Revenue Potentials of Residential Prosumers with Inductive EV-Charging Infrastructure through Energy Management Modelling

H. Triebke
Mobility Concepts and Infrastructure,
Fraunhofer IAO,
Stuttgart, Germany
henriette.triebke@iao.fraunhofer.de

D. Borrmann
Mobility Concepts and Infrastructure,
Fraunhofer IAO,
Stuttgart, Germany
daniel.borrmann@iao.fraunhofer.de

***Abstract*—To achieve national climate protection goals, the decarbonisation of the transport sector is of primordial importance. However, the development of electromobility is still slowed down by high investment costs on one side and missing suitability for daily usage on the other.**

By means of wireless power transfer (WPT) through inductive coupling, the user comfort during the charging process can be increased significantly which leads to a wider adoption of electric vehicles (EV). Unfortunately, the contactless charging technology is still at an early stage of market maturity for domestic application. As a consequence, it cannot compensate the elevated capital costs by its additional benefits alone: On the one hand, comfort gain does not represent an economically determinable benefit and on the other, revenues from power factor correction are irrelevant for domestic usage.

All the same, the additional investment costs for inductive charging infrastructure can be amortised when taking fully advantage of the EV flexibility and the prosumer's local power generation. The present paper[1] therefore aims to identify necessary conditions for long-term profitability of residential prosumers with inductive EV-charging infrastructure by means of advanced energy simulations in Matlab/Simulink®. Primary purpose of this study is a comprehensive presentation to what extend wireless EV charging in home application can already be cost-effective in order to further promote electromobility.

Keywords— inductive charging; WPT; electric vehicle; V2H; photovoltaic; profitability; energy management; Matlab/Simulink®

I. Introduction

Inductive charging systems for electric vehicles are already available on the market in a large variety - providing charging powers from 3.3 to 7.2kW [1]. In the near future, charging powers up to 11kW are expected. The necessary technology is developed within the *BiLawE* project [2]. Nonetheless, wireless power transfer for EVs is still unattractive for various reasons. On the one hand, missing standardisation prevents EV owners from charging producer-independently at any inductive charging station. Overcoming this deficit is the main objective of the US-guideline *SAE TIR J2954* [3] and the project *STILLE* [4], where several automobile manufacturers and suppliers work together among others to harmonise frequency bands and coil dimensions to increase brand compatibility. On the other hand, wireless power transfer for EVs is still not attractive yet, as the price for the stationary part of the technology is already very high [5]. Depending on the installation site, such as private, semi-public or public areas, an inductive charging infrastructure is twice or even thrice as expensive as a conductive one [6].

Interestingly enough, financial competitiveness of inductive charging infrastructure compared to cable-based systems is claimed in [7] for the US market. Within the mentioned research, the capital expenditures of both technologies are broken down to the EV's annual mileage by means of rough estimate. However, the overly optimistic assumptions regarding investment and operating costs are considered the greatest deficiencies of [7]. Generally, there is a lack of reliable profitability assessments in literature for inductive EV-charging infrastructure. In contrast to this, evaluations concerning conductive systems have been done in great numbers, although they are often subjected to severe simplifications and regard only short periods of time.

For example in both [8] and [9], energy saving potentials for private households using V2H-flexibilities are calculated by MILP-algorithms which take advantage of time-based electricity rates in the first place. The first study comes to the conclusion that the absolute annual savings are not high enough to overcome the initial investment costs, even though the economies represent around 50% of the customer's bill. The second study features a higher accuracy by additionally considering local PV power production on one side and periodical EV availability on the other. As a direct consequence of the local power generation, considerable revenues are realised under the given conditions.

Nevertheless, both studies are unrepresentative in so far that (1) the mobility behaviour of the EV owner is assumed to be identical each day, (2) the simulation period is too short

[1]This work is sponsored by the project *BiLawE - bidirectional, inductive charging systems economically in the grid* funded by the German Federal Ministry for Economic Affairs and Energy within the framework of *ELEKTRO POWER II* in cooperation with Robert Bosch GmbH, GreenIng GmbH & Co. KG, Fraunhofer ISE and IAO

to account for long-term aspect such as seasonal effects, degradation or price increase, (3) the simultaneity of local power generation and consumption is not considered sufficiently as would be the case with time-series simulation, (4) the additional investment costs are only amortised by power savings whereas fuel economies are neglected completely, (5) no sensitivity analysis is carried out in order to assess the results' validity and (6) the outcomes are not transferable to the German energy market.

The present paper addresses those shortcomings by carrying out multiple long-term time-series simulations of a V2H energy network with non-fictive input data. To assess the prosumer's profitably accurately, the impacts of the following parameters are analysed in more detail:

- orientation and size of the PV system,
- battery degradation,
- electric vehicle type,
- annual EV mileage and
- energy price development.

In doing so, the influence factors with the strongest leverage effect on the prosumer's profitability are identified which permits a more focused R&D activity on one side and a better knowledge of the technology's ideal target group on the other. Moreover, along with the comfort gain through wireless charging, the evidence of its cost-effectiveness in specific use cases will leverage e-mobility considerably.

January 16, 2017

II. Case Study Description

A. Case study

The prosumer's profitability addressed in this paper is analysed with the aid of a fictive vehicle-to-home energy network. It consists of residential building with roof-integrated solar panels, a wireless chargeable electric car and an inductive charging infrastructure. As reference scenario serves a conventional residence without decentralised power plant and with a combustion engined vehicle. Both power architectures are schematically illustrated in Figure 1. In terms of energy management and associated revenue potentials, the following power flows of the prosumer system are considered:

- P_{p2h}: from PV plant to home in kW
- P_{p2g}: from PV plant to grid in kW
- P_{p2v}: from PV plant to electric vehicle in kW
- P_{v2h}: from electric vehicle to home in kW
- P_{g2h}: from grid to home in kW
- P_{g2v}: from grid to electric vehicle in kW

As seen in Figure 2, the paper includes vehicle-to-home activity whenever economically reasonable but does not account for vehicle-to-grid potentials due to economic reasons.

