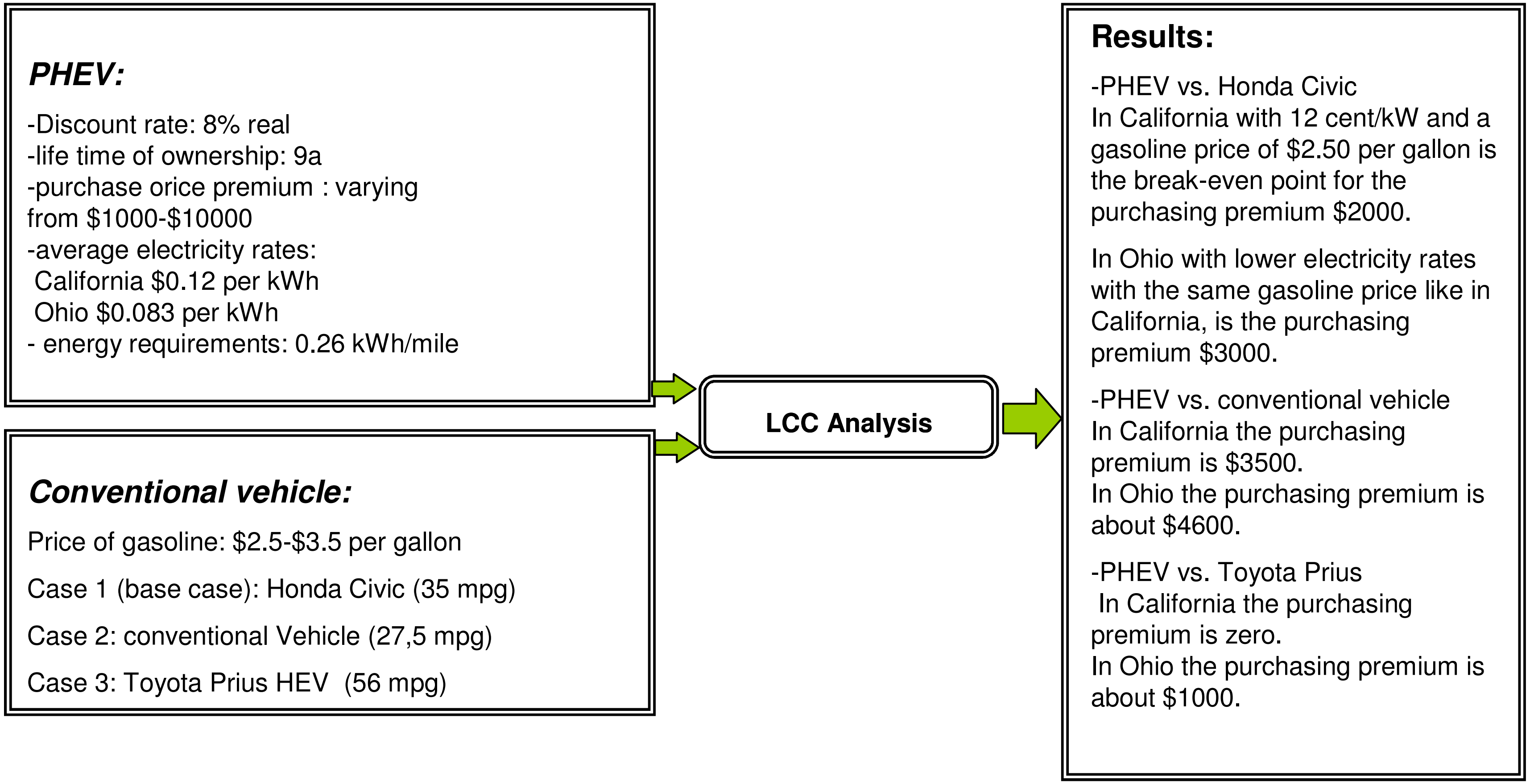

Figure 57 Conceptual function of paper, part 1

2. Analysis of Utilities

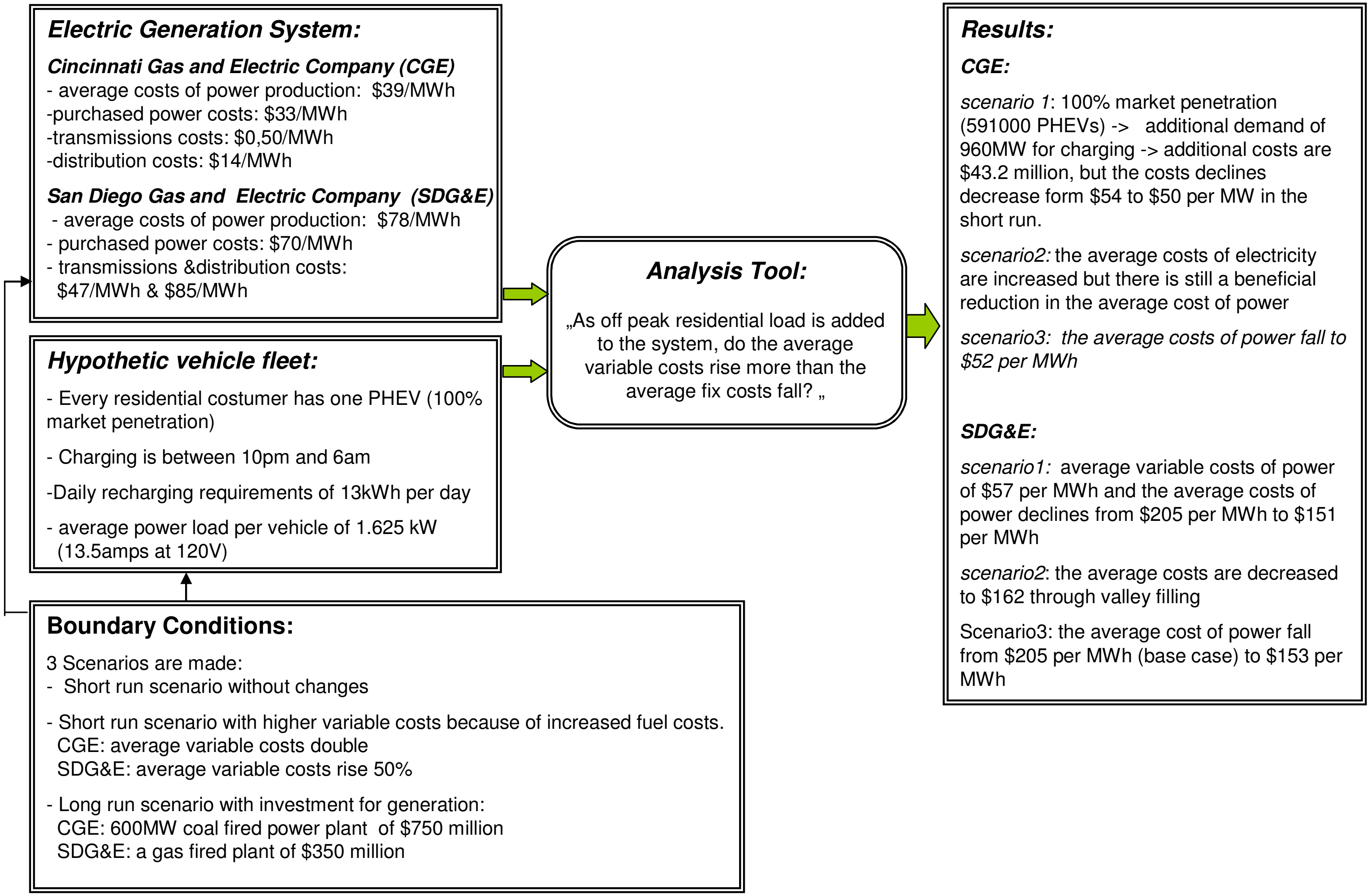

Figure 58 Conceptual function of paper, part 2

Table 20 Paper8: The impact of electric vehicles on the energy industry (Austrian climate research program) [29]

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
The impact of electric vehicles on the energy industry (Austrian climate research program)	• market penetration: 20% • vehicle groups (Passenger cars, two-wheeled vehicles, LDV) • travel purpose: Commuters business trips private shopping education leisure time • secured delivery time • degree of efficiency • emission factor • planed PP expansion	***EV***: ***Passenger car*** range: 200km capacity: 30kWh ***LDV***: range: 250km capacity: 50kWh ***2-Wheeled Vehicles***: range: 80km capacity: 4kWh ***Recharging time***: 7h ***Idle time***: 82% of day ***Electricity import share***: 5%	***Aim:*** To give an analysis of the impact those electric vehicles would have on the Austrian energy industry. ***Resume:*** 20% market penetration won't require the construction of further power plants. There will be need 16200 new electric vehicle charging points. Car emissions would be reduced to 40g/km. The carbon footprint would be reduced by 2 metric tons of CO_2. The introduction of EV would result in a positive net effect of appr. 1.3 billion €.

