The Role of Plug-in Battery Electric Vehicles in the Danish Energy System:

Model Study and System Design

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Sustainable Energy Planning and Management

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Synopsis

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The concept of a smart energy system (SES) is a theoretically valid approach to meet the goals regarding a renewable energy system in Denmark. Within this, it is clear that electric vehicles (EVs) can become an important asset. The focus in this report is on the role that plug-in EVs can have in a Danish SES, by enabling smart charging strategies.

Through an Excel model analysis, two smart charging strategies are analysed; one focusing on low Elspot prices, the other on the integration of wind power, both allowing for participation in the balancing of the market. It is concluded for both that significant annual savings can be gained and the wind share of the electricity used by the EVs can be increased compared to dumb charging. The model shows that the vehicles are able to provide balancing services in the electricity grid.

Through a stakeholder analysis, it is concluded that an aggregator is expected to pool EVs together, optimally utilising their flexibility. Utility companies and DSOs could provide dynamic electricity and distribution tariffs. Governmental institutions need to work on regulations to support EVs and to improve standardisation. In general, collaboration is required between all of the analysed stakeholders.

The results from a survey amongst 105 Danish EV owners show that they are positive towards the smart use of their vehicle, where creating a green profile is the main motivation. The owners seem more hesitant towards the involvement of an aggregator; their main concerns are meeting the driving demands, as well as the effect on the battery lifetime.

This project shows that there is a significant role for EVs in a SES, given that the right conditions are created. This way, savings for the EV owners can be acquired, the wind share used to charge the EVs can be increased and balancing services can be provided in the electricity system.

The pictures used in the front page are taken from the following sources: *(Electric Vehicles Initiative et al. 2013), (Energinet.dk 2015c), (Green Optimistic 2015), (Tesla Daily 2015) and (Uprising Beach Resort 2015)*

Abstract

The concept of a smart energy system (SES) is theoretically a valid approach to meet the goals regarding a renewable energy (RE) system in Denmark. Within this, it is clear that plug-in battery electric vehicles (PEVs) can become an important asset. They can, among other things, bring socio-economic benefits for society, aid in increasing the value of wind, make Denmark more self-sufficient and provide a flexible demand response for balancing the grid.

At the moment, PEVs are not being used to support the electricity system, and can even be a burden to, for example, the distribution grid. It is generally unclear to what extent they could play a role in both the Danish energy system and the Nord Pool market. The degree to which intelligent charging and participating in the regulating market, with or without V2G, could improve the business case of the PEV owner, is also unclear. Furthermore, it is assumed that an entity called the aggregator is a vital actor in the use of the PEVs to provide services to the electricity system, and there is not a lot of current knowledge as to what the owners' perspectives are on having their PEVs being controlled by this actor.

The project focuses around the following research question:

What role can plug-in battery electric vehicles play in the current and future Danish energy system?

In order to answer this research question, the following sub-questions have been formulated:

- To what extent can plug-in battery electric vehicles integrate wind power and provide balancing services to the electricity grid?
- What potential gains are there for the vehicle owners when smart charging is enabled by an aggregator?
- How should the involved actors be organised to enable this role?
- What is the attitude of PEV owners towards having their vehicles used in a smart way?

The analyses in this project consist of two parts. First an Excel model is formed in order to evaluate different charging strategies for PEVs with regards to how they can be used to balance the electricity system and integrate wind power, and the potential income this can provide for the PEV owners. The second analysis focuses on the relevant stakeholders and their involvement regarding the transition towards PEVs in a SES. Here, their current position with regards to the strategies, as well as their expected development in the future is considered. Through these analyses, a system design and recommendations can be made on how a system could be organised that increases the feasibility of integrating PEVs in a SES, where they are used flexibly.

Various methods are used to support these analyses, where especially information gained from literature study and correspondence in the form of interviews and e-mails is used for the model, and a survey targeted at PEV owners is made for the stakeholder analysis.

Charging strategy analysis

Three strategies are analysed; one reference dumb charging strategy and two smart charging strategies. The smart charging strategies have a focus on charging during the hours with the lowest Elspot prices and the highest wind shares in the day respectively. Furthermore, they incorporate the possibility for the PEVs to participate in the day-ahead and intraday markets, the regulating power market (RPM), and the primary and tertiary reserves, all of which are a part of the Nord Pool electricity market. For all these strategies, the aggregator is an essential actor who can pool the PEVs together in order to meet the required bid sizes in the market.

Current and future scenarios are analysed for each of the strategies corresponding to data from 2012-2014 and predicted data for 2025, where 2,000 and 20,000 PEVs are implemented respectively. From the analysis, it can be concluded that compared to the reference strategy, smart charging:

- Offers savings for the PEV owners, where the low price strategy provides the largest savings; there are annual savings of up to 3,900 DKK per PEV in the current scenarios and 1,550 DKK in the future scenarios.
- Can increase the average wind share of the electricity that is used to charge the PEVs and integrate a larger volume of surplus wind electricity. Here the wind integration strategy is the optimal strategy; the wind share increases up to 59% in the current scenarios and 73% in the future scenarios.
- PEVs can integrate surplus wind electricity to some extent; up to 1% of the total surplus volume in the future scenarios.
- Can provide balancing services to the national grid, where especially the frequency regulation can play a role in the current scenarios, and participation in both the frequency regulation and the RPM is possible in the future scenarios.
- Limits the load on the distribution grid due to both the shift in the hours of charging, as well as charging being distributed over more hours.

An extra analysis is made, in which the focus is on increasing the role of the PEVs in the RPM. From this analysis, it is shown that this can be done significantly compared to the other strategies, at the expense of the savings for the PEV owner, as well as the integration of wind power.

Stakeholder analysis

A total of ten stakeholders are considered, where focus is put on the current and future roles of the aggregator, Danish transmission system operator (TSO), utility companies, distribution system operators (DSOs) and the PEV owners. These roles are regarding the implementation of PEVs in a SES.

The purpose of the aggregator is to maximise the value of the customers' flexibility, while still prioritising their driving demands. The aggregator is thus in charge of gathering data on various aspects regarding the status of the PEV, user preferences, and electricity market data, and use this information to determine a charging strategy. The role of the aggregator can be played by

different actors, but it is deemed important that the aggregator has access to the electricity market.

The main tasks of Energinet.dk, the Danish TSO, are to maintain the security and quality of electricity and gas supply in Denmark. They see the need for flexible demand in a SES and are supporting the integration of PEVs where they can. In order to maintain the security and quality of the electricity supply, the TSO buys regulating electricity and reserves through the Nord Pool market, and PEVs have the potential to provide part of this capacity. They have the possibility to influence the market mechanisms in Nord Pool, and in this way help promote PEVs.

The utility companies sell the electricity to the end users and are therefore the link between the electricity market and the users. They could be an aggregator in collaboration with a trader due to this link. In order to utilise demand response, price signals are required for the PEV owners. Utility companies could provide this through dynamic electricity tariffs, however, they are currently not considering this option to a large extent.

DSOs are the responsible authorities of the distribution grid in Denmark. Generally, DSOs are interested in looking into smart grid solutions and are forming tools for this. Furthermore, they are responsible for gathering data from the smart meters that have been installed, which is required for smart charging. The DSOs are expected to enable the customers by encouraging them to provide flexibility to the grid, and are also expected to collaborate with the aggregators in order to provide the needed flexibility.

The PEV owners are often under prioritised in studies concerning PEVs in a SES. Here, they are considered one of the major actors, as they are the ones ultimately making the decision of if their PEVs are to be used flexibly by an aggregator. There are already PEV owners that adjust their charging when connected to home chargers, mainly to obtain a green charging profile. Furthermore, the majority of the respondents are interested in charging flexibly, and have the insight to do so, but the insight is not currently leading to action. When involving an aggregator, concerns increase. Here, more would be required to convince the PEV owners; proof that using the PEVs is helping the system, as well as an economic incentive.

System design proposal and recommendations

Depending on the preference of the PEV owner, or the aggregator, one of the two smart charging strategies analysed in the project can be implemented, and result in benefits for society and the PEV owners. In order to successfully implement the system design, the following main recommendations are made.

Priority should be given to playing a larger role in the primary reserve for the PEVs due to the economic benefits for the PEV owners. Furthermore, priority should be given to the inclusion of the required technology in both the PEVs and charging points, to allow for the aggregator to implement the charging strategies.

The Danish government should find a solution for the tax exemption for PEVs, whether this is to gradually decrease it after 2016, or to re-evaluate the whole taxing system for vehicles. The EU should then push the agenda of standardisation for PEVs and charging infrastructure.

The electricity consumption should be considered at least on an hourly basis, to allow for flexible prices. Utility companies and DSOs should evaluate the potential of applying dynamic prices and tariffs for their customers, where especially the DSOs can gain from this. Collaborations should be made between the aggregators, DSOs, utility companies and PEV owners to establish charging strategies, price settlements and make these factors transparent for the PEV owners. There should be an economic incentive for the PEV owner to allow for the aggregator to control their PEVs. This could be in the form of a refund of the electricity tax, or compensation for the battery usage.

Further studies should be made to show the effect on the battery lifetime of increased charging cycles. Priority should be given by the aggregator to ensuring that unplanned/emergency trips can always be made. It should be easy and reliable for the PEV owners to state their preferences to the aggregator. This could be done through a mobile phone application, where relevant information can also be provided to the PEV owners by the aggregator.

Preface

This 4th semester Master thesis is written by Group 2, from the study programme Sustainable Energy Planning and Management, from the Department of Development and Planning, Aalborg University. The title of the project is "The Role of Plug-in Battery Electric Vehicles in the Danish Energy System: Model Study and System Design", and the project period spanned from 2nd February 2015 to 3rd June 2015.

The topic was chosen due to its current and future relevance seen from an energy planning perspective. With an increasing amount of wind power in the Danish energy system, and the goal of becoming 100% renewable, there is a need for finding solutions to both incite the transition to an electric transport sector, as well as to integrate the wind power in Denmark. Furthermore, in order to main the high security of electricity supply now experienced in Denmark, solutions for balancing the grid have to be found for the future.

In the project, emphasis is put on the development of an hourly based model used to determine the potential of using electric vehicles in the Nord Pool electricity market, as it was the desire of the writers to gain a deeper understanding of the modelled system, as well as the complexity of creating a model from scratch. Next to this, it was chosen to put focus on a survey targeted at Danish electric vehicle owners, used to evaluate their engagement and preferences towards the use of the vehicle in a smart energy system. This decision was made due to the lack of knowledge regarding this important player and the curiosity of the writers regarding the opinions of the electric vehicle owners.

Reading Guide:

All the figures and tables in the project are labelled according to their placement in the report, so that Figure 1.1 is used for the first figure in Chapter 1. A similar labelling system is used for chapters, sections and subsections. For the appendices, alphabetic labels are used.

The Harvard style is used for referencing the sources, so that the surname of the relevant author(s), as well as the year of production, appears in the reference where used. The bibliography can be found before the appendices in the study.

An Excel model is made in the project, for which Excel 2010 or a more recent version of the programme is required. This is due to missing functions in the older versions of Excel. Furthermore, a CD is attached to the project in which the Excel model, survey, interview audio files and transcriptions, and e-mail correspondences can be found.

Acknowledgements:

Thanks are given to the group's supervisor, Associate Professor Karl Sperling, for his supervision throughout the project, which has been helpful, motivating and insightful. Furthermore, a big thanks is given to all the external actors contacted for the project, without whom the analyses could not be made. This applies to all the interviewees and e-mail correspondents, as well as all the respondents from the survey, all the responses of which are highly appreciated.

List of Abbreviations

Abbreviation	Description
BRP	Balancing responsible party
CEESA	Coherent Energy and Environmental System Analysis
CHP	Combined heat and power
DEA	Danish Energy Agency
DSO	Distribution system operator
EV	Electric vehicle
EVI	Electric Vehicles International
FIT	Feed-in tariff
IEA	International Energy Agency
PEV	Plug-in battery electric vehicle
PPA	Purchase power agreement
PSO	Public service obligation
PV	Photovoltaic panels
RE	Renewable energy
RPM	Regulating power market
SES	Smart energy system
SOC	State of charge
TSO	Transmission system operator
V2G	Vehicle-to-grid

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1 Problem Analysis

Denmark is moving towards an energy system that constitutes of more and more renewable energy (RE); a move that is encouraged by the energy goals set by the government. These goals include that 35% of the primary energy consumption should come from RE in 2020, the heat and electricity sectors should be fossil free in 2035, and the remaining energy sectors should be fossil free in 2050. (Danish Energy Agency 2015)

In order to enable such a transition in Denmark, it is expected that the majority of the energy will be harnessed from biomass, wind and solar units, the latter two of which are defined as being fluctuating, due to their variable nature (Lund et al. 2011). These RE sources will replace large conventional units, among others, such as fossil fuel driven power plants. In Figure 1.1, the increase in the share of RE in the primary energy consumption in Denmark can be seen.

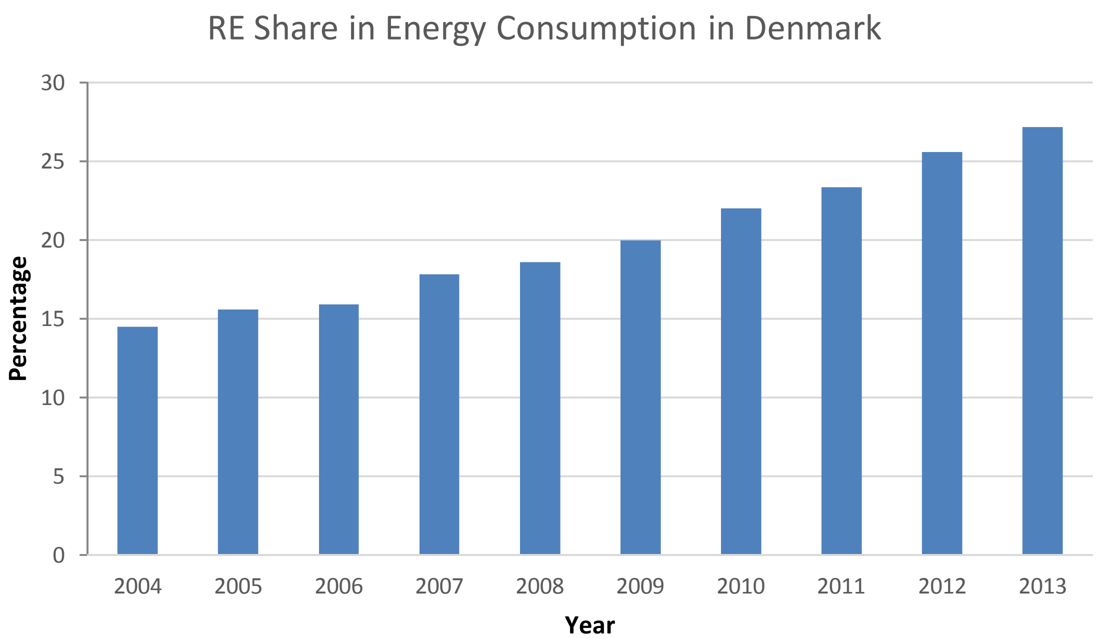

Figure 1.1: RE share in energy consumption in Denmark, 2004-2013 (Eurostat 2015)

The increase in the graph approximates a linear tendency, and if this tendency is assumed to be valid for the following years, it can be expected that there will be about a 32% share of RE in 2020. However, it is expected to become more challenging to cope with the increasing amounts of RE in the existing energy system, for which considerations need to made to ensure that the transition is feasible (Lund 2014).

Several energy plans have been made to analyse the transition to a fossil free energy system in 2050, two of which are considered in this project. These are the Danish Energy Agency's (DEA) report (Danish Energy Agency 2014a), as well as the 'Coherent Energy and Environmental System Analysis' (CEESA) report (Lund et al. 2011). The general technologies are the same in the two reports and in both, the different energy sectors interact to ensure that the energy targets are met. In both reports, different scenarios are analysed and compared based on different parameters; in the DEA's report, the scenarios are formed based on the main focus of energy source, while the CEESA report forms the scenarios based on the available technologies that are assumed to be made available, based on different technological developments.

Despite the differences in the two reports, both conclude that a 100% RE system is feasible in Denmark in 2050. This is based on the socio-economic calculations for the different scenarios in the reports compared to the calculations for the respective reference scenarios. These reference scenarios represent cases in which the energy goals are not met; fossil fuel sources are still used. In the DEA's report, the reference scenario implements the cheapest solutions, whereas in the CEESA report, the reference scenario is based on projections made by the DEA from 2010 to 2030. Furthermore, both reports state a need for the collaboration between the different energy sectors in order for the system to be feasible;

"…it is necessary to integrate the electricity, heat and transport sectors much more than in traditional supply systems based on fossil fuels." (Lund et al. 2011, p. 3)

This form of integration is related to the topic of smart energy systems.

1.1 Smart Energy Systems

The definition chosen for this project is that a smart energy system (SES) is a system in which the different energy sectors (electricity, heat, gas and transport) collaborate in order to create synergies and obtain an overall optimal energy system, seen from a socio-economic perspective (Lund et al. 2011, pp. 138–139). This allows for more flexibility in the system, as well as aids in integrating the fluctuating energy sources. For example, the gas sector can be used for long-term storage, while the heat sector can be used for medium-term storage through the use of, for example, heat pumps, and electric vehicles (EVs) can be used flexibly and provide short-term storage. (Lund et al. 2011, p. 10)

In order to exploit this flexibility, a large amount of data has to be gathered, communicated and processed between different units and actors, and this is envisioned to be done in an automatic and intelligent way, as is described in the concept of smart grids. (Energinet.dk, Danish Energy Association 2011, p. 6) It should be noted, however, that smart grid projects focus mainly on the communication systems, i.e. the IT platform, and the electricity grid. Smart grids are required to efficiently form a SES.

In Denmark, multiple smart grid projects have already been initiated; 22% of all demonstration and development projects in Europe within this field up to 2011 were carried out in Denmark, making the country a clear forerunner (Danish Intelligent Energy Alliance 2011). The large number of initiatives thus shows that Denmark is interested in implementing a smart system.

The next step in the process is then to gain understanding, through demonstration projects, on the efficient synergies between the energy sectors, roles of the involved actors, as well as on how to ensure that the required units (heat pumps, EVs, etc.) are effectively implemented.

1.1.1 Main Advantages of a SES

Seen from a general perspective, there are many advantages regarding the implementation of a SES. The increased flexibility and large scale integration of RE were mentioned previously, and in this subsection, some of the other main advantages are briefly explained.

Socio-economic benefits

As mentioned previously, the DEA and CEESA reports conclude on the feasibility of 100% RE systems based on the socio-economic costs. The costs from the CEESA report can be seen in Figure 1.2, where, for each of the years, the socio-economic costs are lower for the CEESA system compared to the reference system in which fossil fuels are still used.

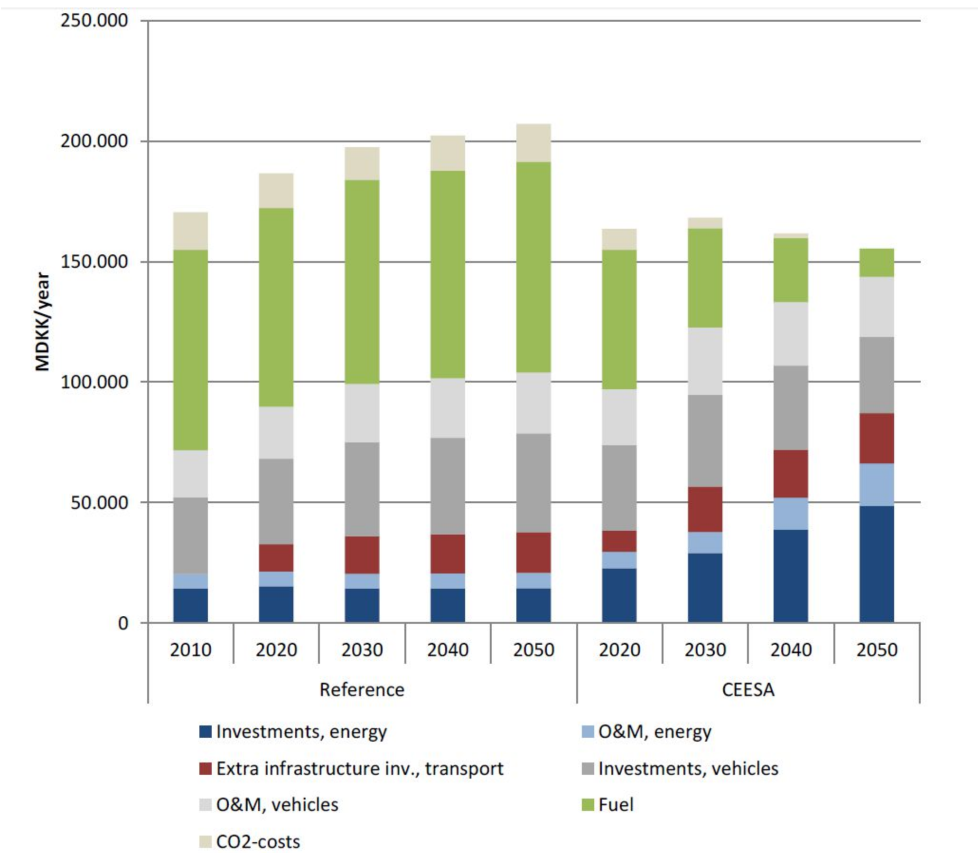

Figure 1.2: Socio-economic costs of reference and CEESA systems (Lund et al. 2011, p. 62)

In the DEA report, the fossil fuel reference system is cheaper than the renewable systems, however this is expected as this reference system only considers the cheapest solutions, regardless of the energy policies made. Despite this, the renewable systems are in the same order of magnitude as the reference, and therefore the socio-economic costs can be considered to be acceptable.

Increase in the value of wind power

With an increasing amount of RE in the energy mix, it can be expected that, under current conditions, the electricity prices will have a tendency to decrease. Low electricity prices, even today, are especially encountered in hours in which there is a lot of wind power, as wind power has a low short-run marginal cost. This can be explained through the merit order curve shown in Figure 1.3.