B. Scientific approach

The present study methodically divides into two parts:

(1) Time-series simulation: In order to provide scientifically valid results, the research rests upon a long-term simulation of all above-listed energy flows. For this purpose, the prosumer's energy network and user behaviour are initially modelled in Matlab/Simulink®. By means of time-series simulation, the annual energy amount of each energetic pathway is determined as the simultaneous occurrence of domestic energy generation and consumption is taken into account. Beyond that, the simulation considers long-term effects such as technical progress, seasonal aspects or degradation impacts due to its multi-year character. To further enhance reliability, real load profiles and weather data (both in quarter-hourly resolution) serve as input signals.

(2) Economic assessment: Based upon the simulation results, a profitability calculation is applied in Microsoft®Excel in order to assess the prosumer's revenue potentials. Thereby the observation period has been set to 20 years in conformity with the PV plant's lifetime. To account for capital losses in time, the calculation is based on the cash value method, whereby future cash flows are discounted to the present day according to the applied rate of interest. However, the long observation period entails the need of thorough sensibility analyses on one side and the necessity to replace out-dated components on the other. Both matters are elucidated in the following passage. In context of investment costs, it has to be mentioned that only additional or reduced costs compared

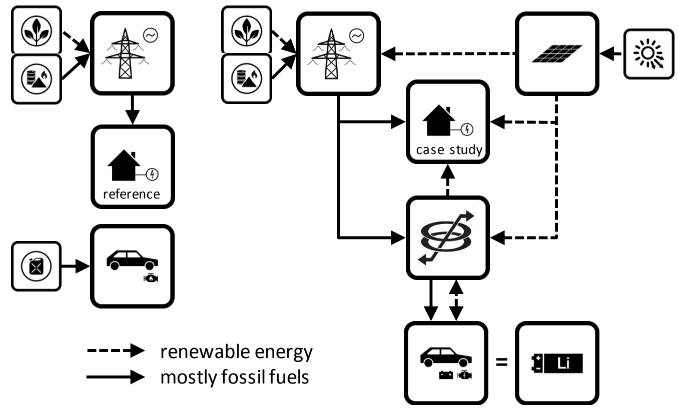

Fig. 1. Case study description: reference scenario *(left)* and examined case study for residential prosumers *(right)*

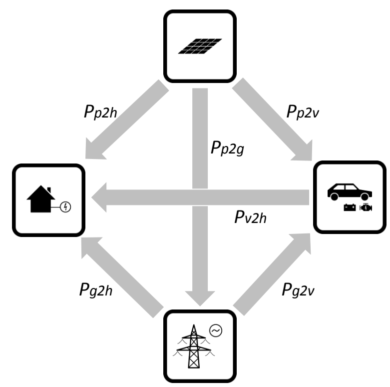

Fig. 2. Considered energy flows within the fictive V2H energy network

TABLE I
SCENARIO DEFINITION AND BELONGING ASSUMPTIONS

Sensitivity Scenario	Parameter		Assumption
0) Baseline Scenario	km_c	one-way commuting distance to place of employment	$10km$
	km_a	annual mileage EV	$5873km/a$
	N_p	number of PV panels	$14 \ \text{x} \ 255Wp$
	α	azimuth PV system	$180°$
	E_{pv}	annual PV generation	$3958kWh/a$
	E_h	annual household load	$3088kWh/a$
	SC	solar coverage of EV and household load during 1st year	$\approx 100\%$
	EV	electric vehicle type (1 = BMW i3)	1
	d_p	annual PV degradation	$1\%/a$
	d_b	battery degradation (1 = on)	1
	t_p	observation period profitability calculation	$20a$
	r_d, r_{pi}	annual discount rate or respectively energy price increase	$2\%/a$
	C_{elec}	electricity price	$28.69ct/kWh$
	C_{feed}	grid feed-in tariff	$12.40ct/kWh$
	C_{fuel}	fuel price	$1.30€/l$
A) Battery Degradation	d_b	enabling battery degradation (1 = on, 0 = off)	$[1, 0]$
B) PV Orientation	α	variation azimuth PV panels (180° = facing south)	$180°$ vs. $90/270°$
C) Electric Vehicle Type	EV	1 = BMW i3, 2 = Renault Zoe, 3 = Nissan Leaf, 4 = Smart eD	$[1 : 1 : 4]$
D) Commuting Distance	km_c	variation annual mileage	$[10 : 10 : 40]km$
E) Number of PV-Arrays	N_p	variation number of PV panels	$[10 : 2 : 18]$
F) Electricity Price	C_{elec}	variation electricity price increase	$[3 : -1 : -1]\%/a$
G) Fuel Price	C_{fuel}	variation fuel price increase	$[3 : -1 : -1]\%/a$

to the reference scenario are regarded in order to avoid the modelling of a second simulation environment. The following financial revenue (+) and loss (-) sources are considered during the profitability calculation:

- (+) *fuel savings* due to more favourable electricity prices from utility grid and PV plant
- (+) *power savings* due to self-consumption of solar power
- (+) *feed-in remuneration* due to grid injection of solar power
- (-) *straight-line depreciation of capital costs* from electric vehicle, PV plant and inductive charging infrastructure
- (-) *operating costs* from PV plant and inductive charging infrastructure

The operating costs of electric vehicles are assumed to be comparable with those of combustion engined cars and therefore neglected. Moreover, the German EEG reallocation charge is not considered due to the minimum limit for small PV plants.

C. Scenario definition and general assumptions

To minimise modelling effort, only one power architecture has been implemented in Simulink. However, due to flexible model design and input parametrisation, the analysis of different sensibility scenarios is feasible. The initial parameter setting is referred to as *Baseline Scenario* whose input initialisation is given in Table I above. Within every additional sensitivity scenario A) to G) one parameter is altered slightly compared to the baseline case in order to evaluate the parameters' impact on the simulation outcome. Table I provides a brief overview of all examined sensitivity scenarios, whereas Table II and III summarise all fundamental assumptions regarding the underlying EV features and inductive charging infrastructure characteristics.