Content:

This study shows the impact of electric vehicles with a 20% market penetration rate will have on the Austrian energy sector. Therefore answers to the following questions have been made:

1) What are the impacts on Austria's electricity generation through charging EVs during off-peak periods at night?

2) What will be the impact on Austria's power grid?

3) Will there be a change of the Austrian carbon footprint through the introduction of EV?

4) What results are shown through an economic analysis, realized by a cost-benefit analysis?

A hypothetical electric vehicle fleet is installed, which consists of passenger cars (average range: 200km, battery charging capacity: 30kWh), LDVs (average range: 250km, battery charging capacity: 50kWh) and two-wheeled vehicles (average range: 80km, battery charging capacity: 4kWh)

Results:

A 20% market penetration rate would cause a 3% increased power consumption, therefore it's no problem for the actual power grid infrastructure, because it provides enough supply for the PHEVs. Due to the more efficient electric vehicles, the car emissions would go back to 40g/km and the carbon footprint could be reduced by 2 metric tons of CO2 (16% reduction). Moreover there will be a positive net effect of €1.3 billions, due to the introduction of EV. And because of the higher efficiency of electric vehicles, even the conventional assumption of a 20% penetration rate, would make an energy reduction of 8.4 TWh (37% of the energy efficiency target set for 2016).

Moreover you can see that the V2G technology has the potential to transform the energy and transport system, which includes;

- ✓ accelerating the uptake of new transport technologies
- ✓ reducing the installation of conventional peak generation capacity
- ✓ supporting the installation of renewable electricity sources
- ✓ and because of these reasons, helps to lower GHG emissions.