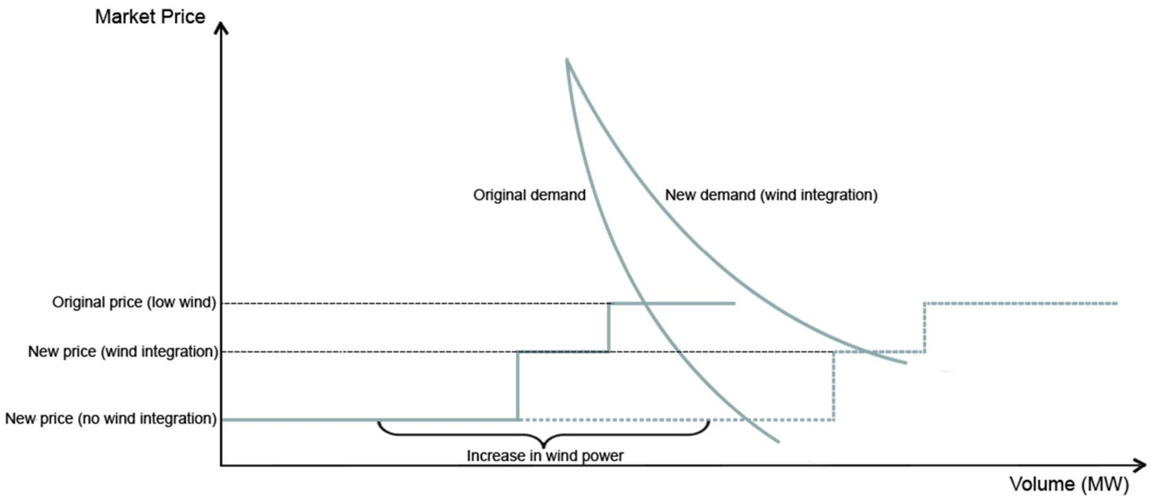

Figure 1.3: Effect on merit order curve of integration of energy sectors

When more wind power is implemented in the system, the electricity supply curve will shift to the right, as shown in the figure. This causes a decrease in the electricity price if the electricity demand curve remains the same. If the demand curve were to increase and thus also shift to the right, this would cause an increase in the price, thus minimising the price decrease compared to the original case. The increase in demand can be obtained through the integration of the energy sectors. For example, if heat pumps are implemented in the heat sector, a new (flexible) electricity demand is introduced. The same can be said for electrifying the transport sector and using power to gas technologies. (Hvelplund et al. 2013)

By increasing the value of wind power, the need for public service obligation[1] (PSO) payment for wind power generation will consequently decrease. Currently, a feed-in tariff[2] (FIT) paid from PSO is provided to wind turbine owners in order to cover the difference between the market price and the long-run marginal costs. Thus, by increasing the electricity price, the difference between the two costs will decrease. As the PSO has recently received a lot of criticism, and there is a general desire to decrease it, the increase in the value of the wind power can be seen as a valuable solution. (Altinget 2014) This is as long as there are options to integrate wind electricity in other sectors, and thereby shift the demand curve to the right.

Less dependency on interconnectors and large power plants for grid balancing

Regulating power, which is explained in more detail in Chapter 4, is currently used in order to ensure a balance in the electricity grid at all times, and thereby the security and quality of electricity supply. Regulating power can be provided through the use of different methods; two of the main methods involve using units such as large power plants and interconnectors. Interconnectors are used to trade electricity between neighbouring countries in the common Nord Pool power market. They can also be used to aid in the balancing of the grid, by activating regulating power in neighbouring countries. Large power plants and CHP units can also be used for up- and downward regulation in moments when the actual electricity production is different from what was predicted, in order to maintain the balance in the grid. (Kop, Zepeda 2015, p. 3)

The Danish transmission system operator (TSO), Energinet.dk, sees a need for the further implementation of interconnectors, connecting more countries and allowing for a larger volume of trade over the interconnectors. This can especially be valuable when increasing the production from fluctuating sources such as wind power, as this could potentially result in a larger need for balancing the grid compared to the current need. However, relying on other countries to provide the required regulating power makes Denmark more dependent on its neighbouring countries. Furthermore, neighbouring countries might increase their amounts of RE from fluctuating sources as well, which could decrease their ability to import Danish surplus electricity[3]. Finally, there is a potential loss of revenue for the Danish society from using the interconnectors, as electricity is generally exported for low prices and imported for higher prices. (Kop, Zepeda 2015)

The Danish TSO states in their strategy plan that there is a need for flexible demand, and therefore a SES could mitigate the problems brought by over-dependency on other countries, as well as limit the amount of surplus electricity (Energinet.dk 2014b, pp. 5–7). By providing storage capacity through units such as heat pumps in combination with heat storages and the batteries of EVs, the

[1] The PSO is a tariff that is, amongst others, given to wind and biomass electricity producers and research in this field, in order to encourage the use and competiveness of RE. (Danish Energy Agency 2014d)

[2] Feed-in tariff is a subsidy agreement for wind turbines which depends on the date of commission. For onshore and nearshore plants a fixed bonus is paid on top of the market price with a maximum price (feed-in premium). For offshore plants a fixed feed-in tariff is settled through a tender procedure. Feed-in tariff agreements are limited to a number of full load hours. (Danish Energy Agency 2014c)

[3] When the supply of electricity in Denmark exceeds the consumption of electricity.

surplus electricity can be stored and used in hours when the power would have been imported (Lund 2014).

At the moment, large conventional power plants and CHP units are used for up- and downward regulation, due to their reliability, response time and ability to offer the required volume, all of which are needed to balance the grid effectively. A SES could decrease the dependency on these plants, as the issue of unreliable fluctuating energy could be solved through the integration of the energy sectors; for example, units such as heat pumps and EVs could potentially play a role in the regulating market. (Lund et al. 2011) In order to meet the energy targets, it is required that the fossil fuels become phased out, and a SES could make this possible.

Although it is clear that a SES could be advantageous for the future energy system in Denmark, the required technologies within the SES need to be analysed in order to determine their potential and optimum use. For each of the technologies, it is relevant to look into the technical and organisational changes required, as well as the economic, social and institutional aspects of implementing them. Furthermore, it is important to consider how the technologies function together in an integrated system, and what synergies might be achieved. These technologies include power to gas units, heat pumps and EVs. In the semester project 'Integration of Large Scale Heat Pumps in District Heating' (2015), written by the authors of this thesis, the integration of heat pumps in district heating is analysed, where it is concluded that their integration, seen from both the district heating company's perspective, as well as an overall system perspective, is economically feasible. In this thesis, the focus is on the role that EVs can play in a SES.

1.2 Plug-in Battery Electric Vehicles as a Part of a SES

Road transportation currently contributes with around 20% of the total energy consumption in Denmark (Danish Energy Agency 2014b, p. 18). A transition towards EVs is seen, both by governments and researchers, as an important aspect for achieving a 100% renewable transport system, as part of a RE system in Denmark. Furthermore, electrification of the transport sector in a renewable energy system should be prioritised where possible, since it is the most energy and cost efficient sustainable fuel alternative. (Connolly et al. 2014) By 2020, 10% of the transport sector's energy demand should be supplied by RE, an obligation that is set through the EU's RE directive (Danish Energy Association 2015). Next to EVs, this could also be achieved by using alternative fuels such as bio-fuels, synthetic fuels, as well as hydrogen for transportation. However, this project focuses on passenger EVs and more specifically on plug-in battery electric vehicles (PEV)[4].

1.2.1 Development of PEVs in Denmark

There are currently no strict goals set by Denmark regarding the amount of PEVs in the future. In an EV Roadmap, made by the International Energy Agency (IEA) in 2011, the DEA presents a target of 200,000 PEVs for 2020, whereas Electric Vehicles International (EVI) reports a target of

[4] In the project the term PEV is used for all battery EVs (full electric and hybrid) with the ability to charge the battery by connecting the vehicle to the electricity grid (plug-in).

50,000 PEVs for the same year for Denmark (International Energy Agency 2011, p. 18). At the moment, about 3,500 PEVs have been sold in Denmark (Danish Electric Vehicle Alliance 2015a), with a significant increase in sales in 2014, as can be seen in Figure 1.4.

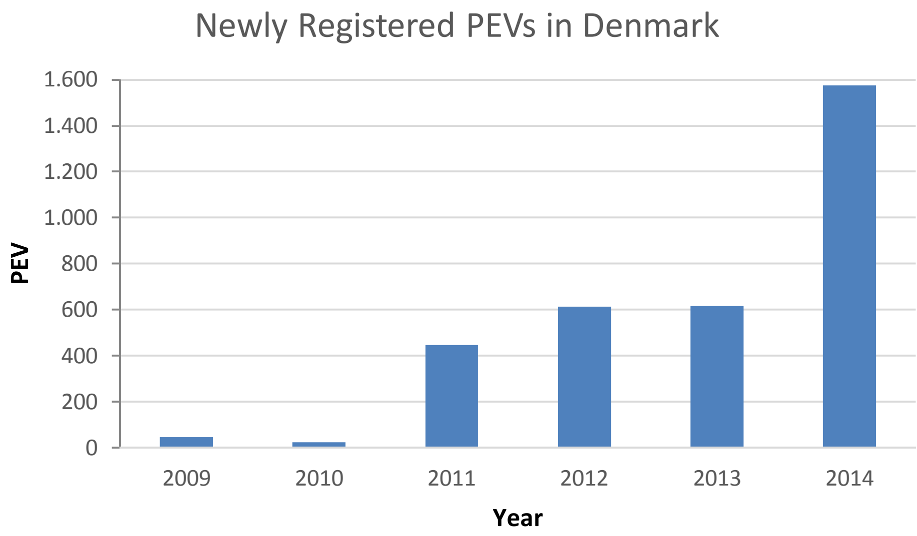

Figure 1.4 Amount of newly registered PEVs in Denmark in the period 2009-2014 (Danish Electric Vehicle Alliance 2015b)

The increase in 2014 is probably related to an increasing amount of available models of PEVs from different manufacturers. However, even with the increased sales in 2014, Denmark is far from reaching the PEV targets set by the DEA and the EVI for 2020.

The purchase of PEVs is currently supported by the Danish government through an exemption from the registration tax. This initial registration tax for conventional vehicles amounts to 105% of the vehicle's value up to 81,700 DKK; for more expensive vehicles the initial registration tax is 180%. (SKAT 2015a) The amount paid in registration tax is then adjusted based on the fuel consumption of the vehicle[5] (Retsinformation 2013). Furthermore, PEVs are not subjected to the green ownership tax, which is an annual fee that is based on the fuel type and consumption of the vehicle. For example, a gasoline driven car with a fuel usage of about 10 km/l has to pay about 6,500 DKK/year, whereas if its fuel usage is about 20 km/l, it only pays about 600 DKK/year (SKAT 2015b). The exemptions on the registration and green ownership taxes last until the end of 2015, however, at the moment it is expected that support for PEVs will be extended to 2016. (Politiken 2015)

[5] Vehicles that perform better than 16 km/l and 18 km/l, for gasoline and diesel vehicles respectively, receive a discount on the registration tax of 4,000 DKK/km/l (limited by a minimum total registration tax of 20,000 DKK). Vehicles with a lower performance receive a tax increase of 1,000 DKK/km/l.

Despite the support for PEVs, the share of PEVs is currently around 0.2% of the total amount of passenger cars in Denmark, based on numbers from Statistics Denmark (2014). A survey done for the Danish Electric Vehicle Alliance in 2014 shows that customers have limited knowledge regarding PEVs, e.g. they are unaware of the potential savings of driving a PEV compared to a conventional vehicle. Their main concerns towards a PEV are a limited range of the vehicle, the high price and limited charging possibilities. However, one out of six respondents state that they would consider a PEV for their next car. (Danish Electric Vehicle Alliance 2014)

It is hard to predict how many PEVs there will be in Denmark in the coming years. A lot will depend on the financial support for PEVs. The technology of the PEV is constantly improving, resulting in an improved efficiency of the motor as well as the battery, which affects both the range and the price of the vehicle (CleanTechnica 2013). Both the CEESA and the DEA’s future energy plans have included PEVs as a significant part of their prediction of the future energy system.

1.2.2 Smart Use of PEVs

The PEVs that are in use at the moment can be seen as additional electricity consumption units and thereby an extra load on the grid, which can potentially cause problems mainly in the distribution grid[6]. In a research carried out by EA Energy Analyses and published in “Grid integration of electric vehicles” (Wu 2013), the effect of a 25% electrification of the Danish personal vehicle fleet on the distribution grid is analysed. It is concluded that, when the charging is not managed, a high PEV penetration may cause problems in the distribution grid. However, if charging is done in a smarter way, more than 3.5 times more PEVs can be incorporated in the distribution grid. Figure 1.5 illustrates the additional load on the distribution grid if 75% of the PEVs start charging when coming home from work (picture on the left) and the same charging load if it is spread out over the night hours instead (picture on the right).

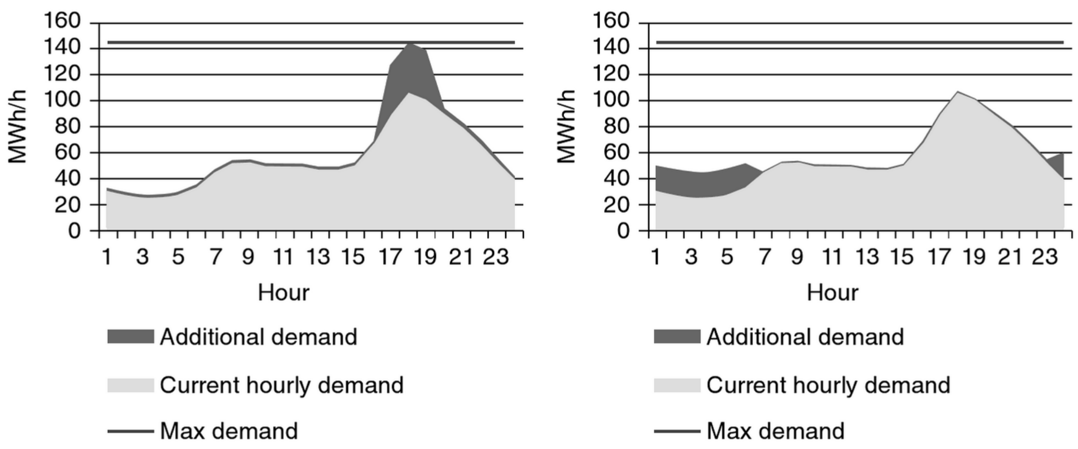

Figure 1.5: Effect of charging on the distribution grid with 25% of the Danish personal vehicle fleet electrified (Wu 2013)

[6] In this report, the term distribution grid is used for the low voltage grid, also referred to in literature as the local grid.

Due to a lack of incentives, charging strategies and bidirectional communication possibilities, PEVs are currently unable to be used to benefit the grid operation. (Pillai et al. 2012) However, PEVs can potentially benefit the electricity system in several ways by utilising demand response. Different researches have proven the theoretical value of PEVs in the electricity system both from a system, as well as a vehicle owner's perspective, and therefore see PEVs as an important part of a SES. (Kempton, Tomić 2005b; Downing et al. 2011; Lund, Kempton 2008b) Due to the storage capacity of the batteries in PEVs, and relatively small amount of hours that are required to charge the battery to the desired level, the charging can be optimised in several ways. The moment of charging can be shifted to hours where the electricity price is low or to periods with a high share of RE, or the moment of charging can be based on the needs of the distribution system operator (DSO) and/or TSO. By utilising this demand response, a potential overload on the distribution grid can be avoided and PEVs can aid in the balancing of the transmission grid[7], as well as improve the integration of RE, while potentially providing savings for the vehicle owners. (Pillai et al. 2012; Kempton, Tomić 2005b)

In order to make the optimisation of the charging possible, PEVs need to be able to shift the moment of charging, as well as the charging load. Furthermore, PEVs need to be pooled together to be able to meet bidding requirements for, e.g. the regulating power market (RPM). An aggregator is an entity that is expected to be required in the future, to pool PEVs together and optimise the charging strategy for its customers. Bidirectional communication between the vehicle/charging point and the aggregator is needed to acquire the required data to determine the optimal charging strategy and control the charging of the vehicle. Next to these demand response based services, PEVs are able to increase the level of service they can provide to the electricity system in case connected PEVs are able to discharge. Such a system requires bidirectional charging infrastructure to allow for delivery of electricity from the vehicle back to the grid and is called a vehicle-to-grid (V2G) system. A V2G system could potentially increase the savings for PEV owners, compared to only providing demand response based services to the system. (Hosseini et al. 2012)

1.3 Research Question

With an increasing amount of RE in Denmark, it is expected that larger challenges will appear in the energy system due to the fluctuating sources used. This is especially for the wind power production that is expected to increase in the future. Currently, most of these challenges are overcome through the use of conventional power plants and CHP units, as well as interconnectors. Already in the current system these solutions are not always assessed to be optimal. The concept of a SES, in which the energy sectors collaborate in a smart way, is in theory seen as a valid way to meet the goals and targets regarding a RE system in Denmark. With regards to the transport sector, a green transition is envisioned for the future, and within this, it is clear that PEVs can become an important asset in a SES. They can, among other things, bring socio-economic benefits

[7] In this report, the term transmission grid is used for the high voltage grid, also referred to in literature as the national grid.

for society, including economic benefits for the PEV owner, aid in increasing the value of wind and making Denmark more self-sufficient, and provide a flexible demand response to avoid overload in the distribution grid and for balancing the national grid.

However, at the moment, PEVs are not being used to support the electricity system. It is generally unclear to what extent PEVs could play a role in the Danish energy system. From the PEV owners' perspective, it is unknown to what degree smart charging, with or without V2G, could improve their business case, as well as what their perspective is on having their PEVs being controlled by an aggregator to provide services to the electricity system.

This project looks into different strategies for how PEVs can be used to aid the electricity system and the potential income this can provide for the PEV owners. Furthermore, this project focuses on how a system could be organised that increases the feasibility of integrating PEVs in a SES; which actors have to be involved and what their roles have to be. This results in the following research question:

What role can plug-in battery electric vehicles play in the current and future Danish energy system?

In order to answer this research question, the following sub-questions have been formulated:

- To what extent can plug-in battery electric vehicles integrate wind power and provide balancing services to the electricity grid?

In the future, there is a need for new solutions for integration increasing volumes of fluctuating RE, as well as for balancing the electricity grid due to the transition into a 100% RE system. It is expected that PEVs can play a role in a SES as part of the solutions, however, the extent of this role is currently unclear. It is considered both relevant and interesting to evaluate this extent for both the current and future energy systems.

- What potential gains are there for the vehicle owners when smart charging is enabled by an aggregator?

There is a potential for PEVs in a SES to provide socio-economic benefits for the system, including benefits for the PEV owners. In order for the PEVs to play a role in the energy system, their owners must first approve of their use for this purpose. It is thus considered to be an imperative point to consider and the benefits for the owners are therefore evaluated in this project, as it is assumed that economic incentives is a major factor.

- How should the involved actors be organised to enable this role?

In order to promote the optimal flexible use of the PEVs, it is expected that certain actors are required to be involved, as well as there to be a collaboration between these actors. Their current influence on these matters, as well as their potential roles in the future are thus considered.

- What is the attitude of PEV owners towards having their vehicles being used in a smart way?

As the PEV owners are key actors in the realisation of the flexible use of PEVs to benefit society and the energy system, their perspectives regarding this matter are important to determine. This is not something that has currently been done to a large extent, as the owners are often under prioritised in studies made about PEVs. Evaluating the perspectives can thus give a better idea of the requirements and possibility for using the PEVs in a SES.

The project has a focus, within the Danish energy system, on the electricity grid and within the electricity market, specifically on the price area of Western Denmark; DK1. The focus is on the current system and the predicted system for 2025.

1.4 Project Limitations

There are some limitations in this projects that would otherwise have been subjects worth researching, however, for reasons of time and focus, these are chosen to be out of the scope of the project.

It is chosen to investigate the role of the PEVs in a SES due to the benefits it could bring; socio-economic benefits, increase in the value of wind power, etc. These mentioned benefits, as well as the value for the distribution grid, are not evaluated directly in the project. Instead, the analyses in this project should be seen as an initial evaluation of the potential of the PEVs, in order to gain a better understanding of their use, as well as the requirements for this use. Further research into factors such as the socio-economic benefits can then be made.

Integration of RE in the heating sector, as well as power to gas technologies in a SES, are not part of this project. Furthermore, the interaction between the technologies in the different sectors is not considered. As mentioned previously, it is chosen to focus solely on the role of PEVs in a SES. It is clear that a SES requires the implementation of all the mentioned systems, however, it is assessed to still be relevant to focus on the role of PEVs individually.

In the model analysis, it is assumed that 20,000 PEVs can be implemented into the transport sector in 2025. This is required in order for the PEVs to play a more significant role in the balancing of the electricity grid. In the project, a detailed analysis is not made on how and if these vehicles are actually implemented, however, both the RE goals in Denmark, as well as the future energy plans that have been made, expect the implementation to occur.

When evaluating the costs for the PEV owner in the model, consideration is not made regarding the relevant taxes and tariffs. This point is an important factor to consider, however, the model is used to show the potential of the PEVs in a SES, where it is assumed that, in a future case, the regulations will be changed to the advantage of RE systems, and thus also the flexible use of PEVs. Furthermore, considerations are not made on the costs relating to the battery due to the flexible use of the PEVs, or on the required investments for the infrastructure on both the vehicles and the grid. As previously, it is assumed that solutions will be found in the future for these factors, in order to attain the benefits from using PEVs in a SES.

In the model, the effect of the charging strategies on the distribution grid is not analysed in detail. This could be done, for example, through the use of a power simulation tool such as Power Factory. This could bring further knowledge of how the strategies affect the grid, as well as the benefits and limitations of implementing the strategies. Furthermore, using such a tool allows for the inclusion of other units such as photovoltaic panels.

In the model, the PEVs have the possibility to discharge electricity to the grid. The discharging is limited, however, to only being used when the PEVs are participating in the RPM. This is due to the assumption that discharging to a greater extent will cause barriers towards the acceptance of the PEV owners in allowing the use of their vehicles, as the discharging could affect the battery lifetime.

1.5 Report Overview

In Chapter 2, the theoretical framework and methodology are presented, where considerations on the system environment regarding PEVs in a SES are described. The different methods applied in the different analyses are also explained. In Chapter 3, the model analysis framework is shown, in which a description of the charging strategies chosen is presented, as well as the technical requirements to allow for said strategies. Chapters 4 and 5 look into answering the first two sub-questions, in which the model background and structure for analysing the strategies is first described, after which the results from the scenarios evaluated is presented. Chapter 6 looks into the final two sub-questions, in which the relevant stakeholders are analysed and described in relation to the project topic, and where especially the PEV owner is described in detail according to the results of the survey made for the project. Chapter 7 looks into forming a system design and recommendations for how to promote and implement the charging strategies analysed, also taking into consideration the relevant stakeholders. Chapter 8 presents the main conclusions of the project, and Chapter 9 the perspective analysis, in which a brief evaluation is made on further aspects also relevant to the topic.

2 Theoretical Approach and Methods

In this chapter, the theoretical framework and methods applied in the different chapters are presented. This is done in order to give an overview of the process through which the research question is formulated, analysed and concluded on, as well as to discuss the opportunities and limitations of using the different methods. The theoretical framework relates to the developments in the system environment.

2.1 Developments in the System Environment

In this section, the factors that have influence on the transition towards the smart use of PEVs in a SES, but which are not directly part of this project, are discussed. This is done in order to show the understanding of the system environment and the expected development in this, in which this project is placed. Figure 2.1 shows a representation of the system environment in which the factors are grouped in four groups; political, technical, market development and competition.