TABLE II
ASSUMPTIONS ELECTRIC AND ICE-POWERED VEHICLES

Feature	Renault Zoe	BMW i3	Nissan Leaf	Smart eD
a) battery capacity in kWh				
- gross (usable only 85%)	22	32	30	17.6
b) consumption in kWh/100km				
- as specified by manufacturer	14.6	12.9	15	15.1
- on-road adjustment (+33%)	19.5	17.2	20	20.1
c) reference ICE vehicle	Clio	Cooper	Pulsar	forTwo
d) ICE consumption in l/100km	7.2	7.5	7.2	6.1
e) add. CAPEX EV in € [10]	6,710	8,350	12,095	12,785
f) reacquisition and other:				
- additional OPEX EV	0 €/a			
- operational lifetime EV/ICE	6 - 7 years			
- reacquisition EV/ICE	7th and 14th year			
- recovery values EV/ICE	1st 15/25%, 2nd 20/25%, 3rd 25/25%			
- cost reduction add. OPEX EV	by -50% for each reacquisition			
- techn. progress battery capacity	by +25% for each reacquisition			
- EV bonus of 4,000 €	1st and 2nd vehicle yes, 3rd car no			

TABLE III
ASSUMPTIONS INDUCTIVE CHARGING SYSTEM (11KW, PRIVATE AREA)

Category	Assumption
a) investment costs including:	Σ 4,750 €
- unidirectional charging infrastructure	3,400 €
- upgrade bidirectionality	250 €
- safety features	100 €
- forecast and intelligence unit	400 €
- assembling costs	600 €
b) reacquisition and other:	
- operating costs	250 €/a
- operational lifetime / reacquisition after	10 years
- cost reduction reacquisition by	-40%

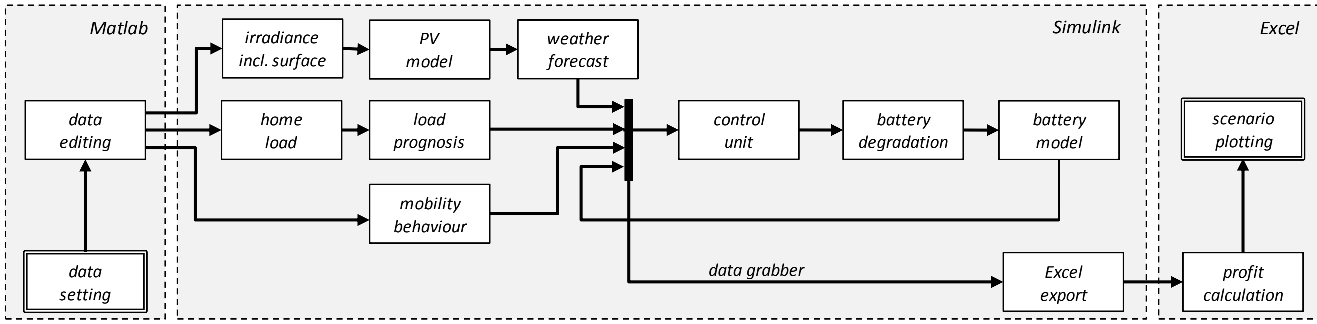

Fig. 3. Schematic overview of the simulation environment

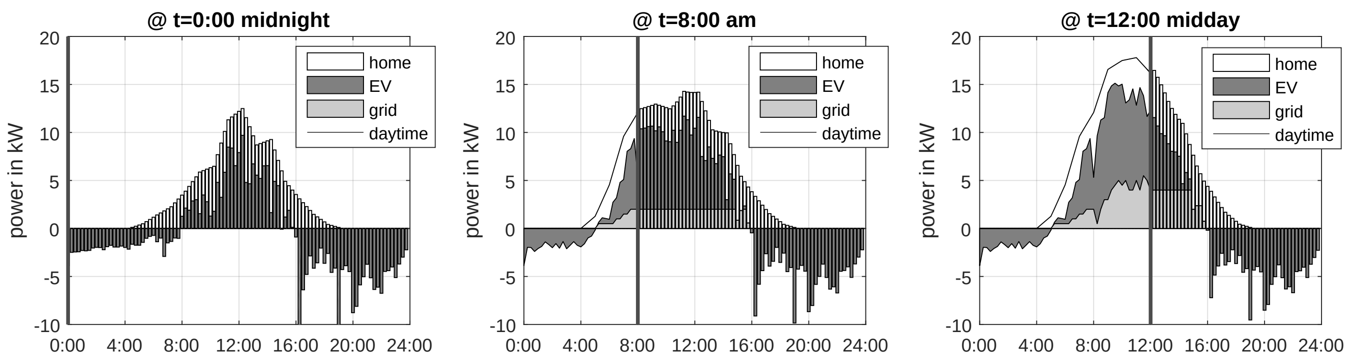

Fig. 4. Exemplary illustration of the adaptive PV power and load prognosis algorithm (@30kWp): Plain areas represent historical energy flows, while bar graphs show the expected ones. Positive areas illustrate how the PV power is used, whereas negative ones indicate the source of additionally needed energy.

III. Simulation Environment within Simulink

This sections describes the simplified power flow model in more detail by emphasizing its capabilities and limits. The aim is to heighten the method's comprehensibility to permit a proper assessment of the simulation results. As schematically illustrated in Figure 3, the main components of the prosumer energy network are individually modelled within Simulink. In the following, the basic features of some components are further explained:

a) data editing within Matlab environment:
A Matlab UI serves to initialise all boundary conditions and relevant simulation parameters. With the aid of a setting file, the different scenarios and their belonging data sets are called and simulated in an automated fashion. Before entering Simulink environment, the different time-series are subjected to mathematical treatment which includes data cleansing, signal processing and reshaping. To accelerate simulation speed, the solar position for the area of Stuttgart is calculated one year in advance using the SUNAE-algorithm extracted from [11]. Based on this solar altitude and the TRY-weather data of the German Meteorological Service [12], the solar irradiation on the horizontal level is computed to serve as input signal for the later Simulink model. The weather is assumed to be identical each year.