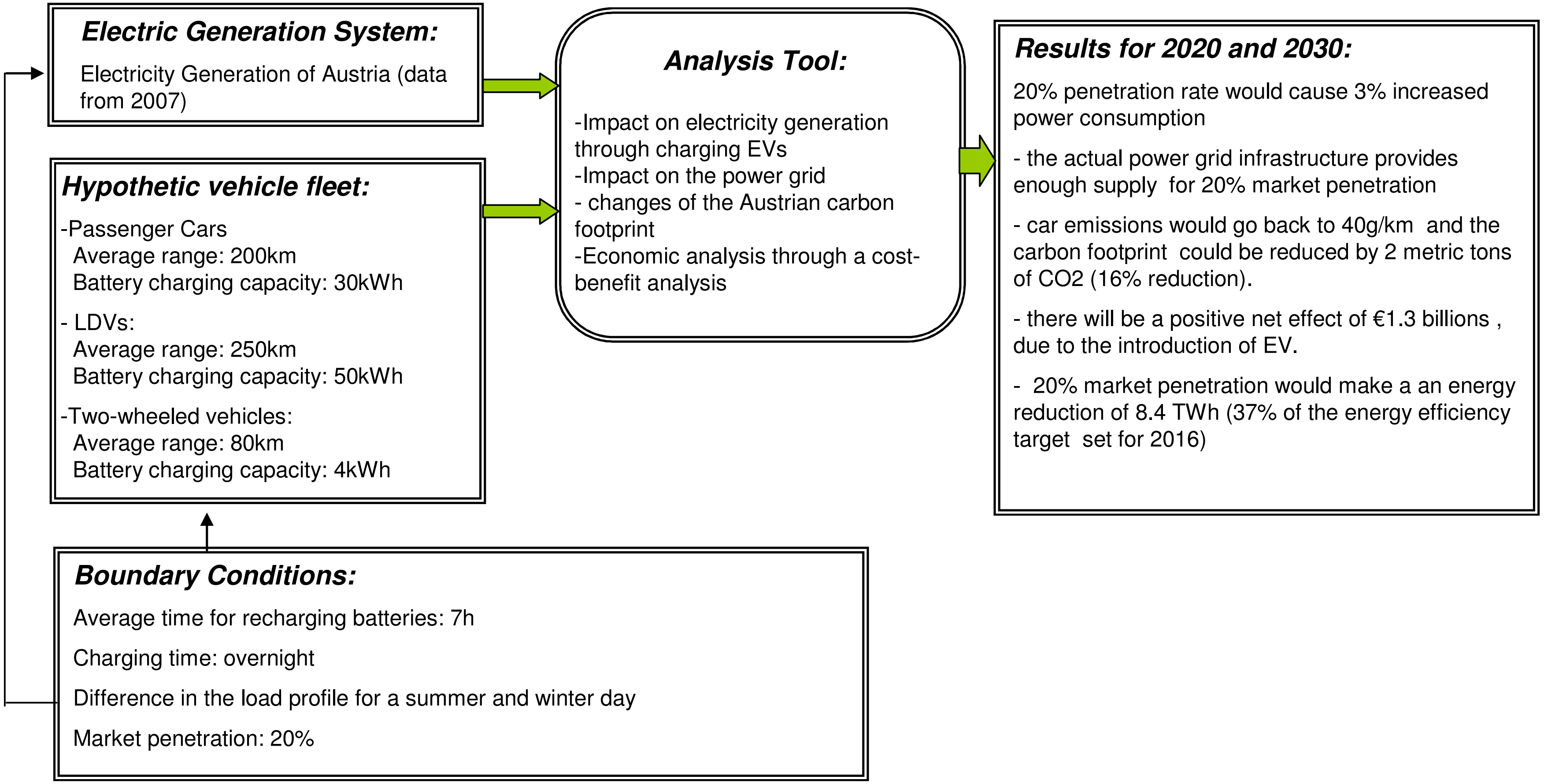

Figure 59 Conceptual function of paper

Table 21 Paper 9: Vehicle-to-Grid systems for sustainable development: An integrated energy analysis [30]

Paper/ Project	Used Parameter	Parameters for model region	Aim of Study/ Conclusion
Vehicle-to-Grid systems for sustainable development: An integrated energy analysis	• ***Model used***: ERIS (Energy Research and Investment Strategies) a long term, dynamic, bottom up, global energy system model • ***used submarkets:*** - covering regulation (up and down) - spinning reserve - peak power	***Basic V2G system:*** 6.6kW, 400$ ***Upgrade system***: 15kW, 1500$ ***EV lifetime***: 10a ***Idle time***: 12h per day	***Aim:*** Whether V2G technologies represent a potential opportunity to bring forward and accelerate a transition towards EVs by improving the commercial viability of new vehicle technologies. ***Resume:*** V2G technology has the potential to transform the energy and transport system, which includes: - accelerating the uptake of new transport technologies - reducing the installation of conventional peak generation capacity - supporting the installation of renewable electricity sources and because of these reasons, helps to lower GHG emissions. ***Future work:*** There will be required alternative methodological approaches including issues related to consumer, electricity market and regulatory acceptance.

Content:

This study is the first, which introduces a long term energy model till 2100, containing V2G and G2V technologies. Therefore the electricity system of each world region has to maintain the following three services

- 5% spinning reserve margin
- 10% regulation up and down margin
- 50% peaking margin

As input parameters for the ERSIN model, different V2G technologies were installed as wiring, metering, communication to the grid manager and safety systems. This will cost for a basic V2G system $400 (capacity: 6.6 kW) and for an advanced V2G system $1900 (capacity: 15kW).

Then four different Scenarios are implemented:

1) Baseline scenario without V2G technology
2) Baseline scenario with V2G technology
3) Climate policy scenario without V2G technology (tax of $500 per ton of carbon-equivalent)
4) Climate policy scenario with V2G technology (tax of $500 per ton of carbon-equivalent)

Results:

Baseline Scenarios

The scenarios show, that it’s possible with V2G to serve the following electricity markets: spinning reserves, regulation, peak power and non peak generation. V2G systems diffuse slowly early in the century. In the basic V2G system there is 1 V2G system for every 50 vehicles and 1 one for every 6.5 V2G capable vehicles, afterwards the market penetration accelerates to 0.8 systems per vehicle. Moreover it’s shown that in the Base Case scenario with V2G technology, the market penetration of new technologies increases earlier than in the no V2G scenario. The FCVs (Full Cell Vehicle) have a negligible impact in the scenario without V2G and just a small impact in the scenario including V2G (18% market shares in 2100).