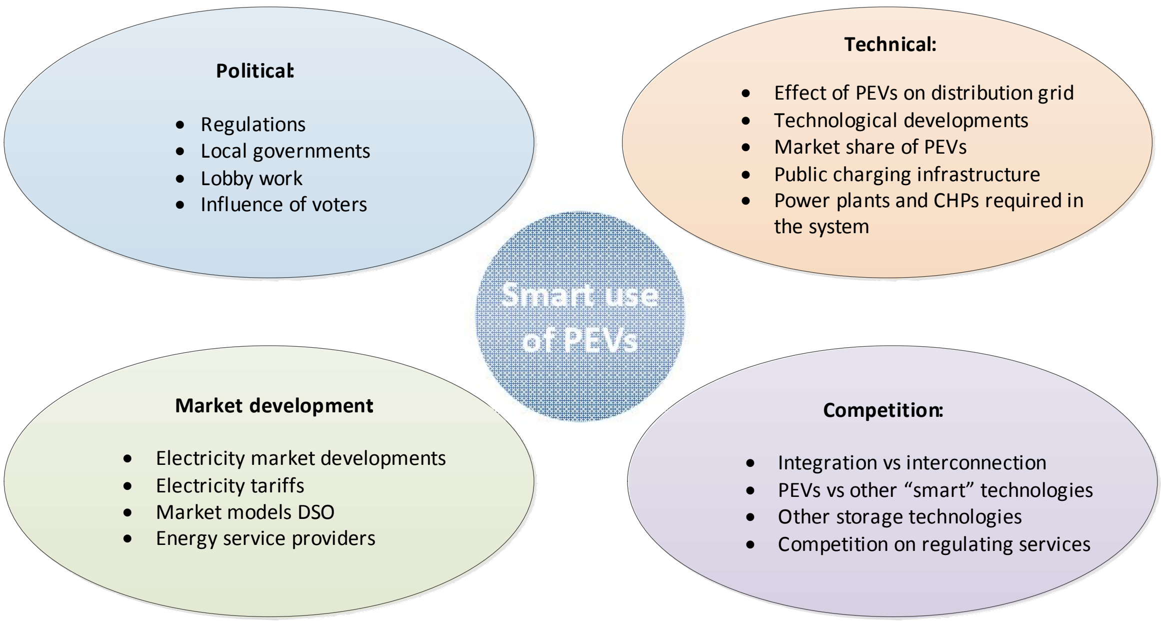

Figure 2.1: Presentation of system environment

2.1.1 Technical

The charging of the PEVs has a direct impact on the distribution grid, nevertheless, with the current amount of PEVs in the system, this is not expected to be a problem. However, towards a future with more PEVs, avoiding grid overload in the distribution grid may become part of the charging strategies of PEVs, next to the charging strategies analysed in this project. Technologies are developing on all levels; batteries are expected to be able to charge faster, have an improved capacity/weight ratio and be able to do more charging cycles without an effect on the battery lifetime. The charging infrastructure is developing, which enables more flexible charging, both in time and load, connection to smart meters and bidirectional communication. It is expected that more differentiation will be seen in the types of PEVs that will be available on the market. The development of the market share of PEVs in Denmark is unknown; a lot will depend on, next to the technological developments, the price competiveness with conventional vehicles and the governmental support. The amount of PEVs has a significant influence on the impact PEVs can have on the electricity market and to what extent they can provide services to the grid by offering flexibility. The role of public charging infrastructure regarding the smart use of PEVs might increase in the future. Public charging infrastructure has a negative business case at the moment; this creates opportunities to allow for smart charging and offer the flexibility of the PEVs connected to public charging points to the system and thereby improve the business case of the infrastructure. This is, however, outside the scope of the project, where the focus is on PEVs that are connected to home chargers. PEVs in a SES are expected to replace conventional power plants and CHP units in regard to providing regulating services to the grid. The might affect the business case for these conventional units. However, these electricity and heat suppliers are still required in the system to meet the heat demand and provide electricity in hours where RE and/or import cannot meet the electricity demand. This creates a potential dilemma, which is not included in the project, but is expected to play a role in the future of the Danish energy system.

2.1.2 Competition

There are generally two ways of dealing with high shares of fluctuating RE production; either by connecting to other electricity grids through interconnectors, or by integrating the RE in other energy sectors as proposed in the SES. It is not necessarily a matter of either interconnectors or integration, but a strong focus on interconnectors limits the potential for integration. The role PEVs can play in a SES is therefore dependent on the extent to which the Danish electricity system is going to focus on interconnectors. The Danish electricity grid is currently connected to Norway, Sweden and Germany. Norway and Sweden have large amounts of hydropower, which is one of the main sources for cheap regulating power in Denmark, as long as there is capacity available on the interconnectors. PEVs have, next to the interconnectors, competition from other units that can provide regulating services and flexibility by demand response. These units can be household units such as heat pumps or home batteries, but also larger units such as heat pumps and electric boilers in a district heating system and the aforementioned power plants and CHP units. Most of these units are expected to become part of a SES, which thereby forms competition for the role PEVs can play in, for example, regulating services in the national grid. From a system perspective, more flexible units than just PEVs are required to go towards a 100% smart RE system. However, this competition makes it hard to predict what volumes in the different parts of the market are available for PEVs. The effect of these different forms of competition are only to a small degree incorporated in the analyses done in this project.

2.1.3 Market Development

The electricity market is slowly, but constantly, developing. The Nord Pool Spot market was initially not designed for an electricity system with high shares of fluctuating RE, or the introduction of demand response. Within the Nord Pool electricity market, changes are expected in the very near future, such as a decrease in the bid size in the RPM from 10 MW to 5 MW. In the further future, a five minute real time market might be introduced. The traded volumes and prices in the different parts of the market are changing all the time and are hard to predict. The volatility of the electricity market is expected to increase due to increasing amounts of fluctuating electricity production. These dynamics make it hard to predict the (future) role PEVs can play in the electricity market and the savings they might obtain. The way electricity is sold to customers is also likely to change; flexible tariffs might be introduced, as well as changes in tariffs for electricity that is sold back to the grid. New market models are expected, also on the level of the DSOs, in order to optimise the distribution grid. The right incentives are required in order to utilise the potential flexibility that PEVs can offer. The transition towards smart charging of PEVs is therefore dependent on aspects like flexible electricity and distribution tariffs. In the model analysis in this project, the PEVs are already expected to be able to determine the moment of charging with the help of an aggregator, based on the Elspot prices or wind shares. Flexible tariffs for electricity distribution are not included in this project. Insight in matters such as the electricity consumption, when the PEV is charging and how much wind electricity is used to charge the vehicle, can be provided by energy service providers. These services may increase the involvement of PEV owners in having their vehicles being controlled by an aggregator to optimise the moment of charging.

2.1.4 Political

Different governments have a lot of influence on how transitions develop, and the same applies for the transition towards PEVs in a SES. Governments try to steer behaviour and transitions through regulations. Examples of such regulations are subsidies for PEVs, RE goals, PSO tariffs to support RE, electricity taxes and standardisation requirements. The decision making is influenced by lobbyists from different sectors and the ruling parties based on elections. Local governments might have different goals than national governments, which again might be different from governments at the European level. Certain kinds of standardisation are required in order to optimise the introduction of smart charging for PEVs, for example, to prevent that PEVs of some brand are incompatible with a certain type of smart charging infrastructure. This is something that should be organised by governments, as it is important to achieve a smart use of PEVs. A lot of regulations will have influence on the development of this transition, however, it is hard to predict which regulations there will be in the (near) future.

2.2 Methods

In this section, the different methods used in the project are presented in an overview of the relevant individual chapters, which can be seen in Table 2.1. These methods are used to answer the sub-questions from the research question, and include: literature study, statistical data, various forms of correspondence with relevant actors, and modelling, all of which are subsequently discussed in more detail. In the table, the chapters are placed under the relevant sub-questions.

Chapters	Methods
1. Problem Analysis	Literature study
Sub-question 1 and 2	
3. Model Analysis Framework	Literature study, interviews, e-mails
4. Modelling of PEV Charging Strategies	Literature study, statistical data, interviews, e-mails, survey, Excel modelling
5. Charging Strategy Analysis	Statistical data, Excel modelling
Sub-question 3 and 4	
6. Stakeholder Analysis	Literature study, interviews, e-mails, survey
Concluding remarks	
7. System Design and Recommendations	Literature study, interviews, e-mails, survey

Table 2.1: Methods used in the project

2.2.1 Literature Study

The information gained from studying a variety of literature is used throughout the project. During the first phase of the project it is used to determine what problem to consider and to limit the scope of the project. It is also used to obtain an understanding of the problem being addressed; its relevance and extent, and what the status is regarding trying to solve it. From this, a research question is formulated.

In the remaining analysis chapters in the project, literature is used in two main ways; the first is to better understand the current roles that the different actors play, and which ones they could play in a future energy system. Secondly, literature is used to gain the information needed to make a model that represents realistic situations in Denmark, both for current and future scenarios, so that the results from the analyses can be validated. For example, knowledge of how the electricity market is operated is needed in order to determine how to model using PEVs for different regulation strategies. Furthermore, the information gained from this literature can be used to form the system design and policy proposals.

There are various sources of literature that can be used; internet websites, articles, reports, etc., all the mentioned ones of which are used in this project. In order to ensure that the information found is usable, literature from acknowledged and reliable sources is used. This could be known authorities such as Energinet.dk, Nord Pool Spot, the DEA, the Danish Electric Vehicle Alliance and Danish distribution systems operators (DSOs), as well as experts within the field from different Universities, many of whom have their work peer reviewed by other experts. Where possible, the most updated literature is used, and the different sources are compared to obtain objective and relevant information.

2.2.2 Statistical Data

Statistical data can be used for different purposes; it can, among other things, be used in the formation of models, and it can also be gathered and analysed in order to conclude on factors relating to the data. Both of these methods are used in this project. These methods can provide a more extensive understanding of the information gained from the literature study, and allows for new analyses to be made.

Formation of models

For the Excel model, which is described in Subsection 2.2.4, statistical data concerning the prices and traded volumes on the Nord Pool electricity market, the wind production and the availability of the PEVs for each hour is used. The market and wind data is obtained from Energinet.dk and Nord Pool Spot's websites, where hourly data is made available for numerous topics relating to the electricity market for different years (Energinet.dk 2015b; Nord Pool Spot 2015b). As mentioned previously, the Danish TSO and Nord Pool Spot are considered reliable sources, and their data is widely used and accepted. Predictions of the mentioned market and wind data for the future are also used in the model, and are obtained again from reliable sources such as the TSO, as well as from the correspondence described in Subsection 2.2.3.

The hourly data on the availability of the vehicles is taken from a report made by the Centre for Electric Technology from the Technical University of Denmark (Wu et al. 2010). The data from this report is taken from over 130,000 survey results[8] given to the University by the department of transport within the University, and therefore the data is also considered to be reliable. The raw data points for finding the availability are not freely available, and therefore a programme is used in this project to plot the points based on the figures from the source, an example of which can be seen in Figure 2.2.

[8]Transportvaneundersøgelsen (TU) which can be found here:
http://www.modelcenter.transport.dtu.dk/Transportvaneundersoegelsen

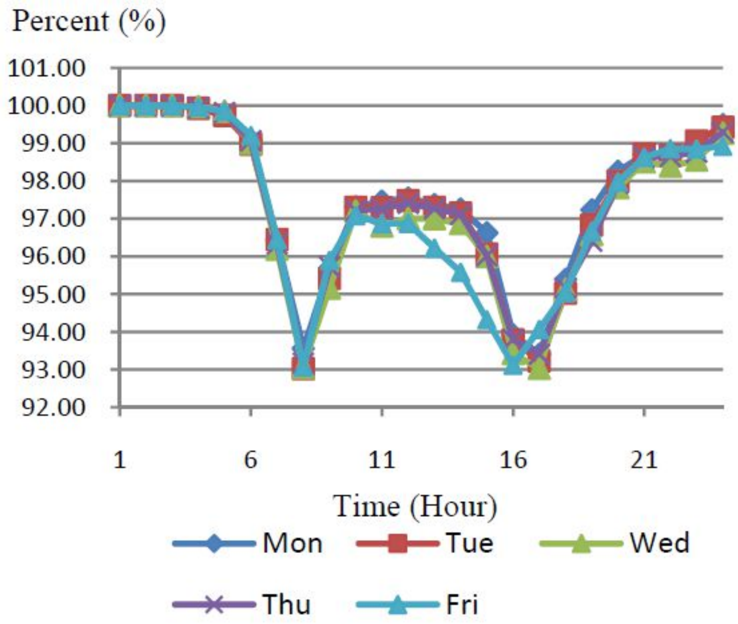

Figure 2.2: Hourly availability data for vehicles from TU (Wu et al. 2010)

This is seen as a limitation in the model, as there is a risk of errors in the measurement. This is not, however, expected to affect the results significantly, as the measurements are assumed to not deviate from the original data to a large degree. Furthermore, it is expected that this data can be used as a basis for all the scenarios, both current and future, as it is not expected for driving behaviours to change considerably within the timeframe of the model.

Apart from the raw availability data for vehicles from the TU, data concerning hourly parking locations and driving demands is not freely accessible either. The first set of data can give information regarding the portion of the vehicles that are parked at home chargers for each hour, which is required for the model, as only home chargers are considered. The second set of data can give information regarding the driving demand of the vehicles for each hour. In the model, assumptions are made to simulate this data, which can result in uncertainty in the results, however, this uncertainty is not expected to be significant.

For the calculation of the total annual cost for the PEV owners in the model, statistical data is used to estimate the effect on the electricity price due to the implementation of the PEVs. This effect is explained through the merit order effect, as discussed in Chapter 1, where an increase in the consumption of electricity causes the electricity supply and demand curves to intersect at a higher price level. The increase in consumption in this case is a result of the charging in the day-ahead market of the implemented PEVs in the model. In order to estimate the effect on the Elspot price due to the increase in consumption, a correlation is used, which can be seen in Figure 2.3.

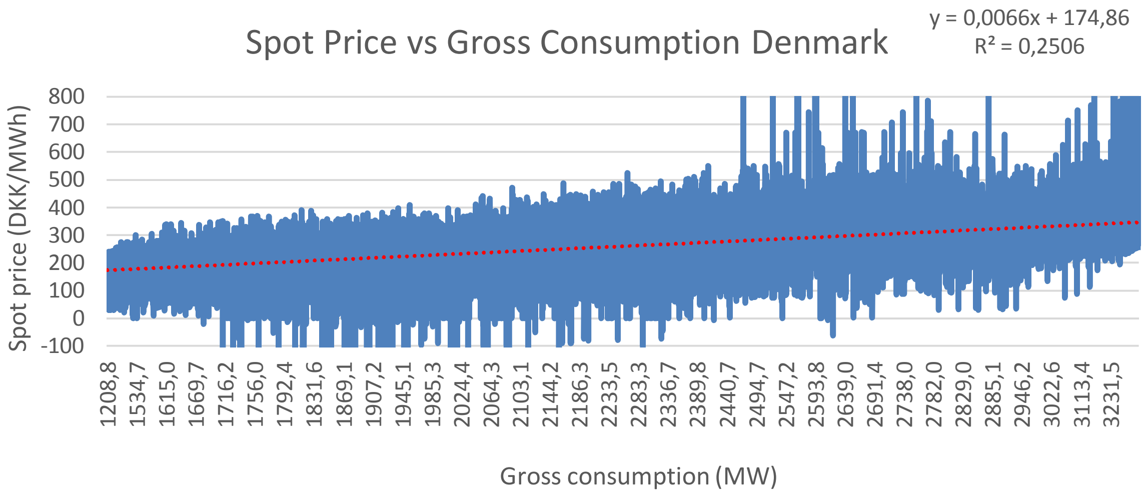

Figure 2.3: Correlation between Elspot price and gross electricity consumption in DK1

Here, hourly Elspot prices are compared to the corresponding gross electricity consumptions, which are sorted in ascending order for 2012-2014, and a trend line is found. The gradient of the trend line is:

$$Gradient = 0.0066$$

This means that an increase of the electricity consumption in one hour by 1 MW results in an increase of 0.0066 DKK/MWh for the Elspot price. This method is inspired by the draft research article "Renewable Energy Subsides and Integration of Energy Sectors" (2015). The correlation found in the figure provides a rough estimate of the effect on the Elspot price, and it should be noted that in reality the Elspot price is influenced by more factors, for example, the supply of electricity. Finding a more accurate correlation is out of the scope of this project, and therefore the simplified correlation found is used, despite the low coefficient of determination. Due to the low gradient, is it expected that the inclusion of the effect on the Elspot price will not change the final results of the model to a great extent.

For the RPM, the price is also affected due to the implementation of the PEVs. For this, the correlation in Figure 2.3 is used if PEVs are used to regulate in the RPM, again due to the merit order effect.

Only data from the price area relating to the western part of Denmark, DK1, is used, as only this area is considered in the model.

Gathering and analysing

For the second use of the statistical data, the results from the model are gathered, analysed and concluded on. Furthermore, a survey, described in Subsection 2.2.3, is made for Danish PEV owners. In order to consider the data from this survey to be useful, it is chosen to set the required amount of responses to at least 100. This value represents about 3% of the PEV owners in Denmark at the end of 2014 (Danish Electric Vehicle Alliance 2015b). In comparison, the data from the TU survey represents about 6% of the total passenger cars in Denmark (Danmarks Statistik). A higher amount of respondents gives a more realistic representation of the Danish PEV owners' general perspective, however, within the time frame given for the thesis, a higher amount is challenging to obtain. This is discussed further is Subsection 2.2.3.

2.2.3 Correspondence

Correspondence can generally be used to gain information that is not openly available in literature study and statistical data, as well as to obtain more detailed information about specific topics. Correspondence in this project is in the form of interviews, e-mails and a survey. Each of the methods has benefits and limitations, determining their use in the project. All of the audio files and transcriptions of the interviews made in the project, as well as the e-mail correspondence and survey, can be found on the attached CD (Appendix D).

Interviews

Semi-structured interviews are conducted for the project. What is meant by this is that questions are formed and sent to the interviewees prior to the interview. During the interview, the questions are asked, however, both the interviewer and interviewee are able to add or modify the questions to get a better flow, as well as to get more out of the interview. This is considered to be an effective method for obtaining relevant information about the topic, as the actual experts can also influence the topics discussed. The transcriptions of the interviews are sent to the interviewees in order to allow them to change or add anything if considered necessary. Doing this ensures that the information in the transcription is correct, as misunderstandings of the answers can occur in the interview.

Both explorative and expert interviews are conducted. Explorative interviews are generally used to attempt to find relevant factors and problems that can be used to further develop the research question or focus points in the project. For these, more general questions are asked, or questions relating to multiple topics. Expert interviews generally have more specific questions, or questions relating to a more narrow set of topics. In Table 2.2, the four interviews conducted in the project can be seen, relating to their interview type.

Interview partner	Explorative interview	Expert interview
NRGi, DSO	x	x
DONG Energy, DSO	x	x
Energinet.dk	x	x
Energi Nord, utility company		x

Table 2.2: Interviews conducted for the project

Regarding the interviews with the DSOs and the TSO, they are classified as both explorative and expert, as some of the questions and topics in them were more general, whereas others were more specific. These interviews were conducted during the first part of the thesis period. The interview with the utility company was conducted later in the period, and therefore a clearer focus was already formed for the project. This allowed for more specific questions relating to the focus of the project. The combination of the two types of interviews during the thesis period provided a strong foundation for the analyses done.

The first three interviews were conducted through the video conference programme Lync, while the last one was conducted at the office of Energi Nord. Although it is generally favourable to have the interview face to face, having some of the interviews through Lync both saved time that would otherwise have been used for travelling, and proved to function satisfactorily. Most of the interviews were conducted in English, which could potentially cause language barriers as Danish is the mother tongue of the interviewees, however, this was not deemed the case for the interviews for this project.

One interview conducted for the 3th semester project of the authors is used in this project, as the information obtained from it is deemed relevant for the stakeholder analysis. This interview was with the Dutch charging infrastructure company ElaadNL, and the transcription of the interview can also be found on the attached CD.

E-mail

E-mail correspondence can be used for multiple purposes. In this project, it is used to contact relevant stakeholders to plan interviews, for information and statistical data for the analyses, as well as a means of distributing the survey, which is described later in this subsection. For the first two purposes, e-mails were, for example, sent to various DSOs, utility and car companies, Energinet.dk, NEAS, as well as Dansk Elbil Alliance.

The majority of the contacts did not reply to the e-mails, which presents one of the limitations regarding the use of this form of correspondence. Another limitation is the time that it takes for some contacts to answer back, making it more challenging to incorporate the information gained into the analyses in the project. On the other hand, e-mails present an opportunity for obtaining information and data, when the stakeholders are unable to participate in an interview, or when there are too few questions for an interview. They are also less time consuming to process, as transcribing is not done.

Generally, although a lot of time was used for preparing and sending the e-mails, the method is considered relevant and useful for the project. Gathering information and data from multiple DSOs and utility companies allows for a more general representation of the stakeholders, and each contact is deemed reliable and relevant for this project.

Regarding the survey, e-mails were sent to multiple contacts related to PEVs: Dansk Elbil Alliance, Dansk Elbil Komite–din elbil klub, Forenede Danske Elbilister, as well as various other PEV enthusiasts. Doing this provided a network through which the survey could be distributed.

Survey

As mentioned previously, a survey is made for PEV owners, in which both general and specific questions are asked. The general questions mainly relate to the charging characteristics of the PEV, as well as the driving and charging behaviour of the PEV owners. It should be noted that respondents leasing PEVs are also included in this. The more specific questions relate to the flexible use of the PEV, and the PEV owners' perspectives regarding this. A minimum of 100 respondents is considered to be required for the survey, in order to be able to use the results to make a general representation of the PEV owners in Denmark.

The programme SurveyXact is used, as it is made available through Aalborg University, and it provides possibilities for the creation and analysis of the survey that are difficult to acquire through other programmes such as SurveyMonkey and other free survey tools. This includes various tools for professionally setting up the survey, as well as filtering and exporting options for the generation of the results.

Surveys can be useful, as a large amount of constructive information can be gained if the survey is widely distributed. This is both due to the shorter time that it generally takes to fill a survey compared to conducting an interview, as well as the anonymity of the results from the survey. As mentioned, a wider distribution allows for a more accurate representation of the group of people to whom the questions are relevant, compared to, for example, an interview. In some cases, new contacts can also be made, to who follow up questions can be asked for a better understanding of the results from the survey.

Some limitations of using surveys include the time that it takes to distribute the survey, gather enough respondents, and analyse the results from the survey. In this project, the survey was first distributed approximately three months prior to the deadline for handing in the project. There were 105 respondents, however, the last respondent submitted his/her answer one month prior to the deadline. This limitation was considered in the project, however, sending out the survey so early in the thesis period resulted in the exclusion of some questions that may have been useful, but were not considered until after the survey was made. This limitation can be mitigated through further contact with the respondents, however, due to time restrictions in the project, this is not done. To gather the amount of respondents needed, the survey was distributed through e-mails, paper flyers, as well as social media, as can be seen in Figure 2.4 and Figure 2.5.

Figure 2.4: Distribution of survey through paper flyers

Figure 2.5: Distribution of survey on Facebook

Using social media provided the majority of the respondents, however, a considerable amount of time was required to enable this distribution. A further limitation comes from the misunderstandings that could arise from the questions, which could be avoided in an interview.

Specific to the survey for this project, it should be made clear that the majority of the respondents are what can be called 'first movers' within the topic of PEVs. This group of people are PEV or RE enthusiasts, who do not necessarily represent the PEV owners of the future. On the other hand, as they are first movers and enthusiasts, it is expected that the time it took to gather the necessary respondents was shortened, and useful information was gained from the extra comments given in the survey.

Despite the limitations of using a survey, this method has provided relevant in depth knowledge regarding the behaviour and viewpoints of PEV owners in Denmark, both of which are invaluable for the analyses made in the project.

2.2.4 Modelling

The model in the project is made in the programme Excel, and it simulates the charging and discharging that is done by a set number of PEVs in the different parts of the Nord Pool electricity market in time steps of one hour. These different parts are the: day-ahead market (Elspot), intraday market (Elbas), RPM and reserves. The purpose of the model is to evaluate the costs for the PEV owners, the potential for integrating wind power, and the role that the PEVs can play in the different parts of the market, all for different charging strategies and scenarios. As is explained in Chapter 3, three strategies are considered: dumb charging, which is used as a reference for the rest of the strategies, national balancing with a focus on low Elspot prices, and national balancing with a focus on the integration of wind power. An additional analysis is also made regarding the use of PEVs in the RPM. More strategies are not analysed, however, the model is designed in order to be able to create and simulate new strategies.