b) PV system modelling:
In order to execute long-time simulations within a reasonable period of time, the PV model is not based on electrical components. The time-dependant PV power generation is implemented in a simplified manner by assuming its linear dependency from temperature and irradiation on the inclined plane alone. For the sake of simplicity, the PV inverter has not be modelled. However, to account for inverter, cable and spoiling losses, the PV power is reduced according to the module's performance ratio of 86.5%. To represent aging effects such as degradation, the PR is further reduced by 1% each year. The PV plant is made of a varying number of mono-crystalline 255Wp modules inclined of 33° which corresponds to the optimal inclination for the area of Stuttgart according to [13]. The investment costs are assumed to be 1500€/kWp with running costs of 2% initial CAPEX per year.

c) PV prognosis algorithm:
To anticipate the PV power production one day ahead, two different forecast algorithms (for short- and long-term prediction) are weighted and superposed according to the forecast horizon. As long-term prediction method serves the simple thesis that today's weather is going be the same as yesterday's. The short-term prognosis, however, is based on a forecast method applied in [14] which uses historical data sets of the considered PV plant to foresee

its future power production. This approach rests upon the assumption that for a short period of time the weather condition $c_w \in \mathbb{R} \wedge (0 < c_w < 1)$ remains constant, whereby $c_w \approx 1$ represents a bright sky and $c_w \approx 0$ a dense blanket of clouds. By determining the weather condition of the last time step ($\Delta t = 15min$) and by multiplying it with the maximum PV power production of the last 10 days at the time interval to come, the PV power production of the next quarter-hour can be foreseen in high accuracy. In order to minimise forecast errors, the power prediction is adaptive and therefore adjusted every 15 minutes as can be seen in Figure 4.

d) building load:
The present research uses real load profiles of German households (2014) which have kindly been provided by [15]. In contrast to standardised residential loads, those time-series account for temporary and seasonal power peaks that render energy simulation more realistic. The underlying annual building load is about 3MWh/a which corresponds to a typical 2-person-household in Germany. During the *Baseline Scenario*, the annual EV and building load were chosen to be equivalent to the annual PV power production. To foresee the building load one day ahead, it is simply assumed that the time-dependant load will be the same next day. This technique may be improved for further simulations. In addition, it is supposed that the annual household load remains constant during the next 20 years due to the annihilation of efficiency gains through the invention of new electronic devices.

e) mobility behaviour:
The EV availability at the residence is mainly derived from the mobility behaviour of a commuter who is full-time employed with core hours from 8:00 am to 5:00 pm. By statistical variation of the departure resp. arrival time and by considering 12 public holidays, 29 vacation days (including 2 long-distance journeys via plane) and 12 sickness days in addition, the business mobility behaviour is reconstructed. The less predictable leisure behaviour by weekday and daytime, however, is rebuilt with the aid of a German mobility study [16]. As result, a vector in quarterly-hour resolution is generated for the year 2014 (in order to match the building load) consisting of *zeros* and *ones* only to indicate the EV's availability at home. Within scenario D), the travelling distance to the business location is altered, whereas the leisure behaviour remains the same. Moreover, further assumptions have been made:

- When at home, the EV is always aligned with the stationary side of the inductive charging infrastructure.
- During long-distance journeys, the car remains at home and is used as bidirectional stationary battery.
- In order to use forecast-based control, the EV schedule and its anticipated travelling distance are known 24h in advance. In practise, this can be realised by vehicle management systems as introduced in [17].
- The EV's charging performance is variable adjustable and assigned by the central control unit within the infrastructure's technical restrictions of 10kW (usable) in order to avoid unnecessary peak loads.
- The mobility behaviour remains constant over 20 years.
- Seasonal EV energy consumption is not considered.

f) battery modelling:
By analogy with the PV model, the battery model is kept simple as well. It bases on lithium-ion-technology and is restricted to a linear charging and discharging behaviour which can be presumed within a state of charge range of $10\% < SOC < 95\%$ ($DOD = 85\%$). The model does not account for self-discharge losses or other non-linearities such as temperature or C-rate dependencies. The round-trip efficiency is assumed to be $\eta = 80\%$ since no inverter and battery management systems are modelled. Bidirectionality is only permitted in case the state of charge exceeds 75% which prevents stagnation during summer without interfering energy flow priorities in general. Battery degradation is regarded as described in the following passage.

g) battery degradation:
Concerning the ageing phenomena of batteries, a distinction between cycle and calendrical degradation must be made. The total aging effect can be obtained by superposing both effects as seen in Figure 5. The cycle stability is often guaranteed by manufactures to be at least 80% of the initial battery capacity after 1000 cycles. The calendrical ageing effect, however, is still the unknown factor due to missing long-term field tests. As a consequence, there are only few reliable data on this subject. To account for technical progress, the following assumptions have been made for both cycle (@1000 full-cycles) and calendrical (@10 years) degradation as further illustrated in Figure 6:

- 1st EV in 2017: 80% remaining capacity
- 2nd EV in 2023: 82.5% remaining capacity
- 3rd EV in 2030: 85% remaining capacity

Both dependencies are consigned to so-called Look-up-tables (LUT) within the Simulink environment.