Climate Change Policy Scenarios

Accelerating the uptake of new transport technologies, less installation of conventional peak generation capacity and supporting renewable electricity sources leads to lower green house gas emissions.

In general, GHG emissions are lower in the climate change policy scenario than in the Base Case scenario. And due to the implementation of V2G technology the GHG emissions decrease more than in the scenario without V2G.

The overall reduction in investment in the stationary power sector is around $2.8 trillion between the year 2000 and 2050.

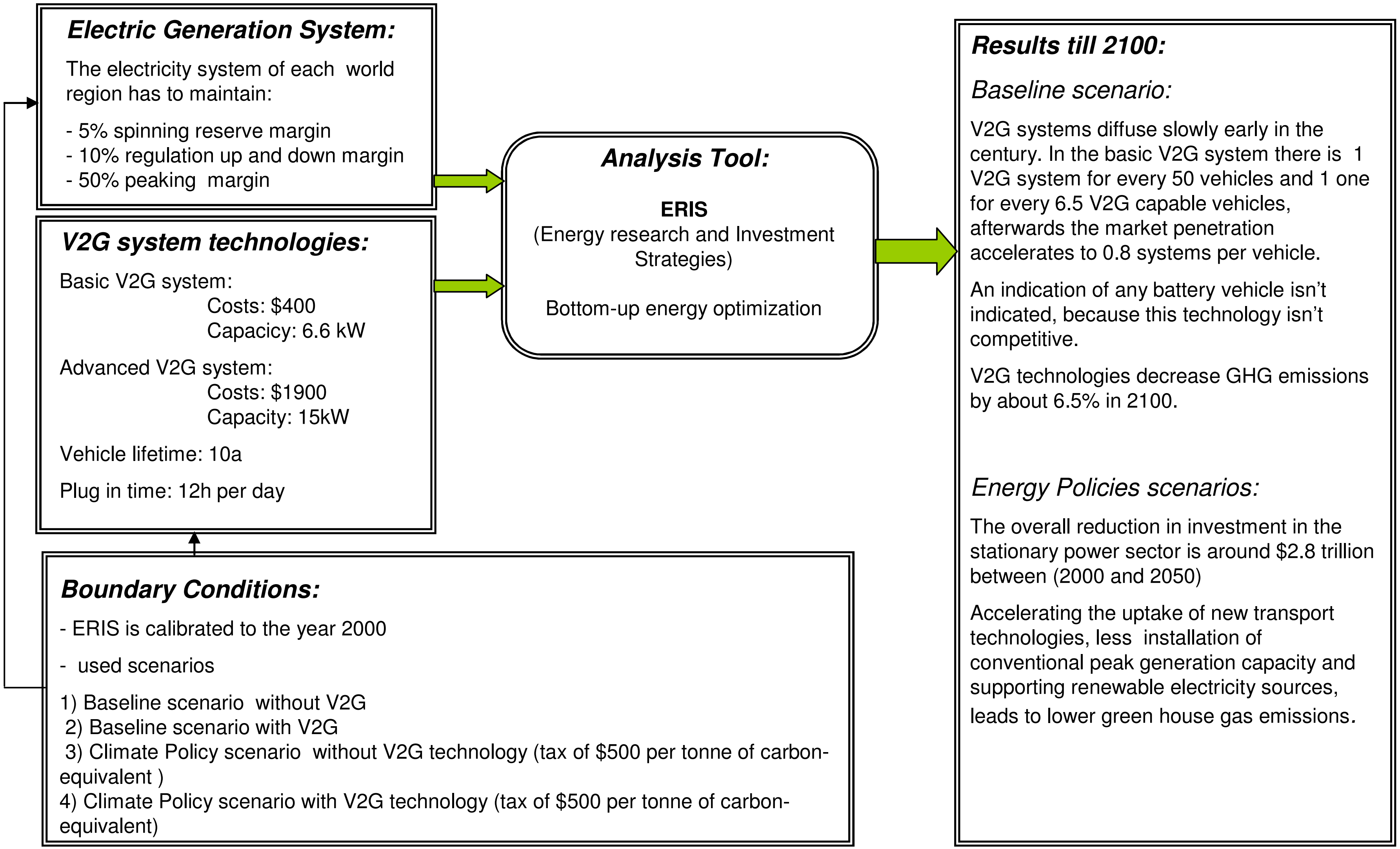

Figure 60 Conceptual function of paper