It is assumed that, in order to enable the participation of PEVs in the electricity market, an entity called the aggregator is required. Theoretically, this actor is able to pool different PEVs together in order to make bids in the different parts of the market. This model can thus be seen as a tool that could be used by an aggregator in order to determine the charging strategy that could be applied onto the pooled PEVs.

From the literature study, it is known that several simulations for the electricity market have been made for various studies, however, these are not considered as an alternative for the Excel model in this project, as they are either limited regarding which parts of the market are included, or which units are accessible. An example of such a program is EnergyPRO, which has the possibility of implementing the day-ahead market. If experienced with the programme, it is also possible to implement the RPM and, to some extent, the other markets, however the interface for this is not advanced. Besides not directly including all the markets, this part in EnergyPRO is still in the process of being tested and improved. (Sorknæs 27/05/15) Excel allows for the inclusion of all the parts of the market, as well as the possibility of setting and changing priorities and strategies. Furthermore, it can give a clearer idea of where problems or barriers could occur regarding the participation of the PEVs in the different parts of the market. A limitation of Excel arises due to the circular references that can occur from the interactions between the markets and reserves in combination with the modelling of the battery. This can be avoided by using system dynamic simulation programmes where continuous variables can be modelled, however these programmes are not well suited as most data for the model is hourly based and thus discrete.

The model is hourly based, and the analyses are done over a timeframe of one year. This allows for more detailed and accurate analyses than could otherwise be done for a larger timescale. Furthermore, the data used in the project is provided on an hourly timescale, making it more convenient to use if the model is hourly based. Furthermore, prices are provided and bids in the different parts of the markets are made for each hour, and therefore the decision process for the bids should also be made for each hour. It should be noted, however, that the actual electricity market functions within the hour, with continuously changing volumes. As there is no data available for what happens within the hour, it is assessed to be a fair choice to create an hourly based model.

It can be concluded that the hourly data used for the current scenarios in the model is accurate, as it is obtained from reliable sources, as explained in Subsection 2.2.2. The future scenarios use the data from 2014 as a basis, after which the expected changes in the market are incorporated. It can be argued that making an hourly based model for the future can give inaccurate results as it is not possible to accurately predict the hourly values for the data in the future. The model here should therefore be seen as an approximation to the future, and not the absolute truth. This is similar to programmes such as EnergyPLAN, which consider the future based on the current and past experiences, as well as assumptions for the development within the energy system in the future.

For each strategy, three current scenarios are analysed corresponding to data from 2012, 2013 and 2014. This is done to be able to obtain more general results, which take into consideration the difference in price level, price volatility and amount of electricity from wind in each year caused by multiple factors such as the weather. For these current scenarios, 2,000 PEVs are implemented. Three future scenarios are also analysed corresponding to three average Elspot predictions for 2025 from Energinet.dk, the DEA/Danish Energy and one formed by the authors. This is done as the Elspot predictions vary significantly. Here, 20,000 PEVs are implemented. The year 2025 is chosen for the future scenarios, as it is far enough away in the future to be able to assume that the amount of PEVs can be implemented into the system, and close enough to be able to make predictions regarding the future development of the data.

Regarding the market criteria and charging characteristics for both the current and future cases, these values are determined where possible based on literature study, statistical data and interviews. Especially for the future scenarios, the assumptions made result in a degree of uncertainty, and for these cases a sensitivity analysis could be made. Due to time restrictions in the project, a sensitivity analysis is not made, however, this would be the next step in the process to further validate the results of the model.

3 Model Analysis Framework

In this chapter, the analysis framework used for the modelling part of the project is presented. This is done in three parts, in which descriptions are first given of the different charging strategies that are analysed in the model. The charging strategies set criteria for when charging (and discharging) is done during the day by the PEVs, and they address some of the issues discussed in Chapter 1; they are considered potential solutions for these issues.

In order to implement the charging strategies, an entity called the aggregator is considered a necessity. The role of the aggregator is thus presented, after which the technical factors relevant to the strategies are briefly discussed.

The current knowledge regarding the strategies, the aggregator and the technical factors is presented based on literature study, interviews as well as demonstration projects.

3.1 PEV Charging Strategies

In this section, three different strategies for using PEVs in the energy system are presented and discussed:

- Dumb charging
- National balancing charging with focus on low prices
- National balancing charging with focus on wind integration

These characterise the basis of the systems for the analyses that are made in the project and represent some of the topics that are discussed in Chapter 1; the need for regulating services in the grid and the benefits that could come from integrating wind power, as Denmark moves towards an energy system with more RE. The discussions will include the reasons regarding the choice of the strategies as well as the purpose of the analyses.

For simplicity, the two national balancing strategies are called low price strategy and wind integration strategy respectively, in the remainder of the project.

3.1.1 Dumb Charging Strategy

With the dumb charging strategy, charging occurs when most convenient for the PEV owner. This is based on hourly vehicle availability data, in which it is assumed that charging occurs when the PEV owner returns home from work in the afternoon during weekdays, and where the availability is more spread out and generally higher during the weekends and holidays. No considerations are made regarding, for example, the electricity prices or the amount of RE in the system during each hour.

This strategy is used as a reference case for the other strategies presented in this section. This is considered a necessity in order to compare the results in the different analyses to a case in which no further measures are taken for PEVs towards a SES. Furthermore, the comparison can be used to define challenges towards the integration of PEVs in the energy system.

3.1.2 Low Price Strategy

PEVs have the possibility to assist the electricity system by providing regulating services to the TSO, which is done through the reserve, intraday and RPM. At this moment, most regulating services in Denmark are offered by conventional power plants as well as (local) CHP plants (Pillai et al. 2011). In a RE system, where conventional units are removed or replaced, other solutions are required in order to provide the necessary balancing in the grid. PEVs that are connected to the grid can theoretically provide the same up- and downward regulation as the conventional units by charging, discharging or interrupting scheduled charging when required (Kempton, Tomić 2005a). In order to offer this service, PEVs have to be pooled together in order to meet the required capacity to operate in the different parts of the electricity market.

In order to incentivise PEV owners to use their vehicles for balancing the grid, it is assumed that the economic aspect will be one of the main factors. Thus, for the analysis of this strategy, it is investigated in which parts of the reserve market and RPM PEVs can play a role, while taking into account the business case for the PEV owners. The strategy thus prioritises hours with the cheapest Elspot prices during the day. The potential gain for PEV owners, as well as the energy system as a whole, of operating PEVs in the RPM and reserve market is analysed and presented in Chapter 5. Proposals are then made on how to operate PEVs in the different markets, based on the results of the analysis. It should be noted that by focusing on low prices the desired demand response can be activated, as hours with low prices often coincide with hours with surplus production or low consumption.

The Nikola project (Technical University of Denmark et al. 2015), which looks into, *"…from a societal and grid point of view, to minimize the cost of operating the overall power system."* (Andersen et al. 2014, p. 2) also looks into the incorporation of EVs into ancillary services. Demonstration projects are planned in order to evaluate the gains for the EV owners showing the relevance of this part of the market for PEVs. Other similar analyses have been made regarding the matter, where it has been shown that using PEVs in the electricity market can bring economic benefits for the PEV owner (Wu 2013; University of Delaware 2015).

3.1.3 Wind Integration Strategy

Denmark is ambitious in its goal to integrate RE into its energy system, and a significant part of this energy is expected to come from wind power. For this strategy, it is chosen to only focus on the integration of wind, and no other forms of RE.

Electrifying the transport sector through the use of PEVs increases the electricity demand in the country. When considering the merit order effect, an increase in the demand curve can cause an increase in the value of the electricity, which could be beneficial for wind power. However, the source of the consumed electricity determines to what level PEVs contribute to decreasing the fuel consumption in Denmark. Currently, when PEVs charge in moments when there is little wind power in the system, conventional power plants and CHP plants generate a significant part of the electricity for the PEVs, supplemented by import from neighbouring countries. In contrast, there are moments when Denmark has a surplus of electricity, which is then exported to neighbouring countries through interconnectors. This is partly due to a large production of power from wind turbines and/or low consumption in these moments, and this otherwise exported wind electricity can therefore beneficially be used or stored in PEVs; it can increase the value of wind power as well as contribute to a Danish RE system.

This strategy focuses, therefore, on optimising the integration of wind power, while still providing regulation services to the grid, as with the previous strategy. Two types of integration are initially considered; the first prioritises hours in which there is a high share of wind power in the energy consumed, while the second one looks into hours in which there is surplus electricity and a high share of wind power. In this project, an hour has surplus electricity if the total electricity production in Denmark is higher than the gross consumption in that hour. If, in these hours, the share of wind power is high, it is assumed that a significant part of the surplus is due to wind power. As is explained in Appendix A, the analyses of the two types of integration show that the first type results in higher savings for the PEV owner, while both types result in similar values regarding the integration of wind power. It is, therefore, chosen to use the former type, so that this strategy prioritises hours with a high share of wind power, regardless if there is surplus electricity in those hours or not. Furthermore, it is assessed to be more convenient for the aggregator to determine when there are hours with a high wind share, compared to hours with surplus electricity from wind power.

It is analysed in which periods it is beneficial to use PEVs for regulating services seen from a system perspective, as well as a PEV owner's perspective, the results of which are presented in Chapter 5. Proposals are then made to incentivise the charging of PEVs at the right moments based on the results.

Using PEVs for integrating wind power is a topic that has already been presented in various articles and projects. The CEESA report, as well as published works by experts within the field of energy planning show that, seen from a socio-economic perspective, the collaboration between the different energy sectors is beneficial (Lund 2014; Lund, Kempton 2008a). Vindenergi Danmark initiated a report in 2012 regarding the matter, in which they looked into controlling the charging of PEVs to optimise the integration of wind power. The focus in the report was on the benefits for the PEV owner, the economy for the wind turbine owners and the economy for society, where it was shown that benefits can be gained if wind optimised charging is done. (Horstmann, Nørgaard 2012)

3.2 Role of the Aggregator

The purpose of the aggregator is to maximise the value of the customers' flexibility by trading their flexible electricity demand and optimising their moment of consumption (and/or production). These customers can have various units that can be used flexibly, however, here the focus is on aggregators that only pool PEVs together from owners that want their PEVs to be used flexibly. These owners enter into an agreement with the aggregator that allows the aggregator to take control over the charging/discharging of the PEVs, for which the owners will be rewarded. The PEVs need to be pooled together by the aggregator in order to make it possible to operate at, e.g. the RPM, which requires a minimum bid size of 10 MW. The aggregator is in charge of gathering data on various aspects:

PEVs:

- Availability (check if the PEV is plugged in)
- Battery state of charge (SOC)
- Charging capacity

PEV owners:

- Planned trip distance
- Planned trip starting time
- Unplanned trip demand
- Expected availability (parked at home and plugged in)

Market data:

- Market prices
- Offered volumes
- Signals for won and activated bids
- Wind productions

Based on this, a charging strategy is made by the aggregator in order to increase the savings for the PEV owners and provide the flexibility, while securing the owners that their driving demands are met.

It is not possible to pool PEVs from all over Denmark together, as Denmark is divided into two electricity price areas with different regulations and an interconnector between the two with a limited capacity. In the model, the aggregator is operating with PEVs that are charging (and discharging) in the Western part of the electricity market in Denmark (Jutland and Fyn), which is referred to as DK1.

3.3 Technical Factors

Regarding the national balancing charging strategies, participation in all the parts of the Nord Pool electricity market, which are presented in more detail in Chapter 4, require that there is the possibility for bidirectional communication. This enables the aggregator to communicate with the PEVs and vice versa in order for the PEVs to be used flexibly. This can be seen as a technical limitation, but it is expected for this to be possible in the near future. (Wargers 30/09/14)

For some of the markets, it might be required for the PEV to discharge to the grid. To allow for this, bidirectional charging technology is required, which means that both charging and discharging can be done. This technology, which is required in both the charging unit and the vehicle, is not currently widely available, and therefore, as with the communication, this can be seen as a limitation. The technology is however expected to be more widely used in the future.

For both bidirectional communication and charging, considerations should be made when evaluating the results of the analyses, concerning the additional costs due to the need for the technology.

It is required by the TSO that suppliers of regulating electricity must have online measurements. As this is expensive to include for all PEVs, it is assumed that such requirements can be changed in the future, to allow for operation of PEVs in the regulation market.

In Chapters 4 and 5, the term charging capacity is used. This relates to the volume with which, in this case, a PEV can charge or discharge to the grid, and is therefore dependant on the charging capacity of the charger that the PEV is connected to, as well as the charging capabilities of the PEV (connector in the vehicle). Home chargers, which are considered in this project, have typical charging capacities ranging between 3.7 kW and 22 kW (The new motion 2015). Some chargers have the possibility of adjusting the charging load, so that charging and discharging can be done at lower loads. Choosing to do this can be due to different factors, for example, the load on the grid at the moment of charging.

The model does not take into consideration the effects on the battery due to the amount of charging and discharging that it done, which determines the amount of charging cycles; the battery lifetime could be affected due to this factor. Studies have shown that the lifetime of the battery can be degraded by the SOC of the battery; if the battery is always charged and discharged completely to the battery limit. However, using flexible charging strategies can mitigate this latter problem. The maximum charging capacity can also vary depending on the SOC of the battery, and further external factors such as temperature are also omitted. (Lacey et al. 2014) These factors are not implemented in the model, however, it is assumed that they would not change the results significantly, as the analyses are only made for one year, and as the amount of additional charging cycles is limited since discharging is only allowed for upward regulation in the RPM.

4 Modelling of PEV Charging Strategies

In this chapter, the Excel model made for the PEV charging strategies analysed in this project is presented. The charging strategies are presented in Chapter 3, where it is decided that three strategies are considered: dumb charging, charging with focus on low prices and charging with focus on integration of wind power. These final two strategies are called low price and wind integration strategies in the project.

The regulation markets and reserves[9] in the Nord Pool electricity market that are used to balance the grid are incorporated into the charging strategies, and therefore it is evaluated to what extent PEVs can be used in the different parts of the market. A presentation of the characteristics in these parts of the market, as well as the day-ahead market, is thus first given, where the benefits and limitations of using PEVs are discussed. The general structure of the model is then presented, where a more detailed documentation of the model, including the inputs, structure and calculations, is found in Appendix A. Finally, the limitations of the model are briefly discussed.

The analyses for the strategies are made in order to evaluate the potential operation of PEVs and the economic gains that can be obtained by the vehicle owner through the flexible use of PEVs in a SES. The purpose of the analyses is not to conclude on a specific value for the benefits for the individual PEV owner, but more to come with a general order of magnitude for these benefits, as well as to gain insight into the operation in the different parts of the electricity market.

4.1 Nord Pool Electricity Market

In this section, a description of the Nord Pool electricity market, with focus on Western Denmark[10] (also known as DK1) is presented. A summary of the characteristics, as well as the benefits and limitations of the different parts of the market is given seen from the perspective of the PEV, and an evaluation is made of what markets and reserves PEVs can operate in, in the current case. The future development in these markets is considered in Appendix A.

In Figure 4.1, a representation of the different parts of the market can be seen in an overview of the market. Here they are placed relating to the moment of activation and are explained in the following subsections.

[9] The reserves are also markets, but they are referred to as reserves in this project for clarity.
[10] Some of the characteristics are different for the Western and Eastern parts of Denmark.

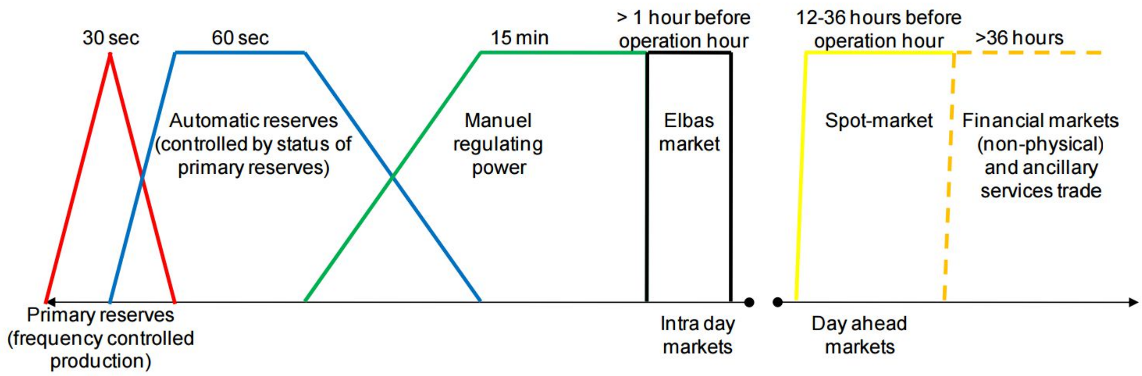

Figure 4.1: Nordic electricity market (Sorknæs et al. 2013, p. 176)

Unless otherwise stated, (Energinet.dk 2008, 2012) is used for the following descriptions.

4.1.1 Day-ahead Market (Elspot)

The day-ahead market makes up about 80% of the traded volume in the Nord Pool region. The bids in this market are placed 12-36 hours in advance with a minimum bid size of 0.1 MW, in steps of 0.1 MW. Offers for buying and selling are placed hour per hour with gate closure at 12:00 CET, and the winning bids are then published an hour later.

Selling bids reflect the short run marginal costs of production units and the price (system price) is set through marginal price setting; the most expensive of the needed units sets the price that all accepted bids receive. Buying bids are in general price inelastic. In the case where there is a limitation on the interconnectors, separate area prices are calculated. As the volumes bought and sold in Elspot have to be in balance, consuming a different amount of electricity than is bought day-ahead causes an imbalance. Imbalances are corrected in the RPM (described in Subsection 4.1.3) and imbalance costs are charged for causing the imbalance, which are based on the costs for regulating power.

The current PEVs in Denmark are already operating in the Elspot through utility companies who buy the electricity for their customers. However, in a future system, it is possible for an aggregator to determine in which hours the PEVs should charge and communicate this with the utility company. It is possible for the aggregator to use the predictions for the day-ahead market to make a strategy based on the prices. He could, for example, choose to charge the PEVs during the cheapest predicted hours, or use the Elspot price (and other factors) to predict when the hours with most wind power will be and base a strategy on that.

Benefits for PEVs:

- Current PEVs are already operating in this market.
- In the case where the aggregator is buying the electricity for the PEVs, the required bid size is relatively small and therefore a small group of PEVs are able to participate in this market.

- As electricity can be bought in all hours on Elspot, and price developments can to some extent be predicted (Plotnikov 13/05/15), different strategies can be implemented depending on different factors, for example, charging during low predicted Elspot prices.

Limitations for PEVs:

- As the bids are made a day in advance, there is some uncertainty in the predictions for the Elspot prices. This could mean that strategies based on the Elspot price could, at moments, be affected. However, the current predictions made for the Elspot prices do not diverge significantly from the actual prices and therefore this limitation is not considered a challenge for the current case. (Nyeng 11/03/15; Plotnikov 13/05/15)
- The amount of charging has to be accurately predicted a day-ahead, to avoid imbalances.

It is expected that PEVs will mainly play a role in this market, especially in the near future (Nyeng 11/03/15), and it is concluded that the Elspot market should be incorporated into the Excel model of this project for the charging of PEVs.

4.1.2 Intraday Market (Elbas)

The intraday market is seen as an addition to the day-ahead market and contributes with about 2% of the traded volume of the day-ahead market in Denmark. This market is used for correcting the imbalances from the Elspot market before the hour of operation, however, paying for imbalances is currently not very expensive in Denmark, and therefore the regulating market is used the majority of the time instead (Houmøller 7/10/14). The average hourly volume[11] was 75 MW of electricity bought in 63% of the hours and 106 MW of electricity sold in 74% of the hours in DK1 in 2014. (Nord Pool Spot 2015a)

The gate closure is 60 minutes before the hour of operation and the minimum bid size is 0.1 MW, in steps of 0.1 MW. Trading on Elbas may take place in each hour of the day and the price is set pay-as-bid. The orders are settled in collaboration between the buying and selling parties.

Benefits for PEVs:

- The required bid size is relatively small and therefore a small group of PEVs are able to participate in this market.
- As the PEVs are parked the majority of the time during the day, it can be assumed that they are physically able to participate in the majority of the hours. This is limited to the charging capacity available as well as to the SOC of the battery.

Limitations for PEVs:

- The savings from buying electricity in Elbas are considered to be small. It is expected that PEV owners can generally gain more in the RPM. (Houmøller 7/10/14)
- Volumes are not traded in all hours on Elbas, which creates uncertainty when incorporating Elbas as part of the charging strategy.

[11] Average hourly volume numbers used in this chapter are based on the hours where volume was offered.

- As bidding in Elbas is done pay-as-bid, it is more complicated to determine which price to bid compared to other markets that have marginal pricing.

It is concluded that the Elbas market should be incorporated into the Excel model of this project, to further evaluate its potential in the PEVs' charging strategies.

4.1.3 RPM

When trade in Elbas is not sufficient to remove the imbalances in the grid, the RPM is used. In the RPM, the TSO buys regulating electricity when the frequency either gets too high, in which case there is a need for downward regulation, or when it gets too low, causing a need for upward regulation. The regulation happens within the hour of operation, and bids placed in this market can be changed up to 45 minutes before the hour of operation.

Regulating electricity can be bought in all price areas, with the restriction that upward regulating electricity can only be bought in other areas if there is available capacity on the interconnectors. The price setting of upward and downward regulation generally occurs through marginal pricing[12] and the traded volumes in the RPM vary throughout the year. For downward regulation, the average volume was 80 MW in 2014 in DK1 and was offered in 25% of the hours. The average volume of 111 MW was offered for upward regulation in the same year in DK1, in 30% of the hours. However, about 80% of the upward regulation in the RPM is reserved in the tertiary reserve, which is described later in this section (Energinet.dk 2015b).

Bids can be activated for parts of the hour, with five minute intervals, and a minimum operation time of 30 minutes is guaranteed (Energinet.dk 2015d). The minimum bid size is 10 MW, after which bid steps of 1 MW can be made. The regulating unit must be operational within 15 minutes after a signal from the TSO is given.

Benefits for PEVs:

- There are potential monetary savings for the PEV owner, as the charging could be cheaper, and money can be gained from discharging.
- The bid can be altered 45 minutes before the hour of operation, which offers flexibility in the charging strategy.

Limitations for PEVs:

- Regulating power is not required in all hours, which creates uncertainty when incorporating the RPM as part of the charging strategy.
- Downward regulation is currently offered by many production units, which makes it more difficult to win bids in this market. About 80% of the volume in the upward RPM is covered by the tertiary reserve, which limits the amount of bids that can be won as upward regulation.

[12] There are moments when the price is set through pay as bid, however this is outside the scope of this project.

- If a bid is activated, it is only guaranteed that it will be activated for 30 minutes. Furthermore, there is the possibility that only part of the bid is activated. In these cases, the charging capacity is reserved for this volume, but is not fully exploited, and limits the use of the capacity in the other markets and reserves.
- The minimum bid size is currently 10 MW, which is larger than for the other markets presented. This means that for the PEVs to participate in this market, they would have to be pooled together to a larger extent than for the others.
- Due to the larger amount of pooled vehicles, it can be difficult to fairly distribute the use of the PEVs; some PEVs could technically be charged and/or discharged more than others.
- The aggregator has to ensure that there are always enough PEVs connected in order to provide the bid. This could be done by pooling more PEVs together than is shown in the model, but it would result in a lower savings per owner.