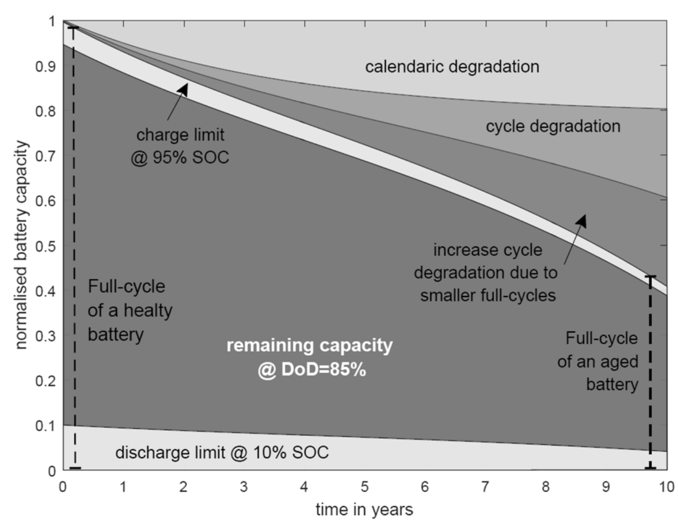

Fig. 5. Total battery degradation over time with presumably 100 full-cycles/a

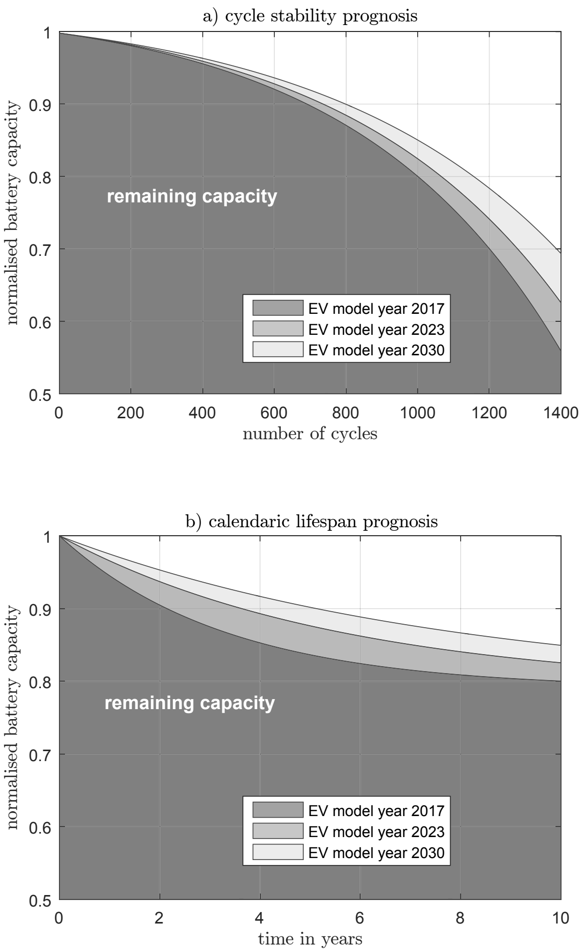

Fig. 6. Battery degradation assumptions for EV replacement: cycle degradation *(top)* and calendrical degradation *(buttom)*

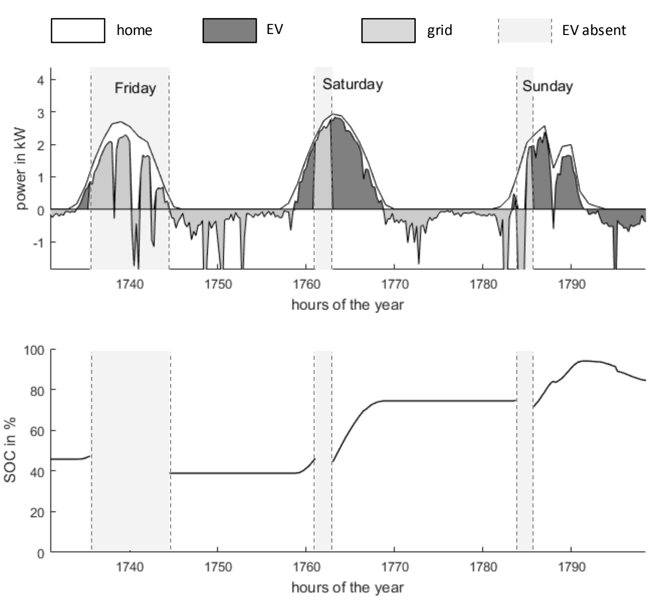

Fig. 7. Impact of the EV availability on the energy flow priorities

h) central intelligence and control unit:
A central control unit processes predicted and present data in order to charge the electric vehicle in an optimal manner. By means of forecast-based control, the central intelligence maximises self-consumption of the locally generated PV power by simultaneously avoiding feed-in peaks in order to heighten grid compatibility. Given the car's presence at home, the PV power peaks at midday are used to charge the vehicle as shown in Figure 4. If the SOC is low, the total excess PV power is stored into the battery according to the vehicle's availability on-site (see Figure 7). In case there is not enough PV power but the car needs to leave soon (with insufficient SOC), the EV is automatically charged by grid at lower charging performances to avoid any harsh power peaks. Based on economical decision-making, the control unit prioritises the considered energy flows as follows[2]:

1) P_{p2h}: Self-consumption of the solar power by the household has the highest priority as the levelised costs of electricity for the PV plant are inferior to the public grid energy price.

$$\begin{aligned} Value_{p2h} &= Costs_{grid} - LCOE_{pv} \\ &= +19.69ct/kWh \end{aligned} \tag{1}$$

2) P_{p2v} *and* P_{v2h}: Beforehand, some preliminary considerations. At first, both energy flows undergo a wireless power transfer from the stationary side to the EV with $\eta_{wpt} = 90\%$, then a charge-discharge-process with a round-trip efficiency of $\eta_{bat} = 90\%$ and finally, a battery-to-wheel-transmission of $\eta_{b2w} = 90\%$ or again, a wireless power transfer back to the stationary side. Therefore, both energy flows suffer from energy losses equal to $\eta_{loss} \approx 1 - (0.9)^3$. Levelised costs of storage are not taken into consideration here, since the battery costs are assigned to satisfy mobility needs in first place and not power demands.

$$\begin{aligned} Value_{p2v,v2h} &= (Costs_{grid} - LCOE_{pv}) \cdot \eta_{tot} \\ &= +14.37ct/kWh \end{aligned} \tag{2}$$

3) P_{p2g}: Compared to self-consumption, grid-injection is not as profitable since the feed-in compensation is considerably reduced by the levelised costs of PV power generation.

$$\begin{aligned} Value_{p2g} &= Revenue_{feed} - LCOE_{pv} \\ &= +3.4ct/kWh \end{aligned} \tag{3}$$

4) P_{g2h}: As the public electricity price is regarded as reference in this context, the grid supply of the household equals *zero*.

$$Value_{g2h} = 0ct/kWh \tag{4}$$

5) P_{g2v}: In case the vehicle is fed directly by the public grid, transmission losses have to be considered once again.