This is also a viable option for the PEV, and it is generally agreed in the literature (Andersen et al. 2014; University of Delaware 2015) and by the relevant stakeholders (Nyeng 11/03/15) that the PEVs can participate in the RPM. This part of the market is therefore included in the Excel model.

4.1.4 Reserve Market (Regulating Capacity)

The TSO purchases regulating capacity, which can be production or consumption, which is reserved to make sure there will always be regulating capacity available. This capacity is placed in three reserves: primary, secondary and tertiary reserves, which are based on factors like the time it takes for the unit to be operational and how long the regulating power has to be provided.

An availability fee is given to the providers of the reserves, and the value of the fee is determined between the two parties in advance or by marginal pricing, depending on the market. If a reserved bid is won, the provider of the bid is obligated to be available, and in the case of the tertiary reserve, the reserved bids are placed in the RPM.

4.1.5 Primary Reserve (Frequency Reserve)

When the grid frequency diverges from 50 Hz, the reserved capacity in the primary reserve is automatically activated to either provide upward or downward regulation, depending on the need in the grid. The hourly traded volume in the primary reserve in DK1 is typically between 20 MW and 30 MW for both upward and downward regulation.

The capacity is traded day-ahead, with gate closure at 15:00 CET. It is traded in blocks of four hours, with a minimum bid size of 0.3 MW, in steps of 0.1 MW, with the possibility of partial load. A delivery can be made up from several production or consumption units and the availability fee is determined through marginal pricing.

When activated through a signal from the TSO, half of the bid capacity must be reached within 15 seconds and full capacity must be reached within 30 seconds. The needed capacity must then be kept stable for up to 15 minutes.

Benefits for PEVs:

- Due to the low minimum bid size, not a lot of PEVs would be needed to play a part in this reserve.
- There are potential monetary savings for the PEV owner, mainly due to the high availability fee.
- As the PEVs are parked the majority of the time during the day, and have a fast response time (Andersen et al. 2014), it can be assumed that they are physically able to participate in the majority of the hours. This is limited to the charging capacity available as well as to the SOC of the battery.
- Discharging/interruption of charging to provide upward regulation in the primary reserve have a small effect on the battery and increase in charging cycles, as the activated volumes are small and for a limited duration.

Limitations for PEVS:

- The total volume is limited to about 20-25 MW, so it can be assumed that the PEV participation is also limited due to competition with other potential providers.

This is considered to be a viable option for PEVs, and Energinet.dk has stated an interest in using the PEVs here; *"This could be a nice niche for EVs, as they are (expected to be) able to respond really fast which is required for frequency reserves."* (Nyeng 11/03/15) This reserve is thus included in the analyses.

4.1.6 Secondary Reserve (Frequency Restoration Reserve)[13]

This reserve is used as a type of replacement for the primary reserve and is used to further maintain the frequency. The hourly volume is around 90 MW for both upward and downward regulation in DK1.

The capacity is reserved on a monthly basis by the TSO, with the availability fee and volume being based on the bids and negotiations between the relevant actors. The bids have to be symmetric meaning that for every hour of the month, the same volume has to be bid for upward and downward regulation. Different units can be pooled together to provide the service, however, all upward and downward regulation must be done by the same type of units, i.e. either production or consumption units.

The minimum bid size is 1 MW and the units must be able to react to signals from the TSO. The units then have to be fully operational within 5 minutes, keeping the needed capacity for up to 15 minutes.

Certain limitations in this market make it unrealistic for PEVs to participate in it. First of all, the contracts that are made every month can potentially limit the monetary gains that the PEV owner could otherwise have obtained from strategies based on shorter time frames. Next to this, it might be a challenge for the aggregator to guarantee availability of enough PEVs to deliver this service

[13] Previously called Load Frequency Control (LFC).

in all hours of the month. Furthermore, at the moment, a large part of these contracts are made with units in Norway, limiting the potential for PEVs even more (Nyeng 11/03/15). The symmetric bids can also further decrease gains for the vehicle owner. Due to these reasons, it is chosen not to consider the secondary reserve in the Excel model.

4.1.7 Tertiary Reserve (Manual Reserve)

The capacity in this reserve is traded day-ahead, and the gate closure is at 9:30 CET. The minimum bid size is 10 MW and the maximum size is 50 MW, with bid steps of 1 MW. The average hourly reserved volume was around 170 MW for upward regulation in DK1 in 2014 (Energinet.dk 2015b). There is no need for reserve of downward tertiary reserve as most operators of production units are willing and able to decrease their production, also on short notice. (Høj 18/05/15)

The price of the availability fee is determined through marginal pricing, and when a bid is won, the provider must place the same bid on the RPM. The regulating capacity must be fully operational within 15 minutes after a signal from the TSO is given, and must provide regulating electricity for up to 45 minutes.

The tertiary reserve is linked with the RPM in the way that it is a reservation of the available capacity (in the form of bids) in the RPM and the bids that are won in the tertiary reserve are placed in the RPM.

Benefits for PEVs:

- There are potential monetary savings for the PEV owner, as the charging could be cheaper, and money can be gained from discharging or interrupting/delaying of planned charging.
- Due to the large traded volumes, it can be assumed that PEVs can win bids in the reserve.

Limitations for PEVs:

- The minimum bid size is currently 10 MW, which is larger than for the other markets presented (except for the RPM). This means that for the PEVs to participate in this market, they would have to be pooled together to a larger extent than for the others.
- If a bid is activated, it is only guaranteed that it will be activated for 30 minutes. In these cases, the charging capacity is reserved for this volume, but is not fully exploited, and limits the use of the capacity in the other markets and reserves.
- Due to the larger amount of pooled vehicles, it can be difficult to fairly distribute the use of the PEVs; some PEVs could technically be charged and/or discharged more than others.
- The aggregator has to ensure that there are always enough PEVs connected in order to provide the bid. This could be done by pooling more PEVs together than is shown in our model, but it would result in a lower savings per owner.
- Bidding in the tertiary reserve is done before the day-ahead bids are placed. This limits the flexibility in determining the charging strategy as the capacity has to be reserved.
- The availability fee is low, in most hours only 1 DKK/MWh.

It is concluded that the tertiary reserve should be incorporated into the Excel model of this project, to further evaluate its potential for PEVs.

4.1.8 Overview of Market Characteristics

In Table 4.1, an overview can be seen of the main characteristics from the descriptions of the different markets and reserves presented. Only the markets and reserves which are considered feasible for the PEVs are included.

Market	Gate closure	Minimum bid size	Average Volume in market	Price settlement	Operation requirements	Average price in 2014
Day-ahead (Elspot)	12:00 CET day-ahead	0.1 MW with steps of 0.1 MW	80% of traded volume in Nord Pool region	Marginal pricing	-	211 DKK/MWh
Intraday (Elbas)	60 minutes before hour of operation	0.1 MW with steps of 0.1 MW	Hourly: 40-60 MW	Pay-as-bid	-	226 DKK/MWh
RPM	45 minutes before hour of operation	10 MW with steps of 1 MW	Varies	Marginal pricing	Within 15 minutes, up to 45 minutes	243 (up), 223 (down) DKK/MWh
Primary reserve	15:00 CET day-ahead	0.3 MW in blocks of four hours with steps of 0.1 MW	Hourly: 15-30 MW	Availability fee	Half of bid within 15 seconds, full bid within 30 seconds, up to 15 minutes	224 (up), 10 (down) DKK/MWh
Tertiary reserve	9:30 CET day-ahead	10 MW to a maximum of 50 MW	Hourly: 250 MW	Availability fee	Within 15 minutes, up to 45 minutes	1 DKK/MWh

Table 4.1: Overview of Nord Pool electricity market characteristics for DK1

In general trading closer to the hour of operation provides higher economic benefits, however, the uncertainty of being activated increases.

The market characteristics are used for the generation of the Excel model, which is explained in the next section.

4.2 Modelling Structure

The annual model, which is hourly based, is made in the programme Excel, and is used for all the strategies considered in this project; dumb charging, low price and wind integration. For these, the individual PEVs are pooled to form one aggregated battery; the battery and charging capacities of the individual PEVs are added together to form one total battery and charging capacity. As mentioned, the purpose of the model is to provide a tool with which the general order of magnitude of the economic benefits for the PEV owners and system benefits can be determined for different charging strategies. Furthermore, the model can be used to gain insight into the operation in the different parts of the electricity market.

For each strategy, three current scenarios are analysed corresponding to data from 2012, 2013 and 2014. This is done to be able to obtain more general results, which take into consideration the difference in multiple factors in each year, for example, the weather. For these current scenarios, 2,000 PEVs are implemented. Three future scenarios are also analysed corresponding to three average Elspot predictions for 2025. This is done as the Elspot predictions vary significantly. Here, 20,000 PEVs are implemented. It should be made clear that only PEVs connected to home chargers are considered in this model as explained in Subsection 4.2.1.

In Appendix A, a more detailed presentation is given of the current and future scenarios, through the relevant input data, parameters and distributions used in the model. To summarise these:

- Input data: It is chosen to base the current scenarios for each strategy on market and wind data for the three years. The future scenarios are based on predictions of this data for 2025.
- Input parameters: The PEV characteristics and market criteria for all the parts of the market are set for both the current and future scenarios, based on literature, assumptions and the PEV owner survey results, and are used to help determine the charging and discharging of the PEVs in the model.
- Input distributions: Distributions are used to determine the final hourly volume with which charging can be done in the day-ahead market, and charging and discharging can be done in the RPM. The hourly PEV availability, as well as the driving demand, is also determined.

Also in the appendix, flow charts are used in order to represent the build-up of the model, in which a detailed description is given for each of the parts of the market. It is recommended that these sections are read in order to gain a complete understanding of the model. The model itself can be found on the attached CD in Appendix D, in which all of the strategies and their corresponding scenarios can be found; in the sheet 'Overview' in the model, the strategy and scenario can be chosen, and the relevant market criteria and charging characteristics can be changed.

The dumb charging strategy is used as a reference for the analyses and therefore represents the general current use of PEVs in the Nord Pool market. As PEVs do not currently operate in the intraday and regulating markets or reserves, only charging in the day-ahead (Elspot) market is incorporated. For this strategy, there are no market restrictions for the charging, thus in an hour, if PEVs are available and the SOC of the battery is below 100% (taking into account the driving demand in that hour), charging occurs either up to the charging capacity available in that hour or until the battery is fully charged. In this way, this strategy only considers the current charging behaviour of PEV owners, without taking into account Elspot prices, wind production or the need for balancing the grid. It should be noted that this reference strategy cannot be directly compared to the real dumb charging that is done, as flexible tariffs are used in the model, and fixed ones are used in reality.

In this section, a more general structure of the model for the low price and wind integration strategies is described. Here, an example of an hour of operation is used in order to facilitate the understanding of the decision making process for when, in what order and to what extent the PEVs participate in the different parts of the market. The parts of the market include the Elspot, intraday market (Elbas), the RPM, and the primary and tertiary reserves.

As mentioned, an aggregated battery is used in the model. The parts of the market mentioned previously are incorporated in the model, and this is considered in the aggregated battery for these strategies. This can be represented by Figure 4.2.

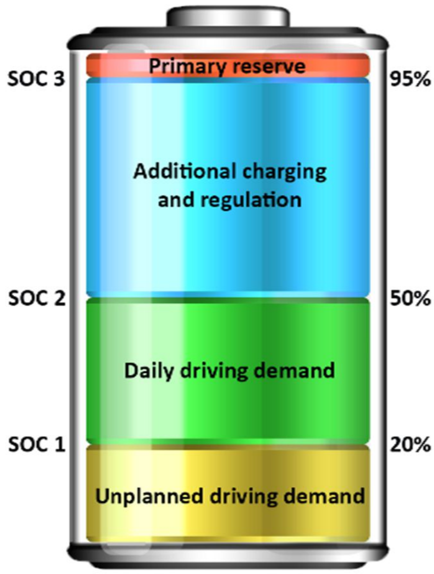

Figure 4.2: Capacity reservations for aggregated battery in current scenarios, figure inspired by (Sony 2014)

In the figure, the battery is divided into sections which are given the labels SOC 1 to 3; these labels are used for the example later in this section. These sections are described in Subsection A.2.2 in the appendix, however, they are presented in more detail here. They represent capacity reservations that are used for the different parts of the market:

State of charge 1 and 2

Before entering the intraday and regulating markets, and reserves, the main guarantee for the PEV owners is that their driving demands are always met. These capacity reservations therefore represent what is required in the battery for the unplanned driving and daily driving demands respectively. The former demand represents the required capacity for emergency trips, and is thus the capacity that should always be present in the battery. Only the Elspot market is used for these sections of the battery, as it is the only market that can guarantee that charging is done.[14] It should be noted that SOC 1 and SOC 2 correspond to 20% and 50% of the total battery capacity respectively. This is true for the current scenarios. For the future scenarios, the total average battery capacity per vehicle is increased and therefore the actual percentages are decreased to 12% and 21%, as no development in the driving demand is expected.

State of charge 3

The Elspot market is used again here, however, the charging is defined as being additional charging; any charging in Elspot that is not done to meet the driving demands. Downward regulation in Elbas and upward and downward regulation in the RPM can also be used in this section of the battery. Here, only discharging is allowed for upward regulation in the RPM. The tertiary reserve is included in this in that the bids activated in the tertiary reserve are placed in the RPM, where only interrupting charging is allowed. From this, additional charging and the mentioned regulations can be done, if the SOC of the battery is still below SOC 3 and higher than SOC 2 once the charging and/or discharging is done. It should be made clear that all the markets can potentially be used simultaneously, as long as the market and charging criteria allow for it. This is shown in the example given.

Finally, the remaining 5% of the battery is reserved only for the primary reserve. This is to ensure that there is always capacity available for bids to be made in this reserve, as it is expected to bring economic gains due to the high availability fees.

Example of one hour of operation

In the model, a priority is placed on the markets and reserves based on the need to first meet driving demands, and then on the characteristics, benefits and limitations discussed in Section 4.1, so that the priority is:

- Day-ahead market (planned and then additional planned)
- Primary reserve
- Elbas

[14] Bilateral agreements could also be made, however, this is outside the scope of this project.

- RPM and tertiary reserve

This is better shown in the following example in Figure 4.3, which is made for the low price strategy. Only small changes are made for the wind integration strategy, which are explained after the example. It should be noted that the priority is different from the one presented in Section A.2 in the appendix, and this is due to an extra reservation that can be made for the RPM, which can be activated through a switch in the model. The flowcharts in the appendix include this switch, however, it is not included in the example in this section. This is to simplify the description of the model, and as the switch is not used for the analyses in the project.[15] An extra analysis is presented in Section 5.3, where the switch is considered.

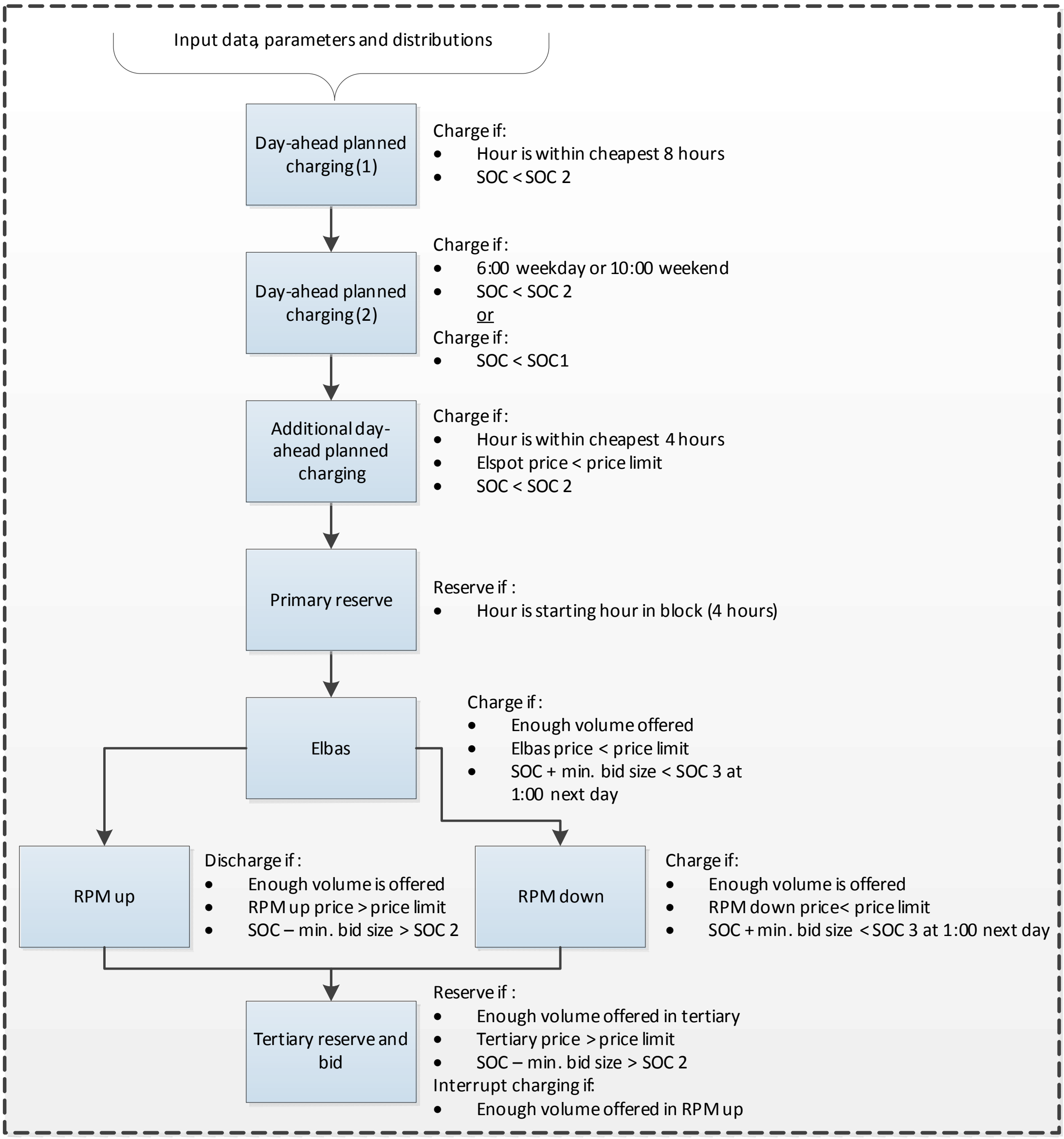

Figure 4.3: Diagram of one hour of operation in the model, low price strategy

[15] When analysing the scenarios, it was discovered that using the switch resulted in a worse business case for the PEV owner, and it was therefore decided to remove it for the results.

The diagram should be seen in the way that first the input data, parameters and distributions are put into the model depending on the scenario that is analysed, after which the day-ahead planned charging is considered, and so on, in order of the priority. Although not stated in the diagram, for each of the market blocks, the available charging capacity is considered. This is dependent on the availability of the PEVs, as well as the charging and/or discharging that is expected to be done in the blocks before the one being considered. Thus in each market, charging or discharging is only planned if there is still charging capacity left for it, if this capacity and the volume offered in the markets meet the requirements for the minimum bid size, and if the criteria in the diagram are met. All the market criteria, including the set price limits and maximum bid sizes, are presented in Subsection A.1.2 in the appendix for both the current and future cases. It should be noted that downward and upward regulation in the RPM is never required at the same moment.

If charging or discharging can be done, it is done up to either the:

- Charging capacity available
- Maximum/minimum allowed SOC, as shown in Figure 4.2
- Maximum allowed bid size, a market criteria that is explained in Subsection A.1.2 in the appendix

The smallest value of these options is the one determining the actual volume that is traded in the parts of the market. As shown in the example, as long as all the factors and criteria are met, trading can be done in simultaneous markets and reserves. In the case where both charging and discharging are done (for example, charging in the Elspot market and discharging in the RPM), it is assumed that within the pool of PEVs, some of the PEVs are charging, while some others are discharging.

Regarding the reserves; for the primary reserve, no price signal is used, as it is assumed that the high availability fees always make it economically beneficial for the PEV owner to participate in it. The tertiary reserve only interrupts charging in the additional day-ahead planned charging, as this is not required to meet driving demands or to balance the system, and thus the bid is only made if there is additional day-ahead charging that can be interrupted. It is chosen to not allow for discharging in the tertiary reserve, due to the complications in planning the traded volume, as the reservation is done a day ahead. Similarly, only discharging is permitted for the upward regulation in the RPM for simplicity in the model.

Finally, although the model is hourly based, consideration is made for the operation within the hour in some of the markets. In the primary reserve, it is known that small amounts of upward and downward regulation are done within the hour, however, due to the short duration of these regulations and the lack of data regarding this, it is chosen to not consider it further in the project. In the RPM, it is known that bids are only guaranteed to be activated for half of the hour, and therefore the randomise function in Excel is used to determine, for each hour, for how much of the hour the bids are activated. The model also looks beyond the single hour of operation in that, for downward regulation in Elbas and the RPM, the battery SOC in the start of the next day, after planned charging in the day-ahead market is done, is considered; in this way the regulations do not affect the charging that is already planned in the day-ahead market, thereby avoiding imbalances.

Regarding the wind integration strategy, the only changes in Figure 4.3 are in the day-ahead market for both the planned charging to meet driving demands and the additional charging. Here, instead of looking at the cheapest hours, the model looks at the hours with the highest shares of wind power. The share of wind power is calculated as the share of the gross consumption which is supplied by the wind production in Denmark.

4.2.1 Limitations

It can be said that there is a degree of perfect knowledge in the model, in that the driving demand and availability are set for each hour. In reality, it is not expected that this knowledge can accurately be pre-determined by the aggregator, however, it is assumed that the aggregator will have tools to aid in the planning of the strategy, such as usage statistics.

The PEVs in the model are modelled as an aggregated system. This is done to facilitate the modelling and to simulate what is assumed to be a realistic strategy seen from an aggregator's perspective. The case for the individual PEV owners could be different, for example, the driving demands and battery capacities could be different, however, average values are used in the model, and it is therefore assumed that general conclusions can be made. The purpose of the analyses is not to come with a specific value for the benefits for the individual PEV owner, but more to come with a general order of magnitude for these benefits, as well as to gain insight into the operation in the different parts of the electricity market. Another limitation regarding the aggregated system comes from the way the availability is used in the model; in reality there is no guarantee that the PEVs that are available in an hour have enough battery capacity for charging, as it is assumed that not all PEVs will charge or discharge by exactly the same amount each hour. Some might charge or discharge more than others, and thus the available PEVs might already have full batteries. This is, however, not considered further in the project.

The model uses market data for DK1, and it incorporates the market criteria that are applicable for this area. Some of the input parameters, however, are taken from the results from the PEV owner survey that is presented in Chapter 6, which is made for the whole of Denmark. As some market criteria[16] and volumes are different for the two price areas in Denmark, these should be changed in the model, if DK2 were to be incorporated. However, as the input parameters used relate to the technical aspects of the PEVs, it is assumed that they are applicable for both DK1 and DK2.

In the model, only PEVs connected to home chargers are considered in each hour. This is done as it is assumed that most charging currently occurs through these charging points and PEVs are connected to these the majority of the time, providing more flexibility to shift the moment of charging. It can be expected in the future that more work places will install charging stations, and therefore PEVs could play a larger role in the regulation market or in the integration of wind power during the day. It is, however, difficult to make a prediction for the increased usage during work

[16] The primary reserve market, for example, is designed differently in DK1 and DK2.

hours, as different work places might have different policies for charging at work. Furthermore, it is still expected for the PEVs to mainly charge at home, even with the possibility of charging at work, as the prices are generally still lower during the night. Integration of wind power is also currently most relevant during the night hours.

The amount of discharging allowed is limited in the model to upward regulation in the RPM. This is done as it is assumed that allowing selling bids to be made in the day-ahead market will significantly increase the amount of charging cycles of the PEVs' batteries (discharging and charging) compared to only having upward regulation. With the current battery technology, this could significantly affect the battery lifetime (Guenther et al. 2013; Lacey et al. 2014) and therefore, it is expected to be a barrier for the PEV owners towards allowing flexible use of their PEVs. If the selling of the electricity would be allowed, it is expected to increase the economic feasibility (not considering the battery costs), and therefore the results from the analyses can be considered to be conservative.

In the model, the determination of the reservation of a bid in the tertiary reserve is, among other things, dependant on the volume that is planned in the additional part of the day-ahead market. This means that a bid in the tertiary reserve is only made if there is enough volume that can be interrupted in the day-ahead market. In reality, the bid in the tertiary reserve is made before the planned charging is determined in the day ahead (9:30 vs. 12:00), and therefore the bid in the tertiary reserve in reality cannot be determined as is done in the model. However, as it is only a few hours difference between the bidding times, it is expected for the planned charging to be accurately predictable.

This chapter described the structure of the model for the different strategies analysed. In the next chapter, the results from the model analysis are presented.

5 Charging Strategy Analysis

In this chapter, the results from the analyses made for the charging strategies presented in Chapters 3 and 4 are compared and discussed. In Appendix B, the results are presented in detail for each of the scenarios within the three strategies. A summary of these results for the individual strategies are thus first presented here, after which comparisons of the strategies are made.

An extra analysis is made to evaluate the potential of using the PEVs, when focus is put on the RPM. The results of this analysis are also shown in the chapter.

5.1 Overview of Main Results

The main findings from the results of the three strategies are regarding the annual:

- Total cost for the PEV owner
- Integration of wind power
- Role that the PEVs can play in the different parts of the market

In Appendix A, the calculations for these factors are explained in more detail, however they are briefly described here. The total cost for all PEV owners takes into consideration the annual volumes traded or reserved in the different parts of the market and their corresponding prices, as well as any imbalances caused by the PEVs. It should be made clear that only the electricity costs and market fees[17] are included, and thus the electricity taxes and distribution costs are not considered. The total costs are then divided over the amount of PEVs included in the model, to derive an average cost per PEV. It should be noted, however, that the PEVs are modelled as one aggregated PEV.

The integration of wind power considers the average wind share[18] and surplus wind integration in the model. The former value represents the share of the charged volume in the PEVs that is assumed to come from wind power. The latter value represents the share of the surplus wind power that is consumed, and thus integrated, by the PEVs. The surplus wind power is determined based on the total production and consumption of electricity in Denmark, where there is surplus when the total production is higher than the gross consumption. The system wind share of the total electricity consumption is then used for determining the surplus wind power.

As a reminder, all the current scenarios implement 2,000 PEVs, while the future scenarios implement 20,000 PEVs. The three future scenarios are called high, medium and low scenarios, where the first two correspond to the Elspot predictions for 2025 from the Danish TSO and the DEA[19] respectively. The low scenario uses an average Elspot price which is lower than the current average Elspot prices.

[17] Imbalance costs and availability fees.
[18] The increase in electricity consumption caused by the charging of the additional PEVs is not included to determine the hourly wind share.
[19] The value is a combination of the predictions from the DEA and the Danish Energy Association.

5.1.1 Dumb Charging Strategy

As the regulating markets are removed for dumb charging, only the total cost for the PEV owner, as well as the integration of wind power, is focused on. For the current scenarios, 7,140 MWh of charging is done by the PEVs in the year. This is increased to 61.5 GWh/year for all the future scenarios.

The annual results from the current scenarios show that the costs per PEV differ slightly, due to the different average Elspot prices used; 2013 has the lowest average Elspot price and thus also the lowest cost per PEV. The results also show that, for the all scenarios, the average Elspot price of day-ahead charging is higher than the average Elspot price for the whole year, meaning that charging is generally done in expensive hours of the year, compared to the average. The majority of the charging in the year occurs during 17:00 and 18:00, which corresponds to the hours with the current peak load in Denmark (Melgaard 4/05/15).

The same conclusions can be made from the results for the future scenarios as for the current scenarios. The future scenarios use data from 2014 as a basis, and compared to this current scenario, the average costs per PEV increase significantly. Care should, however, be taken when comparing these numbers, as the Elspot predictions vary significantly, and therefore an average value is not necessarily an accurate measurement. The average is more utilisable in the current scenarios, as the data is based on actual measurements. The data for the future scenarios is based on chosen predictions for the Elspot price. The average wind share and surplus wind integration also increase, where the latter factor's increase is relatively large.

For the remaining strategies, the RPM capacity reservation that can be made when considering additional planned charging and Elbas is switched off, as it is shown to give higher costs in the model. This is mainly in the current scenario, because most of the reserved capacity is not used, as volume in Elbas and the RPM is not offered in all hours and/or the minimum bid size for the RPM cannot be met. This results in more charging done in the day-ahead planned charging, which might be more expensive as it only checks for the eight cheapest hours in a day, without taking into account the level of the Elspot prices that day, in contrast to the charging done in the other parts of the market that have set price limits.

5.1.2 Low Price Strategy

The annual results from the current scenarios show that this strategy provides savings for the PEV owners compared to the dumb charging strategy, the highest of which is in 2012. Furthermore, for all the scenarios, the average Elspot price used in hours with day-ahead charging is lower than the average Elspot price over the whole year. This means that charging is generally done in hours with low Elspot prices compared to the average.

The majority of the charging is done in the day-ahead market (planned and additional charging), which contributes most to the integration of wind power. It is shown, however, that the remaining parts of the market provide a large part of the final savings, where the primary reserve (mainly upward regulation) is the largest contributor due to the high availability fees in this reserve. Compared to dumb charging, the peak charging hours have been shifted from late afternoon to midnight. Furthermore, there is a small peak in the afternoon, which is assumed to be due to the increased availability of the PEVs in these hours.

For the future scenarios, the costs per PEV vary, but there are earnings in all of the scenarios for the low price strategy compared to the dumb charging strategy. These earnings are, however, lower than in the current scenarios. The average wind share and surplus wind integration values are similar in the three future scenarios, and are higher than those in the current scenarios, where especially the surplus wind integration increases significantly. For all the scenarios, the charging in generally done for lower Elspot prices compared to the average Elspot price. The general distribution of the trading is similar to the current case, however, compared to the current scenarios, the RPM plays a larger role in the future scenarios, and the primary reserve has a smaller influence on the costs.

5.1.3 Wind Integration Strategy

As with the previous strategy, the results from the current scenarios for this strategy show savings for the PEV owners compared to the dumb charging strategy, as well as a high wind share, compared to the current wind share of the electricity consumption in Denmark. The highest wind share is found in 2013.

The majority of the charging is again done in the day-ahead market (planned and additional charging), and the primary reserve contributes to the savings substantially due to the high availability fees. Similar to the low price strategy, most of the charging occurs between 21:00 and 3:00. Furthermore, there is a peak at 17:00 for all three scenarios.

For the future scenarios, depending on the development of the Elspot prices, the costs per PEV vary, however, for all scenarios there are savings compared to the dumb charging strategy. The average wind share and surplus wind integration values are similar in the three scenarios, and for all the scenarios, the average Elspot price for the charging done is lower than the annual average Elspot price, which is also seen for the current scenarios. Compared to the 2014 current scenario, the savings are lower for the future scenarios, which is mainly due to the limited volume in the primary reserve market, for which the revenue has to be divided over a higher number of PEVs. The average wind share and surplus wind integration increase in the future cases, again with the latter factor having the largest increase. The general distribution of the trading is similar to the current case, however, compared to the current scenarios, the additional planned charging plays a larger role in the future scenarios, whereas Elbas plays a larger role in the current scenarios.[20] As with the previous strategy, the primary reserve has a smaller influence on the costs in the future scenarios.

5.2 Comparison of Strategies

In this section, the results from the strategies presented in the previous section are compared to each other and discussed. This is first done for all the current scenarios, after which the future

[20] Relative role compared to the total volume.

scenarios are analysed. The comparison is made to evaluate the benefits and limitations of the charging strategies, in order to help in the formation of a system design and recommendations in Chapter 7.

It should be noted that there are two average Elspot prices in the results; the first is for the whole year, whereas the second price is the average price paid for planned day-ahead charging per MWh. This final result is evaluated, as most of the charging is done in this part of the market.

5.2.1 Current Scenarios

The average of all the values for the three years (2012-2014) for the dumb charging, low price and wind integration strategies are used for the comparisons. The numbers that are used for the low price and wind integration strategies are from the scenarios where PEVs are able to operate in all parts of the electricity market. In the remainder of this section, these two strategies are referred to as smart charging strategies. The main results can be seen in Table 5.1.

Average annual results (2012-2014)	Dumb charging	Low price	Wind integration
Total costs (Mill. DKK)	2.04	-4.86	-4.64
Costs per PEV (DKK)	1,022	-2,432	-2,320
Average wind share (%)	32	48	51
Surplus wind integration (%)	0.12	0.23	0.24
Average Elspot price (DKK/MWh)	263	263	263
Average Elspot price day-ahead charging (DKK/MWh)	320	201	232

Table 5.1: Annual results for comparison between the three charging strategies, average current scenario

Compared to dumb charging, the costs decrease is over 300% for both smart charging strategies. This means that substantial savings can be acquired by PEV owners by charging their PEVs intelligently and having them be available to provide services for the grid. The majority of the savings are related to the high availability fee in the primary reserve, which contributes up to 90% of the savings. Compared to dumb charging, the average wind share of the electricity that is used to charge the PEVs is increased between 16 and 19 percent points, depending on the smart strategy used. The actual average wind share in the period of the three years was around 35% of gross consumption in Denmark. In the dumb charging strategy, PEVs are charging on average with electricity with a wind share lower than 35%. In both smart charging strategies, the wind share is higher than the three year average. The average surplus wind integration is almost doubled for both smart charging strategies compared to the dumb charging strategy. However, the amount of surplus wind integration is still very small, since the charging volumes of the 2,000 PEVs that are used in these scenarios are minor compared to the total volume of surplus electricity. In contrast to dumb charging, the average Elspot prices paid in the hours with day-ahead charging in the smart charging strategies are lower than the average Elspot prices. This is to be expected, as the strategies focus either on charging during the cheapest hours of the day or the hours with most wind, which in general results in lower Elspot prices.

In the current case, PEVs can already play a substantial role in the primary reserve, since it is a market with relatively small volumes. The average hourly volume offered in this reserve by the PEVs is around 3.2 MW, which is between 11% and 15% of the total market share in this reserve (both up- and downward offers). Contrary to the primary reserve, the role of PEVs in the RPM and tertiary reserve is limited. The total share of regulating power offered by the PEVs (both up- and downward regulation) is 1.5% of the total traded volume in all markets for the low price strategy and 4.6% for the wind integration strategy. The market share is less than 0.2% of the total traded volume in the RPM for both strategies. This limited role in the RPM and tertiary reserve is due to the relatively small amount of PEVs that are pooled together in this scenario, combined with a high minimum bid size of 10 MW, which results in a small amount of hours where all requirements to bid in the RPM can be met. The market share of the charged volume in Elbas is also limited with a bit over 0.1% of the total traded volume used for charging of the 2,000 PEVs.

Figure 5.1 shows the annual charging and discharging distribution of all three strategies, averaged over the three years.

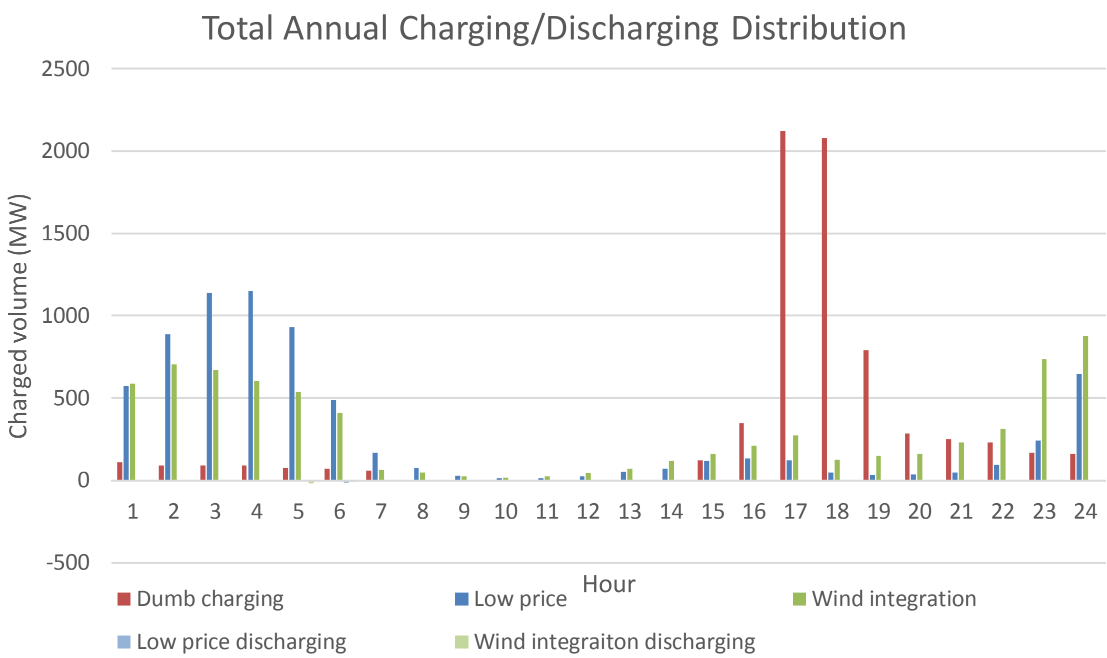

Figure 5.1: Total annual charging and discharging distribution of all three strategies (2012-2014 average)

The figure shows that the two smart charging strategies have comparable distributions that are spread out over a period between 13:00 and 8:00. The low price strategy shows slightly higher charging volumes between 2:00 and 7:00 whereas the volumes of the wind integration strategy are a bit higher between 14:00 and 1:00. The dumb charging strategy results in most of the charging being done between 16:00 and 20:00, and is thereby not spread out over a longer period, which results in higher hourly charging volumes compared to the two smart charging strategies. This might create problems in a future with more PEVs, as this charging distribution corresponds to the current consumption peak load on the distribution grid (Wargers 30/09/14). It should, however, be noted that the charging distribution of the two smart charging strategies are a direct result of that strategy (either charging in hours with the lowest price, or the most wind integration), whereas the distribution of the dumb charging is based on predictions and assumptions of the current moment of charging of PEVs with home chargers. The discharging volumes are so small that they are not considered to have a significant effect and are therefore not further discussed.

It can be concluded that smart charging in the current case can increase the average wind share of the electricity that is used to charge the PEVs, integrate a larger volume of surplus wind electricity and provide balancing services (mainly frequency regulation) to the national grid, while it at the same time offers savings for the PEV owners and limits the load on the distribution grid.

Both of the smart charging strategies provide improved results compared to the dumb charging strategy. The results show that the savings per PEV are larger in the low price strategy and the wind share and surplus wind integration percentages are higher in the wind integration strategy, which is to be expected. The difference in surplus wind integration is small, which is assumed to be due to the small charging volumes of the 2,000 PEVs, as mentioned before. For both strategies, the charging in the day-ahead market is done for a price which is lower than the average Elspot price, however, the difference between the two is larger for the low price strategy, which partly explains the difference in savings.

Another difference is the distribution of charging and discharging over the different parts of the market. Figure 5.2 shows the average volumes of charging and discharging for the low price strategy for the 2012-2014 data. The majority of the charging is done as planned charging; the charging that is required to meet the driving demands of the PEVs. The contribution from downward regulation in the RPM is very small; 1%. This share increases for the wind integration scenario, as shown in Figure 5.3, to about 4%, together with small increases in charging from Elbas and additional planned charging, resulting in a lower share for planned charging. The traded volume in upward regulation (both in the RPM and as activated tertiary reserve) is minimal and almost the same for both strategies.

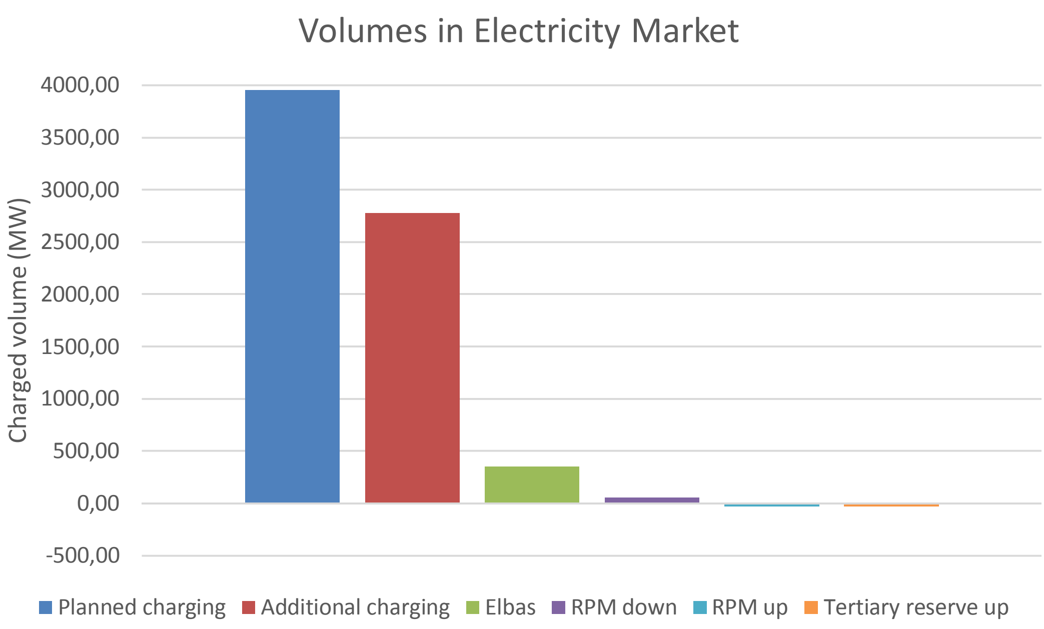

Figure 5.2: Traded volumes for low price strategy (2012-2014 average) over the different markets

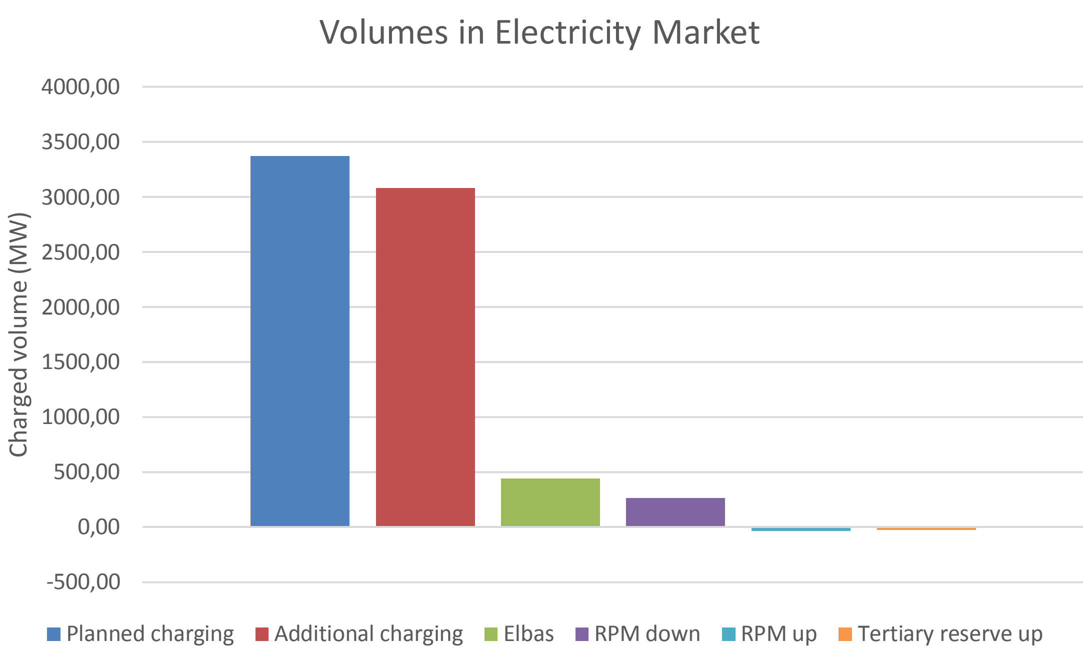

Figure 5.3: Traded volumes for wind integration strategy (2012-2014 average) over the different markets

By decreasing the bid size in the RPM to 5 MW, which is expected to happen later this year, the amount of charging done in the RPM increases from around 1% to 5.3% for the low price scenario and from 4% to 19.3% for the wind integration strategy. A similar increase can be seen in the discharging done as upward RPM. The total market share in the RPM increases from less than 0.2% for both strategies up to 0.5% and 1.2% for the low price and wind integration strategies respectively, by decreasing the minimum bid size. Furthermore, the total savings increases slightly in both strategies due to the increased trade in the RPM. Figure 5.4 shows the traded volume over the different markets with a RPM bid size of 5 MW, as an illustration of the change in volumes.

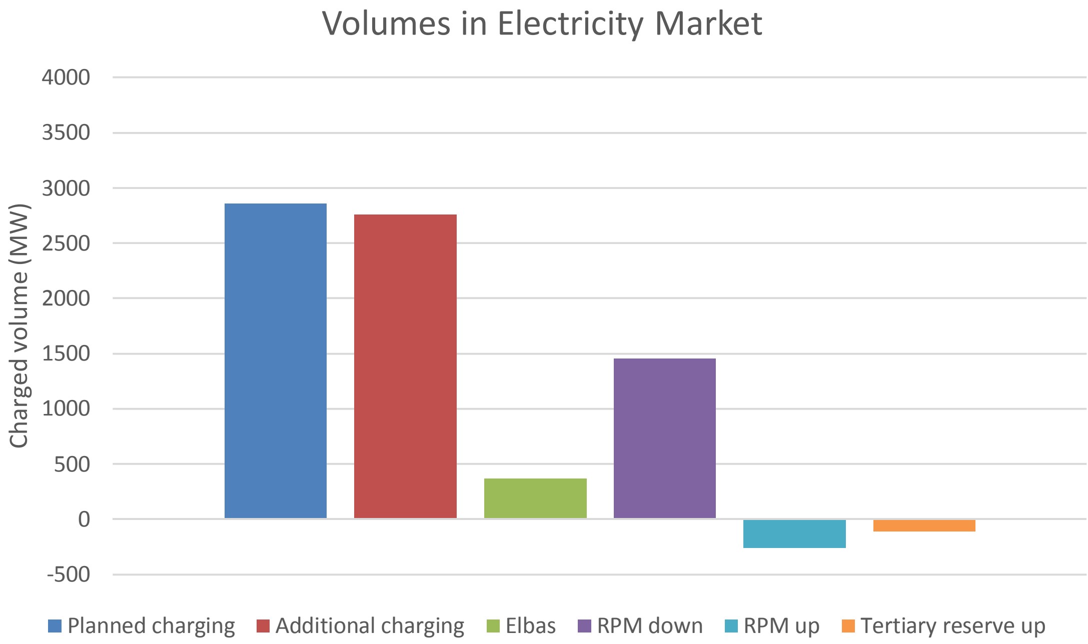

Figure 5.4: Traded volumes for wind integration strategy, 5 MW bid size (2012-2014 average) over the different markets

Based on the comparison between the two smart charging strategies for the current scenarios, it can be concluded that there are not big differences between the two strategies. The role that can be played in the RPM is limited whereas the role in the primary reserve is almost the same for both strategies. However, when the minimum bid size in the RPM is decreased to 5 MW, the traded volume in the RPM increases substantially. This increase is bigger for the wind integration strategy than the low price strategy.