$$\begin{aligned} Value_{g2v} &= Costs_{grid} \cdot (100 - \eta_{tot}) \\ &= -7.75ct/kWh \end{aligned} \tag{5}$$

[2]underlying assumptions: $Costs_{grid} = 28.69ct/kWh$, $LCOE_{pv} = 9ct/kWh$, $Revenue_{feed} = 12.4ct/kWh$, $\eta_{tot} = (90\%)^3 = 73\%$

IV. Scenario and Sensitivity Analysis

In the following, the prosumer's revenue and expenditure sources (as introduced in section II and simulated in course of this study) are presented and discussed by illustrating their dependencies from specific parameters. To begin with, Figure 8 is presented where each sub-figure displays the results of another sensitivity analysis. Within each stacked bar chart, the ground line represents the financial situation of the reference case. Therefore, all positive assets correspond to annual savings whereas negative ones account for additional expenditures compared to a conventional household with ICE-powered vehicle. The over-all results, which add up all cash flows to one single key indicator for each scenario, will be summarised in Section V.

A. battery degradation

Battery degradation leads to a reduced usable capacity over time, therefore older batteries attain their maximum state of charge more quickly. When enabling this ageing effect, less solar power is stored and consumed by the electric car which directly lessens fuel savings as seen in Figure 8A). Otherwise, more PV power is fed into the grid which increases feed-in revenues. Since one kilowatt hour self-consumed PV energy is more valuable than one kilowatt hour grid-injected energy, cf. equations (2) and (3), fuel savings decrease faster than feed-in compensation rises. Consequently, battery degradation affects annual profits negatively. However, degradation has only a relatively small impact on the prosumer's profit under the given conditions as the daily mileage is very low. Since the sum of all annual cash flows is negative in both cases (degradation on/off), no profits are generated compared to the reference scenario.

B. PV-orientation

Within this sensitivity analysis it was examined to what extent the more valuable self-consumption can be increased by specifically exploiting the morning and evening sun with east-west orientated PV arrays (evenly distributed). As a matter of fact, the simultaneity of EV presence and PV power production is slightly increased when changing the orientation to east-west. Yet, this improvement is totally negated by a higher over-all PV power production by south orientated panels. As seen in Figure 8B), south exposure leads to significant higher revenues per year and therefore should be preferred.

C. electric vehicle type

Preliminary considerations lead to the trivial conclusion that high battery capacities, low EV energy consumptions and modest investment costs favour the prosumer's profitability. Having a closer look on Table II once again, it becomes apparent that especially the Renault Zoe and BMW i3 are convincing in this regard. To what extent the car's attributes influence the different revenue and expenditure sources is shown in Figure 8C). At first sight, the minor investment costs of the Renault Zoe pay off clearly since those expenditures do not have to be compensated elsewhere. As further expected, the BMW i3 generates the greatest savings due to its low energy consumption. Furthermore, small battery capacities (Renault Zoe and Smart eD) lead to higher grid injections and electricity savings but entail further grid supply. As anticipated, the additional investment costs for the battery are one of the most negatively influencing parameters as the electric car needs to be driven frequently to make up for them by fuel savings alone.

D. commuting distance

As can be seen in Figure 8D), the annual fuel savings correlate strongly with an increase of the commuting distance. Its influence on the prosumer's profit can be considered equivalent to the investment cost impact. This confirms the general assumption according to which electric vehicles pay off for frequent travellers only. Yet, it will be shown later on that fuel savings particularly depend on the long-term development of electricity and fuel prices. This is troublesome insofar as both indices have not developed favourably to e-mobility during the last few years in Germany.

E. number of PV-arrays

Despite falling feed-in tariffs in Germany, PV systems remain very cost-effective for private households since module prices were steadily decreasing during the last 10 years. In general, the greater the PV plant, the higher the savings. Within this sensitivity analysis it was therefore examined to what extend a larger PV plant compensates the additional capital costs caused by electric car and inductive charging infrastructure. As can be seen in Figure 8E), the operating and investment costs increase linearly with greater solar surfaces. Fuel saving, however, tend to stagnate since PV self-consumption does not rise endlessly with larger PV systems. As a consequence, grid injections go up accordingly. Nevertheless, PV savings rise faster than the belonging expenditures, therefore further PV panels improve the prosumer's profit (but not as strong as an increased commuting distance). Moreover, it has to be mentioned that roof surface is limited in general.

F. electricity price increase

In Germany, the electricity price for private households has increased by 50% within the last 10 years, leading to the controversy whether electric cars can maintain their fuel saving advantage in future. But even though this advantage diminishes with higher electricity prices, PV power becomes even more valuable in this way. Since the latter is given more weight, the prosumer's profit increases with rising electricity prices as illustrated in Figure 8F). Unfortunately, electricity prices seem to stagnate at the time being.

G. fuel price increase

When it comes to fossil fuel prices, the indices have not performed well either. The overexploitation of worldwide oilfields has lead to a veritable fossil fuel boom. For an accelerated development of e-mobility, however, an increasing fossil fuel prise would be most favourable as shown in 8G).