5.2.2 Future Scenarios

For the future scenarios, three Elspot price predictions are used in order to gain insight into the role that PEVs can play in 2025. These different predictions result in a range of results for the three different charging strategies, the main results of which are presented in Table 5.2. Here, two values are shown for each result, corresponding to the lowest and highest values from the three future scenarios analysed. The general trends of the strategies are compared to each other. The numbers that are used for the two smart charging strategies are from the scenario where PEVs are able to operate in all parts of the market.

Range of results	Dumb charging	Low price	Wind integration
Total costs (Mill. DKK)	13.23/29.69	-1.52/-11.08	1.26/-10.16
Costs per PEV (DKK)	661/1484	-76/-554	63/-508
Average wind share (%)	46	66/68	70/73
Surplus wind integration (%)	0.54	0.87/0.93	0.99/1.02
Elspot price (DKK/MWh)	200/450	200/450	200/450
Elspot price day-ahead charging (DKK/MWh)	241/542	137/301	148/342

Table 5.2: Range of results for comparison between the three charging strategies, future scenarios

Compared to dumb charging, the costs decrease is around 129% for both smart charging strategies. These savings are substantial, however, they are smaller than in the current scenario. This is because the revenues from operating on the primary reserve have to be divided by a greater amount of PEVs in the future scenarios. This increase in the amount of PEVs cannot be matched by a similar increase in the volume offered in the primary reserve, since this is a relatively small market. The contribution of the primary reserve to the savings also decreases to around 60%. The wind share increases by 20 to 27 percent points in the smart charging strategies compared to dumb charging. This increase is bigger than in the current scenarios, which can be contributed to the expected increase in generated wind electricity in 2025, with over 50% of the electricity consumption coming from wind power on an annual basis. The amount of surplus wind integration is still about twice as high for the smart charging scenarios compared to dumb charging. The total amount of surplus wind electricity increases in the future scenarios and up to 1% of this surplus electricity can potentially be integrated by the 20,000 PEVs. The average price that is paid for day-ahead charging is higher than the actual average Elspot price for the dumb charging strategy. In the smart charging strategies, the PEVs are being charged with day-ahead purchased electricity with an average price that is lower than the average Elspot price. This contributes to the savings for the PEV owners as the moment of charging is optimised with the smart charging strategies.

The 20,000 PEVs that are included in the future scenarios can in theory meet all the required primary reserve. However, it is not expected that one market player will provide all the required primary reserve volume for DK1. Therefore, the maximum allowed hourly market share in this reserve is limited to 50% for the future scenarios, resulting in about 11 MW of offered reserve volume, or 48% of the required annual volume being offered by the PEVs in this reserve. Compared to the current scenarios, the role PEVs play in the RPM increases substantially. The share of the volume traded in the RPM compared to the total traded volume in all markets is higher for the low Elspot price prediction scenario for both smart charging strategies. The share of volume traded on the RPM ranges between 14% and 32% of the total volume traded by the aggregator. The share of regulating power that is provided by the PEVs varies between 1.6% and 9.3% of the total offered volume in the downward RPM and between 0.8 % and 2.2% for the total traded volume in the upward RPM. With this amount of PEVs, the change in the minimum bid size from 10 MW to 5 MW does not affect the possibility to provide regulating power in the RPM to a great extent.

Figure 5.5 presents the distribution of the trading per hour for the three strategies, measured over one year. The Elspot price prediction with the medium increase (350 DKK/MWh) is used in the figure; the differences in the distributions for the other Elspot predictions are minor.

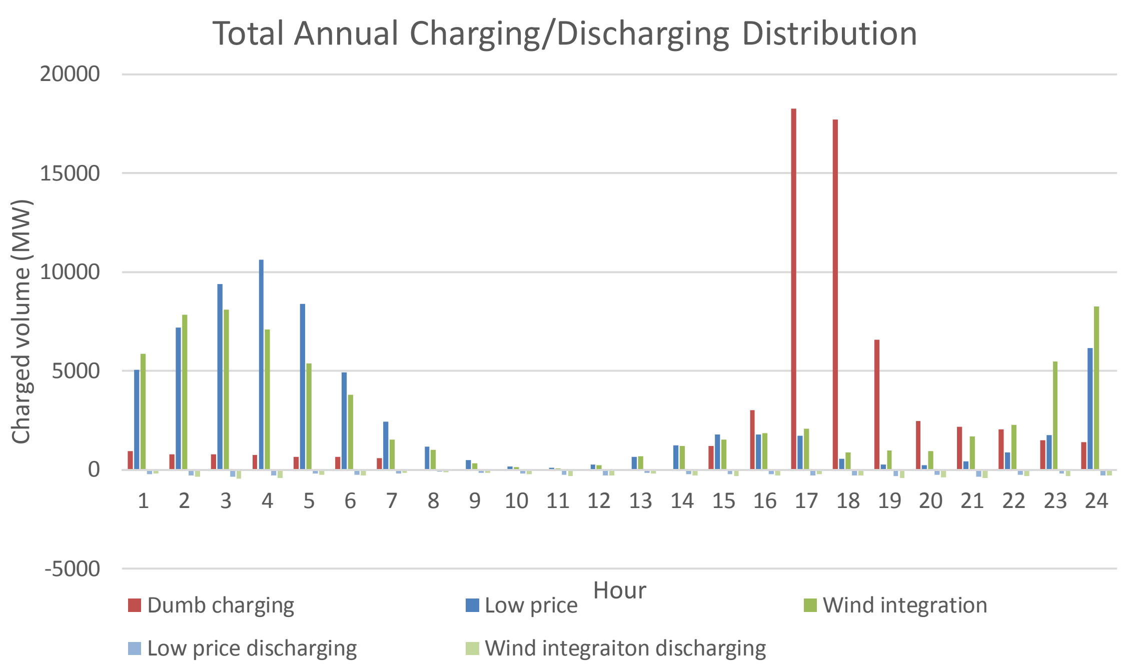

Figure 5.5: Total annual charging and discharging distribution of all three strategies (average Elspot price 350 DKK/MWh)

Just as with the current scenarios, the PEVs in the dumb charging strategy charge mainly between 16:00 and 20:00, as it uses the same predictions regarding the moment of charging. The volume, however, increases to a total of over 18 GW of charging at 17:00 in one year, which may cause problems in the distribution grid as the charging peak occurs in around the same hours as the current electricity peak demand. The load on the distribution grid in those same hours is lower for the smart charging strategies, with charging levels around 2 GW. The charging distributions of both smart charging strategies are quite similar and the charging is spread out over a longer period than the charging in the dumb charging strategy. The low price strategy has higher charging volumes between 3:00 and 7:00 whereas the volumes of the wind integration strategy are a bit higher between 17:00 and 2:00. The distributions of the smart charging strategies generally show the same development over the hours as in the current cases, with just minor differences in the distribution of the charging volume per hour. However, the volumes per hour increase significantly compared to the current scenarios, due to the increase in the amount of pooled PEVs. The amount of discharging is still small compared to the charging volumes and are therefore not considered to cause problems in the grid.

It can be concluded that, within the analysed predictions and assumptions for the electricity market development for 2025, smart charging can increase the average wind share of the electricity that is used to charge the PEVs even further in the future. The integration of surplus wind electricity can also be increased by applying smart charging strategies. In the future case, PEVs can provide balancing services to the national grid, and in theory they can provide all the required frequency regulation in the primary reserve market and play a role in the RPM. This results in savings for the PEV owners and limits the load on the distribution grid.

Both of the smart charging strategies are an improvement over the dumb charging strategy. The results show that the savings per PEV are larger in the low price strategy and the wind share and surplus wind integration percentages are higher in the wind integration strategy, which is to be expected. The difference in savings between the two strategies is higher for the scenario with a low average Elspot price than for the scenario with a high average Elspot price. This is expected to be related to the correlation between low Elspot prices and high wind shares in combination with the creation of the datasets for the future prices, however, this is not examined further in this project. The difference in the surplus wind integration in the two strategies is still small, but larger than in the current scenarios. For both strategies, the planned charging is done for a price that is lower than the average Elspot price, however, the difference between the two is larger for the low price strategy, which again partly explains the difference in savings. The differences in savings and wind integration between the two smart charging strategies are around 10%.

Another difference is the distribution of trading over the different parts of the market. Figure 5.6 shows the volumes of charging and discharging over the different parts of the market for the low price strategy. The majority of charging is done in the day-ahead market as planned and additional charging; 38% and 45% of all charging respectively. The contribution from charging with electricity bought on the intraday market and as downward regulation in the RPM is 3% and 14% respectively, values which are larger than in the current scenarios. When the charging share of the RPM is compared to results with a 5 MW bid size, the differences are very small. For the wind integration strategy, the amount of additional charging increases with 25% compared to the low price strategy, as shown in Figure 5.7. The shares of charging of both day-ahead types are 29% for planned charging and 56% for additional charging. The charging from providing downward regulating in the RPM and buying electricity in Elbas is 13% and 2% respectively. The volume of offered upward regulation from discharging for the RPM and interrupting charging for the activated tertiary reserve is about 20% larger for the wind integration strategy compared to the low price strategy. As mentioned before, PEVs can in theory provide all required primary reserve for DK1, however, in the model the market share is limited, which results in a market share of around 48% of all required primary reserve volume in a year.

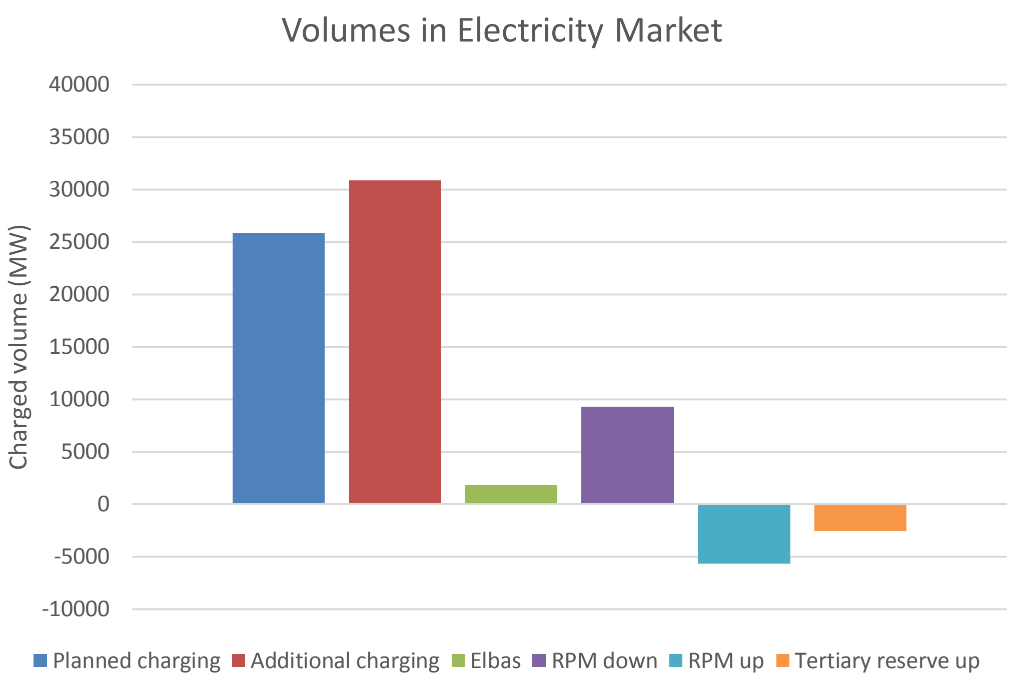

Figure 5.6: Traded volumes for low price strategy over the different markets (2025, average Elspot price 350 DKK/MWh)

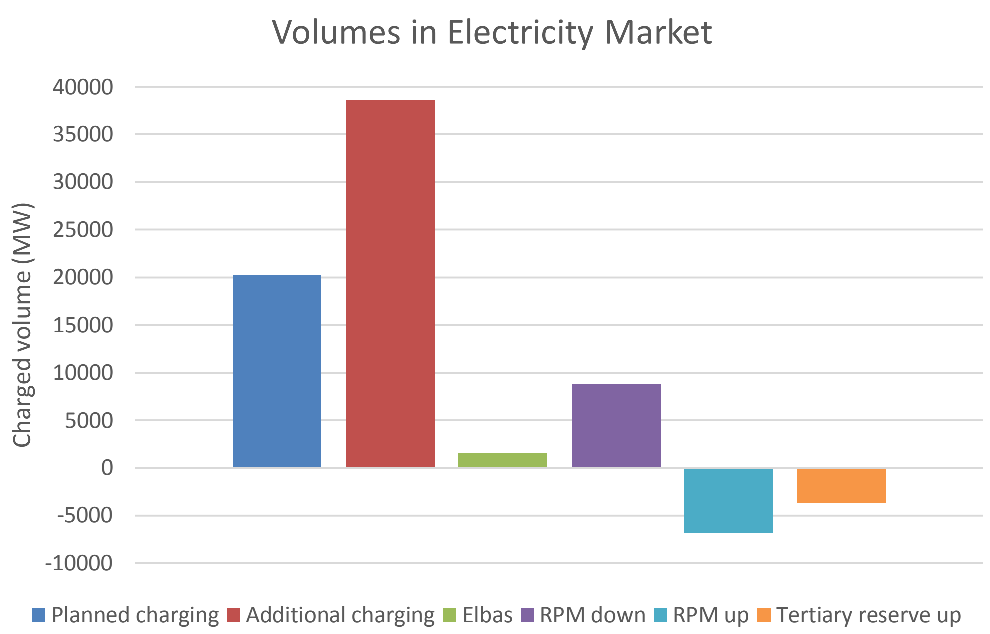

Figure 5.7: Trades volumes for wind integration strategy over the different markets (2025, average Elspot price 350 DKK/MWh)

From the presented results and the insights obtained from the model, it can be concluded that there is a significant difference between the two smart charging strategies in the future scenarios.

The strategy with a focus on low prices has higher savings compared to the wind integration strategy for all three included price levels. The wind integration strategy, on the other hand, charges the PEVs with electricity with a higher wind share and has a higher share of integrated surplus wind electricity compared to the low price strategy for all three price levels. Furthermore, it is clear that there is potential for the use of PEVs in the different markets analysed.

5.3 RPM Optimisation Strategy

The previous sections discuss strategies and scenarios, where the focus has been on the lowest price for the PEV owners and the amount of wind electricity that is used for charging the PEVs. The role that PEVs can play in the different parts of the electricity market within the different strategies has also been discussed, both for the current scenarios, as well as for the future scenarios. However, the amount of balancing services the PEVs can potentially provide might be higher than in the two smart charging strategies. Therefore, an additional analysis is carried out with the focus on optimising the role of PEVs in the RPM, where mainly downward regulation is considered.

A charging strategy is created that is based on the low price and wind integration strategies with all parts of the markets included, however, priority is now given to the RPM over day-ahead additional charging and charging in Elbas. This is done through the switch mentioned previously. In addition, a strategy is introduced where the traded volume in the RPM is maximised, regardless of the gains for the PEV owners; the price limits from the market criteria are adjusted for this. This is done in order to get insight in the maximum potential for PEVs in the downward RPM. These new strategies with the focus on the RPM are called RPM priority strategy and RPM optimisation strategy respectively, and are combined with either the low price or wind integration strategy in order to determine the focus of the day-ahead planned charging.

Table 5.3 presents the results for both RPM strategies within the low price strategy for the future scenario with an average Elspot price of 350 DKK/MWh. The results of the low price strategy with all markets, as discussed in Subsection 5.2.2, is included as a reference situation. The table also includes the traded volumes and, between brackets, the market shares in the specific markets.

Results	2025 low price reference	RPM priority	RPM optimisation
Total costs (Mill. DKK)	-5.50	-3.42	-2.79
Costs per PEV (DKK)	-275	-171	-140
Average wind share (%)	68	63	58
Surplus wind integration (%)	0.94	0.82	0.79
Traded volumes (GW) and market shares			
Elspot planned charging	25.7	41.3	19.9
Elspot additional Elspot	30.7	6.66	8.28
Elbas	2.4 (0.49)	0.94 (0.19)	1.16 (0.23)
RPM downward	9.19 (3.81)	15.5 (6.43)	40.9 (16.95)
RPM upward	-5.88 (1.71)	-2.93 (0.85)	-7.28 (2.11)
Tertiary reserve upward	-2.51 (0.73)	-0.72 (0.21)	-1.34 (0.39)

Table 5.3: Results for comparison between the low price RPM charging strategies (2025, average Elspot price 350 DKK/MWh)

When charging in the RPM is given priority over day-ahead additional and Elbas charging, the savings for the PEV owners decrease, as well as the average wind share of the electricity used for charging and the amount of integrated surplus wind electricity. However, the amount of charging done in the RPM almost doubles compared to the 2025 reference situation (13% of all charging in RPM to 24%). The market share of the charging of the PEVs in the RPM increases from 3.8% to 6.4%.

By changing the settings to optimise the amount of charging done in the RPM, the market share can be increased to almost 17% of the total offered RPM downward volume. 58% of all charging is done as RPM downward regulation with this strategy as can be seen in Figure 5.8.

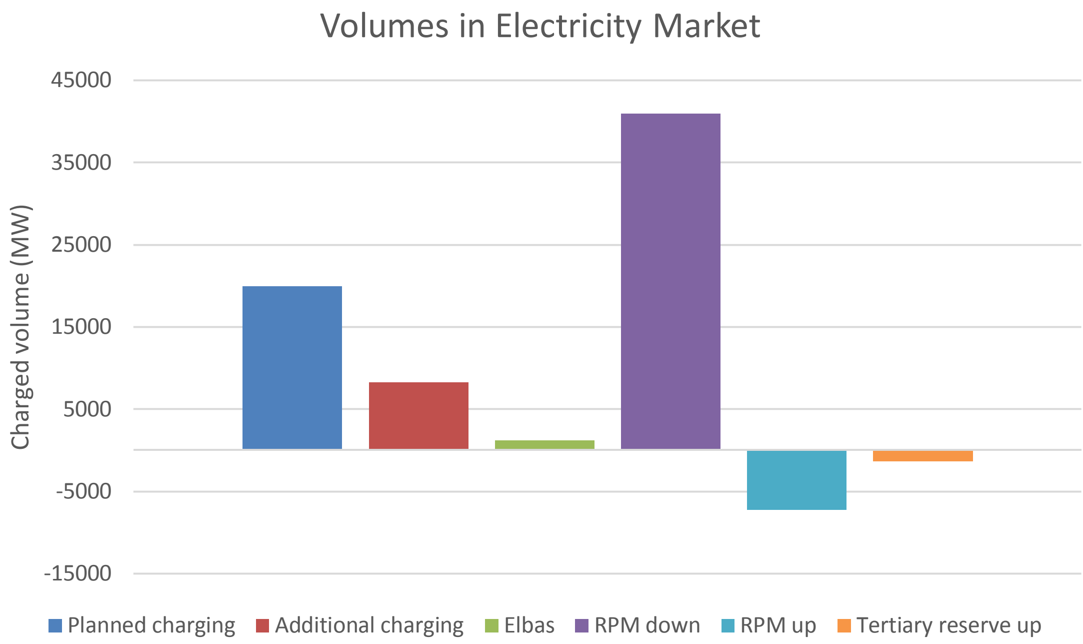

Figure 5.8: Traded volumes for low price RPM optimisation strategy over the different markets (2025, average Elspot price 350 DKK/MWh)

At the same time, the volume of upward regulation also increases compared to the reference situation. However, the savings for the PEV owners decrease further to about half of the initial savings in the reference scenario. The wind share of the electricity used for charging, as well as the amount of integrated surplus wind electricity decrease.

From the charging and discharging distributions in Figure 5.9, it can be seen that the charging distributions follow the same pattern throughout the day, except for the RPM optimisation strategy, where more charging is done between 17:00 and 23:00 compared to the other two strategies. The first period of this increase coincides with the peak consumption in the electricity grid and could potentially cause problems, mainly in the distribution grid.

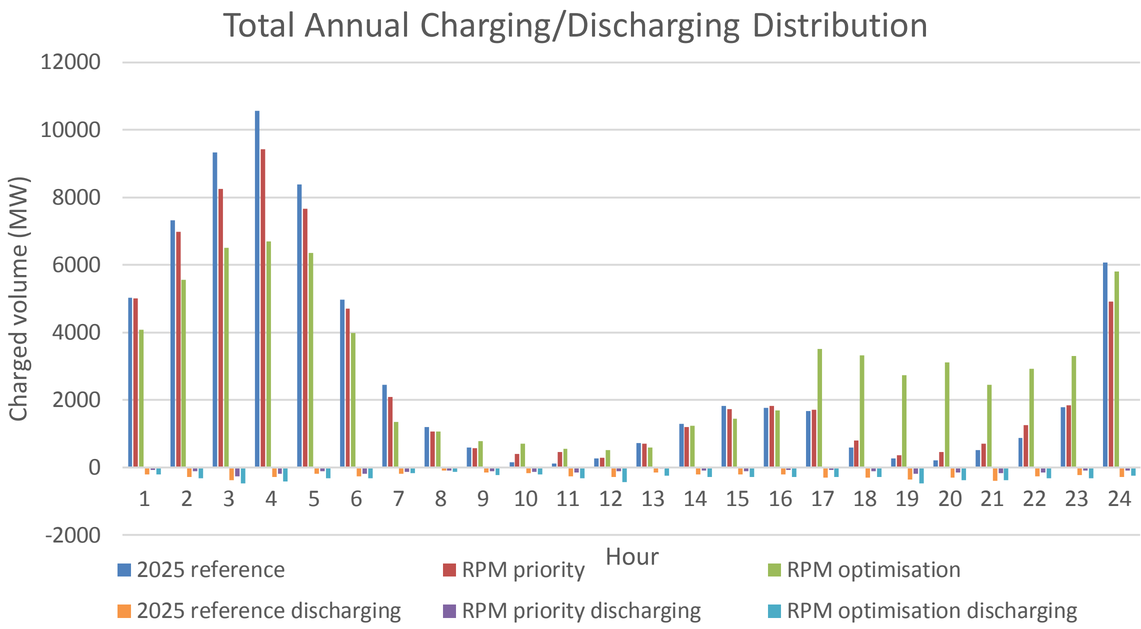

Figure 5.9: Total annual charging and discharging distribution of all three strategies (average Elspot price 350 DKK/MWh)

Charging strategies with a focus on charging in the RPM are also made within the wind integration strategy, the results of which are presented in Table 5.4.