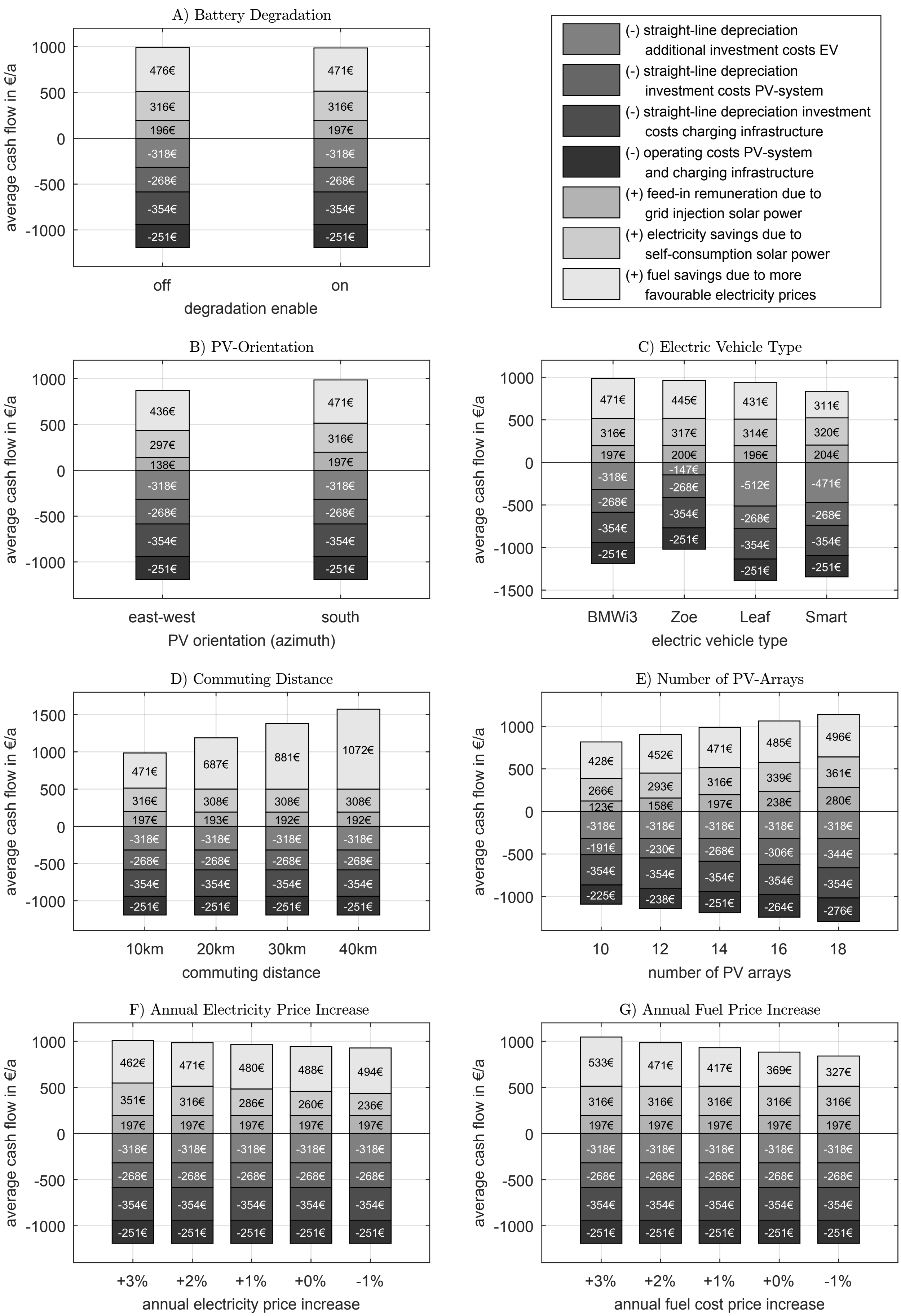

Fig. 8. Simulation results of the sensitivity analyses A) to G) as described in Table I

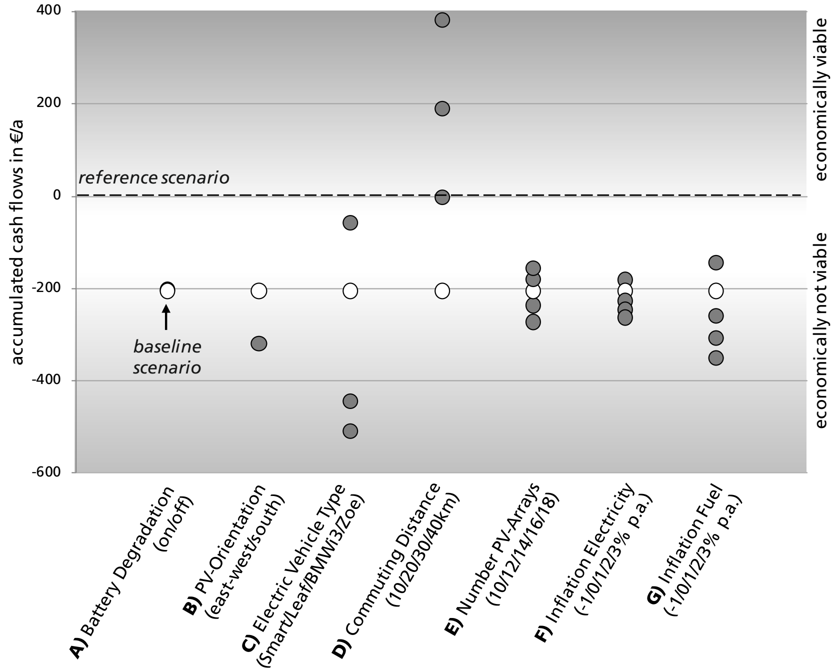

Fig. 9. The prosumer's profitability compared to the reference scenario according to the sensitivity analyses A) to G) as described in Table I

V. Conclusion

When accumulating all income and expenditure sources of every single scenario depicted in Figure 8 and plotting the outcomes into one final graphic, Figure 9 results. Again, the zero line represents the financial circumstances of the reference scenario. Therefore, each scenario whose circle is above the dashed line is a economically viable one. To improve comparability between the different sensibility analyses A) to G), the baseline scenario is highlighted in addition - accounting for battery degradation, 14 south-orientated PV arrays, a BMW i3 as electric car, a one-way commuting distance of 10km and a 2% energy price increase per year.

As can be seen at first sight, a prosumer with a currently available electric car (2016) and prototypical inductive charging infrastructure does not draw any profits in general. However, profitability can be reached under certain conditions:

(a) commuting distances of more than 30km one-way,
(b) energetically conscious driving style (exploiting recuperation possibilities etc.) to maximise fuel savings through lower EV energy consumption,
(c) availability of a large south orientated roof surface,
(d) long-term energy price increase,
(e) purchase of an EV with moderate additional investment costs compared to an ICE-powered equivalent and
(f) claim of the German EV bonus up to 4,000€.

The parameters with the largest leverage effect on the prosumer's profitability are (1) the daily driving distance, (2) the electric vehicle type and its features, (3) the fuel price development and (4) the orientation and size of the PV system.

In summary, it can be said that the underlying prosumer with inductive charging infrastructure can only draw profits from the whole V2H-network in case he performs high driving mileages and has a long EV holding period. However, its profitability is strongly dependant on the development of external factors, such as energy prices and the development of the car's residual value. Down to the present day, both factors are still subjected to great uncertainties.

Being no part of the present study, further research activities might be pursued to assess the impact of the following factors:

- *mobility behaviour:* The prosumer's profit is most likely to improve for part-time employees or night-shift workers since the car's presence at home during sunshine hours is heightened in this way.
- *prognosis algorithms and forecast deviations:* Optimised forecast algorithms lead to higher self-consumption and thus to lower grid supply. Whereas the applied prognosis method for local PV power generation is already satisfactory, the forecast model for household loads remains improvable. In addition, the impact of sudden disturbances or forecast deviations on the prosumer's profitability has to be examined in more detail.
- *variable electricity prices:* By means of variable electricity prices, the profit margin of the V2H-network is most likely to rise considerably as (1) energy storage at PV peak times is rewarded and (2) energy consumption (when supplied by public grid) in the evening is penalized which heightens the motivation for bidirectional usage of electric vehicles.

Acknowledgment

The presented results of this paper are based upon the work done within the project *BiLawE - bidirectional, inductive charging systems economically in the grid* funded by the German Federal Ministry for Economic Affairs and Energy within the framework of *ELEKTRO POWER II*. The collaborations with the Robert Bosch GmbH, the GreenIng GmbH & Co. KG and the Fraunhofer ISE are gratefully acknowledged. The authors thank the anonymous reviewers for their improvement suggestions. If you like cookies, just let us know.

References

[1] Evatran Group Inc, *2nd Generation Plugless Technical Specifications*, online article, pluglesspower.com, https://www.pluglesspower.com/gen2-tech-specs/, accessed: 2016-12-10.

[2] Robert Bosch GmbH, *Charging as if by magic*, online press release of the 12th September 2016, bosch-presse.de, http://www.bosch-presse.de/pressportal/de/en/charging-as-if-by-magic-61440.html, accessed 2016-12-10.

[3] SAE International, *Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology*, US guideline, United States: SAE TIR J2954, May 2016.

[4] P3 Automotive GmbH, *Projekt STILLE erfolgreich gestartet*, online announcement of the 12th October 2016, p3-group.com, http://www.p3-group.com/wp-content/uploads/2016/10/20160930_STILLE_PM_STILLE-erfolgreich-gestartet_freigegeben_2.pdf , accessed 2016-12-10.

[5] D. Borrmann, *Electric operability of an inductive charging system for electric vehicles in an urban area*, Nuremberg, Germany: Proceedings of the 4th International Electric Drives Production Conference, E/DPC 2014m page 329-336, 30th September - 1st October 2014.

[6] S. Schraven, F. Kley and M. Wietschel, *Induktives Laden von Elektromobilen: Eine techno-ökonomische Bewertung*, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany: Working Paper Sustainability and Innovation No. S 8/2010, 2010

[7] P. Bansal, *Charging of Electric Vehicles: Technology and Policy Implications*, Zanvyl Krieger School of Arts and Sciences, Johns Hopkins University, Washington DC.: JSPG. Vol. 6 Issue 1, February 2015.

[8] H. Robledo et al., *Feasibility of energy storage systems to save costs of small, medium and big costumers. Use of batteries and electric vehicles*, Universidad Politchnica de Valencia, Valencia, Spain, Universit Libre de Bruxelles, Brussels, Belgium: 7experience - Negocios Intelligentes, 2014.

[9] A. Dargahi et al., *Optimal household energy management using V2H flexibilities*, Grenoble Electrical Engineering laboratory (G2Elab), Grenoble Institute of Technology, Grenoble, France: Emerald Group Publishing Limited, The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, Vol. 33 No. 3, pp. 777-792, 2014.

[10] ADAC e.V, *ADAC-Autokostenvergleich: auch mit Kaufprämie nur wenige Elektroautos rentabel*, infographics, https://presse.adac.de/meldungen/technik/adac-autokostenvergleich-auch-mit-kaufpraemie-nur.-wenige-elektroautos-rentabel.html, accessed 2016-09-07.

[11] V. Quaschning, *Regenerative Energiesysteme: Technologie, Berechnung, Simulation*, 2nd ed. Munic, Germany: Carl Hanser Verlag Munic Vienna, 1999.

[12] Deutscher Wetterdienst, *Testreferenzjahre (TRY) Klimaregion 12: Oberrheingraben und unteres Neckartal*. Offenbach, Germany, 2004.

[13] PVGIS, *Photovoltaic Geographical Information System - Interactive Map*, http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php, accessed 2016-10-30.

[14] J. Bergner, J. Weniger, T. Tjarden and V. Quaschning, *Verbesserte Netzintegration von PV-Speichersystemen durch Einbindung lokal erstellter PV- und Lastprognosen*, Bad Staffelstein, Germany: 30. Symposium Photovoltaische Solarenergie, 12-14th March 2015.

[15] Hochschule für Technik und Wirtschaft HTW Berlin, *Repräsentative elektrische Lastprofile fuer Einfamilienhäuser in Deutschland auf 1-sekündiger Datenbasis*, provided data set, Berlin, 2015.

[16] Infas Institut für angewandte Sozialwissenschaft GmbH and Deutsches Zentrum für Luft- und Raumfahrt e.V., *MiD 2008 - Mobilität in Deutschland*, result report, http://www.mobilitaet-in-deutschland.de/pdf/MiD2008_Abschlussbericht_I.pdf, accessed 2016-09-07.

[17] D. Satikidis, K. Sivarasah, K. Lehmann, I. Hoffmann and G. Scheffler, *EcoGuru: A system for the integrated management of electrified mobility systems*. Fraunhofer Institute for Industrial Engineering IAO, 15th Stuttgart International Symposium for Automotive and Engine Technology, Stuttgart, Germany, 14-15 March 2015.