Results	2025 wind integration reference	RPM priority	RPM optimisation
Total costs (Mill. DKK)	-3.43	-2.00	-1.54
Costs per PEV (DKK)	-172	-100	-77
Average wind share (%)	71	67	61
Surplus wind integration (%)	1.01	0.91	0.84
Traded volumes (GW) and market shares			
Elspot planned charging	18.5	31.7	15.7
Elspot additional Elspot	37.8	14.9	16.6
Elbas	1.40 (0.28)	0.71 (0.14)	0.71 (0.14)
RPM downward	12.1 (5.01)	19.4 (8.06)	38.3 (15.9)
RPM upward	-7.18 (2.08)	-4.75 (1.38)	-8.11 (2.35)
Tertiary reserve upward	-3.72 (1.08)	-1.97 (0.57)	-2.72 (0.79)

Table 5.4: Results for comparison between the wind integration RPM charging strategies (2025, average Elspot price 350 DKK/MWh)

The savings for the wind integration strategy are lower than for the low price strategy, as previously discussed. By giving priority to charging in the RPM, the savings for the PEV owners decrease further, as well as the average wind share of the electricity used for charging and the amount of integrated wind electricity. However, the amount of charging done in the RPM increases from 17% of all charging in the 2025 reference scenario to 29%. The market share of the charging of the PEVs in the RPM increases from 5% to 8.1%.

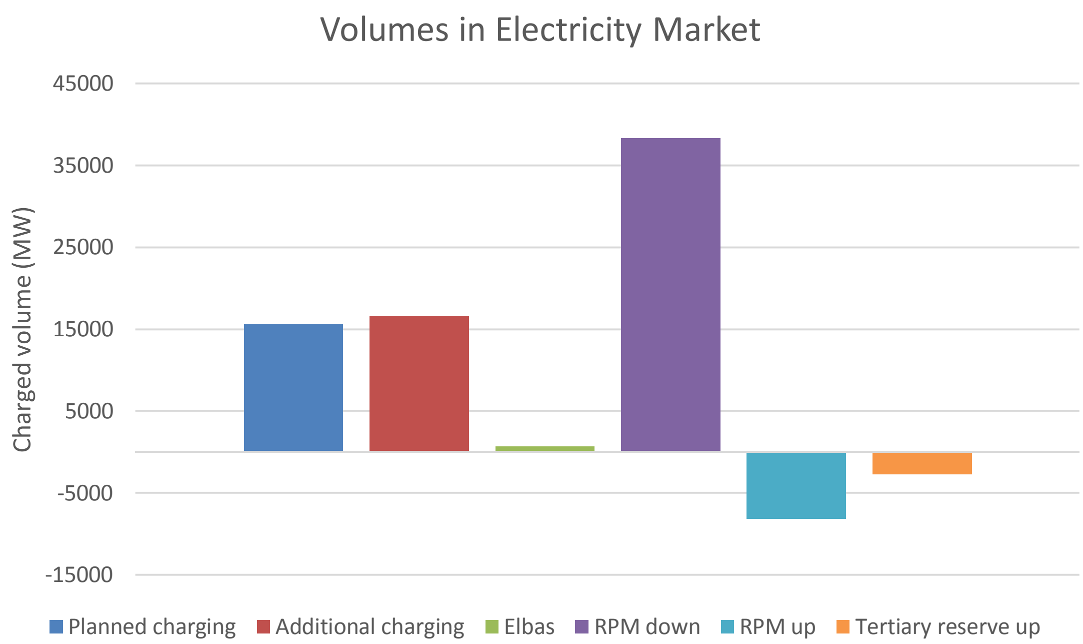

Figure 5.10: Traded volumes for wind integration RPM optimisation strategy over the different markets (2025, average Elspot price 350 DKK/MWh)

The market share of charging in the RPM can be increased to almost 16% of the total offered RPM downward volume by changing the setting to favour RPM charging. In Figure 5.10, it can be seen that 54% of all charging is done as RPM upward regulation with this strategy. The volume of upward regulation also increases compared to the reference situation. However, the savings for the PEV owners decrease further to less than half of the initial savings in the reference scenario. The wind share of the electricity used for charging, as well as the amount of integrated surplus wind electricity decrease. The annual charging and discharging distributions show similar distributions for all strategies, and is therefore not included here.

5.4 Conclusion

In this chapter, the Excel model is used to gain insight in a variety of charging strategies based on a current case (2012-2014) as well as a future case (2025) for which three different Elspot price predictions are used. The two main charging strategies focus either on a low price, and thereby the highest savings for the PEV owners, or on the optimisation of the amount of wind integration and the wind share of the electricity used for charging the PEV. Due to these different focus points, there is not one optimal strategy based on the presented criteria. It is clear, however, that both strategies provide significant savings for the PEV owners compared to the dumb charging strategy. These savings are higher for the current scenarios than for the future scenarios, which is mainly due to the increase in the amount of PEVs from 2,000 to 20,000 and the limited volume in the primary reserve, which contributes with 90% of the savings in the current scenarios. This shows the importance of operating the PEVs on the primary reserve. Next to the savings, it is also clear that the smart charging strategies can support the integration of wind power and increase the amount of wind electricity that is used to charge the PEVs, compared to the dumb charging strategy.

The role of the PEVs in the other parts of the market is also analysed. Most charging is done with electricity purchased in the Elspot market, either for planned charging or additional charging. The amount of charging through Elbas is limited in both the current and future scenarios. The same applies for the charging volume of downward RPM in the current scenarios. The charged volume in the RPM can be increased when the minimum bid size in the RPM is decreased from 10 MW to 5 MW or by increasing the amount of PEVs. This is the case in the future scenarios, where charged volumes in the RPM increase up to 9.3% of the total volume traded as downward RPM in DK1. The amount of discharging and interrupted charging in the upward RPM and activated tertiary reserve is also small in the current case and increases in the future scenario, however, to a lesser extent than the downward RPM.

An additional strategy is created that focuses primarily on the role of the PEVs in the downward RPM. By changing the price limits of the different parts of the markets, as well as the switch that gives priority to the RPM over additional Elspot charging and charging in Elbas, increased market shares up to 17% of the total traded volume in the downward RPM are achieved. Within this strategy, the majority of all charging is done as downward regulating, with up to 58% of all charging. The amount of discharging and interrupted charging through upward regulation or activated tertiary reserve varies between the scenarios in this strategy and no clear increase or decrease can be seen within it.

Offering upward regulating electricity by discharging the PEVs increases the annual charging volume. This occurs as the discharged part of the battery is charged again later. The losses that occur when discharging and charging the battery in order to provide support to the grid have to be taken into account as well. Furthermore, allowing discharging increases the amount of charging cycles of the battery, which may have a deteriorating effect on the battery.

Checks are included in the model to monitor if e.g. charging demands are met and the battery SOC stays within the limits. It is concluded that the battery SOC is able to meet the planned driving demands at 7:00 on weekdays over 95% of the times and at all times at 11:00 in weekends. The unplanned charging demand is met in about 98% of all hours, which in reality is also not always met, as some PEVs may arrive home with a battery SOC that is lower than their preferred unplanned driving demand. With small adjustments it should be possible to increase the amount of times the planned charging demand in weekdays is met, however, it should be noted that the battery SOC in the remaining 5% of the hours is, in general, close to the desired amount. The battery SOC exceeds the maximum battery capacity in some hours, however, this happens in only a few hours, and is not expected to have an effect on the results. Adding a buffer of 2% of the battery capacity that is never charged can already alleviate the problem.

It should be noted that all results in this chapter are affected by modelling decisions and assumptions regarding the parameters. These results should therefore be used to get a general understanding of the role PEVs can play in the different parts of the electricity market.

To gain more insight into which strategy would have the preference seen from the PEV owner's perspective, a survey is carried out amongst PEV owners, which is presented in the next chapter. Here, other stakeholders are also described, which are relevant to the implementation of the system represented by the model in this project.

6 Stakeholder Analysis

A system with PEVs that are part of a SES requires new stakeholders and different roles for the relevant current stakeholders. This chapter discusses these stakeholders, with the focus on PEVs in a SES in Denmark. The following points are thus considered for each stakeholder:

- Their current position in the energy system; their influence and interest
- The initiatives that have already been made
- How they expect themselves to develop in the near future

This is done to gain a better understanding of the stakeholders' knowledge and perspectives regarding the implementation and flexible use of PEVs, in order to evaluate the requirements and possibilities for involving these actors in the process. In Chapter 7, the roles that some of the stakeholders are required to play in the future to enable and utilise the potential of smart charging are then considered; this analysis can thus be seen as a supplement to the model analysis made in order to form a system design and recommendations.

First, an overview of the different stakeholders considered is presented, after which they are discussed individually. A total of ten stakeholders have been selected as relevant actors regarding a transition towards the smart use of PEVs in a SES. Figure 6.1 presents two groups with five stakeholders in each; the inner circle includes the stakeholders that are considered the most important in the transition and that have to be actively involved in the process. The outer circle includes the ones that are considered in a more supporting role, but are still relevant.

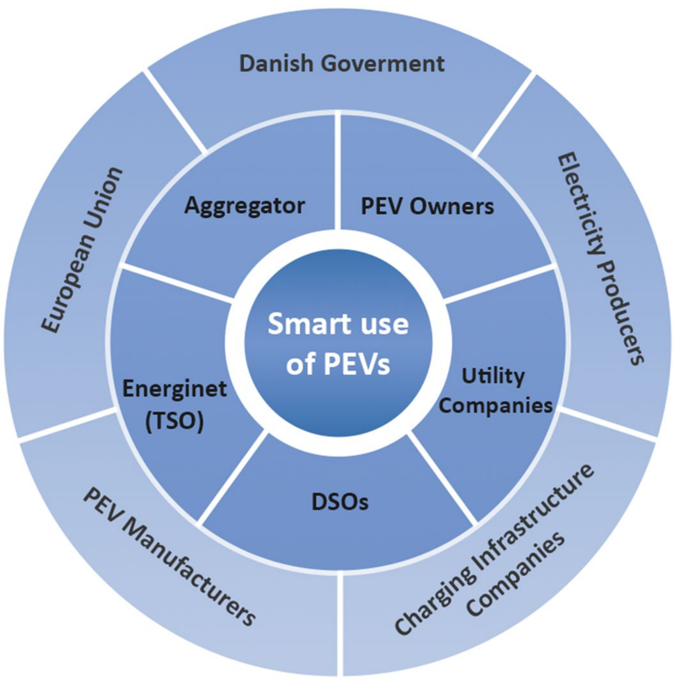

Figure 6.1: Presentation of the main stakeholders regarding the smart use of PEVs

The relevance of the stakeholders is chosen based on gained knowledge from literature study and complemented by perspectives presented through the different stakeholders that are interviewed in the project. More information is acquired about the stakeholders in the inner circle, as they were assessed to have a more important role in the transition to PEVs in a SES. The actual relevance of the individual stakeholders can vary depending on the stage of the transition.

The descriptions in this chapter are based on interviews, various types of literature and documentation about different stakeholders, and a survey made for the project for PEV owners. The survey is carried out as the PEV owners are considered an important stakeholder, since they are the ones who should want to have their vehicles be used in a smart way by an third party; the aggregator. Although they are considered an important stakeholder, not a lot of information is available about their opinions towards the use of their PEVs in a SES. More insight in this is given through the PEV owner survey amongst 105 private Danish PEV owners.

6.1 Description of Stakeholders

The stakeholders that are considered relevant regarding the smart use of PEVs are discussed in this section. Because of the different approach and the lack of general data regarding the PEV owners, the section about that stakeholder is more elaborated than the description of the other stakeholders and can be found in Section 6.2.

6.1.1 Aggregator

In order to describe the role of the aggregator, the market players 'trader' and 'balancing responsible party' (BRP) are explained first, as the roles of these actors are closely related.

Electricity is generated by the producers, but they do not trade electricity. This is typically done by trading companies (e.g. NEAS, Danish Commodities), as these buy the generated electricity from the producers. Next to this, they can buy electricity from retailers as well. During the trading, traders are the owners of the electricity. Traders sell electricity to retailers, with no differentiation of from whom it was bought (producers or another retailer).

Small land-based wind farm owners, for example, hire a trader to sell their electricity, and in order to optimise the revenue, traders have separate departments specialising in forecasting wind production. A lot of district heating companies hire a trader to represent their production and consumption units and lower the operational cost of the district heating company. Another advantage is the possibility for the trader to pool units of different owners together and place them as one bid (in order to meet bidding criteria). Traders usually will not get control over the production and consumption units, but communicate through operation schedules, which entail the optimal operation strategy. (Kop et al. 2014)

Some traders are also the BRP for (some of) their customers. All traded electricity implies the (economic) responsibility of balancing issues. This responsibility entails that an actor must be accountable for possible imbalances between the forecasted behaviour on the market (the bid) and the actual behaviour (measured during the hour of operation). Caused imbalances can be solved within the portfolio[21] of a BRP, or by trading electricity in the intraday market (Elbas). In case imbalances are not dealt with before the hour of operation, they entail the need for regulating electricity. Most traders are BRPs for their customers, however, retailers and producers can also be their own BRP. In order to be a BRP you have to be approved by the TSO and pay certain fees. (Kop et al. 2014)

Another possibility to cope with imbalances comes with the introduction of a SES in which smaller units can activate demand response, and for this, a new role is envisioned; the aggregator. As mentioned in Chapter 3, the purpose of the aggregator is to maximise the value of the customers' flexibility by trading their flexible electricity demand and optimising their moment of consumption (and/or production). In this project, the focus is on aggregators that pool PEVs together of owners that want their PEVs to be used flexibly. These owners enter into an agreement with the aggregator that allows the aggregator to take control over the charging/discharging of the PEVs, for which the owners will be compensated. The PEVs need to be pooled together by the aggregator in order to make it possible to operate in e.g. the RPM, which requires a minimum bid size of 10 MW. The aggregator is in charge of gathering data on various aspects regarding the status of the PEV, electricity market developments as well as the user preferences.

Based on this, a charging strategy is made by the aggregator or the trader in order to increase the savings for the PEV owners and provide the flexibility, while securing the owners that their driving demands are met. This charging strategy can be seen as an operation strategy and can be separated in four parts, which correspond to what is shown in the Excel model. The first part is the day-ahead planned charging, which is based on the driving patterns and preferences of the customers and the hourly prices in Elspot. Once the bids are made in this market, this planned charging has to be met in order to avoid causing imbalances. Next to this, depending on the battery SOC and the remaining charging capacity of the PEVs, there might be more charging planned closer to the hour of operation, if bids are won in the different parts of the electricity market. The third part of the charging strategy is the possibility to discharge electricity from the battery to the grid or to interrupt planned charging, if upward regulation bids are won. Furthermore, there is the possibility to offer primary reserve for which part of the battery, as well as the charging capacity, needs to be reserved, which has to be incorporated into the charging strategy. In order to do this, the aggregator controls the PEVs by sending signals to start the charging/discharging, as well as set the amount that is charged or discharged. The aggregator is also responsible for the accounting of the actual delivered flexibility and the fair distribution of the revenue over the PEV owners. This actor can thus be a trader and a BRP with the ability to communicate with and control the units.

In case flexible electricity and/or distribution tariffs are introduced for private consumers to activate demand response, the aggregator can have an additional function. Private consumers are in general proven to be insensitive to small price variations and are therefore not expected to change their consumption pattern to a great extent. (Andersen et al. 2009) This also brings a

[21] A portfolio is a group of consumption and/or production units that fall under the responsibility of a trader. Imbalances of one unit can be compensated by other units in the portfolio.

certain amount of uncertainty when it is hard to predict how consumers will react on price fluctuations, as further discussed in Subsection 6.1.3. When an aggregator has control over the flexible consumption units, the reaction to price fluctuations will be more accurate and easier to communicate with concerned parties (e.g. utility companies, DSOs, etc.).

An aggregator should preferably have direct access to the electricity market in order to ease its operation. Traders can be an aggregator and use the flexibility of the PEVs to manage their portfolio or trade in the electricity market. Traders like NEAS are looking into this possibility for the future. (Plotnikov 13/05/15) In case the aggregator is a separate entity, it can trade the flexibility with a BRP, as mentioned before. Trading can also be done with the DSO by offering flexibility in order to avoid overload in the distribution grid.

Generally, the role of the aggregator can, and most likely will be played by different stakeholders, as long as they have access to both the vehicles, as well as the electricity grid. It is assumed by different stakeholders that some aggregators will be commercial parties, which are therefore argued to arrive at the most viable solution. (Pedersen 2/03/15; Nyeng 11/03/15; Langvad 26/02/15) Another possibility is that non-profit/consumer owned organisations can be formed, similar to those made within district heating, where the PEV owners are the owners and thus have more insight and influence in the operating decision of the aggregator.

6.1.2 Energinet.dk (TSO)

The main tasks of Energinet.dk, the Danish TSO, are to maintain the security and quality of electricity and gas supply (the latter is not within the scope of this project) in both the short-term and long-term. They are in charge of developing and maintaining the Danish high voltage grid (national grid) and have to create and monitor transparent conditions for competition on the electricity grid. (Retsinformation 2011) Next to this, Energinet.dk administrates the financial support for RE, financed through the PSO (Energinet.dk 2015a). Energinet.dk is furthermore co-owner of Nord Pool Spot, together with six other Nordic and Baltic TSOs.

Although the TSO's focus is on the national grid infrastructure, they see the need for flexible demand in a SES (Energinet.dk 2014a). They are, therefore, supporting the integration of PEVs in the Danish energy system. However, they do not have many possibilities for supporting it other than through their analyses about the potential of PEVs, for example, as presented by Energinet.dk's strategic planners (Hansen 1/30/2012) and their finance programme "ForskEL" (Energinet.dk 2014c).

In order to maintain the security and quality of the electricity supply, the TSO buys regulating electricity and reserves through the Nord Pool market, mainly from Norway and Sweden, and power plants in Denmark (Nyeng 11/03/15). PEVs have the potential to substitute part of this capacity when pooled together and managed by an aggregator, as concluded in Chapter 5. If an aggregator wants to offer capacity from a group of PEVs on the electricity market, the TSO has to check the availability, response times, etc., as reported in (Energinet.dk 2008, 2012).

Energinet.dk is planning to lower the minimum bid size in the RPM to 5 MW in Denmark later this year, which might be beneficial, as smaller pools of PEVs would be able to meet the bid requirements. The TSO is also investigating the potential of a real-time market, which is currently being tested on Bornholm (EcoGrid EU). (Nyeng 11/03/15) The idea is to have a market where electricity price signals are used for five minute intervals, close to real-time. This market is being designed to utilise demand response and would therefore be interesting for PEVs. (Nyeng 11/03/15) It can, therefore, be concluded that the TSO has both the influence and desire to promote the transition into a SES, and has shown initiative regarding the intelligent use of PEVs. In order to promote the pooling of the PEVs, the TSO could ease the requirements for suppliers of regulating electricity, such as the mandatory ability for online measurements.

6.1.3 Utility Companies (Retailer)

The information in the following section is based on an interview with Energi Nord (Melgaard 4/05/15). The utility company, or retailer, buys electricity from a producer through the market via a trader or directly from a producer through a purchase power agreement (PPA). A PPA is an agreement outside of the market between a producer and typically a retailer or trader. This is only possible within the same price area. Such agreements are often done a year in advance, for prices based on Elspot price predictions.

The retailer sells the electricity to the end user and is therefore the link between the electricity market and the users. At the moment, utility companies are generally not affected by the introduction of PEVs. In the current set-up, electricity for customers with a yearly consumption below 100 MWh is bought based on consumption templates. In this set-up, the consumer pays the same price for electricity, regardless of the Elspot price in that hour.

In order to utilise demand response, price signals are required for the PEV owners. With the introduction of smart meters, the possibilities for dynamic electricity tariffs becomes easier, however, at the moment, utility companies are not considering it. They believe that it is the DSOs who have to initiate a dynamic distribution tariff to avoid grid overload in peak hours, when upgrading the grid becomes too expensive. The introduction of a dynamic tariff could, furthermore, make the consumption pattern of the consumers more unpredictable as it is unknown how they will react to the price differences. This could create a challenge for the purchasing of electricity on the electricity market, and if the unpredictability creates more imbalances, the prices for this will be passed on to the consumers. As mentioned in Subsection 6.1.1, this challenge could be alleviated by the introduction of an aggregator.

The utility company itself could be an aggregator in collaboration with a trader. It already has a contract with the consumers, so they could be the link between the PEV owners and the market, where the PEVs are used flexibly. However, Energi Nord does not currently see itself entering the role of an aggregator. Instead, a possibility could be to act as a link between the consumers and the aggregator.

6.1.4 DSOs

The information gathered for the DSOs is from the interviews with NRGi and DONG Energy (Langvad 26/02/15; Pedersen 2/03/15), as well as literature study.

DSOs are the responsible authorities of the local electricity grid in Denmark; they transport and ensure that electricity is supplied to the private users and companies. They are also responsible for the development and maintenance of the grid.

In Denmark, the number of DSOs has been falling throughout the years. In 1997, there were 211 DSOs, while in 2013 there were only 70. (Eurelectric 2011) This is mainly due to the benchmarking model, in which the DSOs are compared to each other, and where is has become increasingly difficult to be efficient enough. Many of the smaller DSOs have therefore merged together or with larger companies, in order to be more competitive and to be able to offer more in the market through the synergies from the larger companies, and this tendency is expected to continue in the future. (Langvad 26/02/15; Pedersen 2/03/15)

Currently, DSOs do not experience any major problems in the grid. NRGi, a DSO known for its green profile, experienced a change when there was a sudden increase in the amount of photovoltaic panels (PVs) due to the regulations that supported them, and mention that this could have been a problem if more PVs continued to be implemented. The situation is similar for DONG Energy, where it is expected that the capacity in most parts of their grid is sufficient for the near future, as the impact from units such as PEVs has not yet been significant, and is not expected to be an issue in the near future. Despite this, tools are still being developed by DSOs in order to prepare for a future with more units such as PEVs; smart meters are being installed, and the DSOs are responsible for gathering and analysing the data from these meters. The data can then be used to optimise the grid and to determine where bottlenecks and other problems could occur. Furthermore, DSOs such as NRGi are also looking into smart grid facilities and analyses, sometimes participating in demonstration projects, and looking into what changes would be necessary in the grid to incorporate units such as PEVs. DONG Energy is also trying to prepare for the future by analysing new grid planning methods, and seeing if investments in the grid can be minimised. This tendency is something that is seen with various DSOs in Denmark. (Pedersen 2/03/15; Langvad 26/02/15) Currently, balancing the distribution grid is not a part of the tasks of the DSO. This could, however, become necessary in the future if more PEVs, PVs, heat pumps, etc. are implemented in the system; the DSOs have to ensure a high quality of supply, which can become more challenging in the future. (Langvad 26/02/15)

Dynamic tariffs can be applied by DSOs for incentivising smart charging. NRGi made an analysis with Danish Energy, where it was determined that in 2016, it would be possible to make two or three different tariffs during the day (Langvad 26/02/15). This can be used to influence the behaviour in the market, in order to mitigate the investments needed for new cables to support the increase in consumption due to the PEVs. DONG Energy is already trying to promote the electrification of the transportation sector by setting low connection fees for the PEVs. They feel that this is currently a necessary step and expect the necessity to change once there are more PEVs in the market. (Pedersen 2/03/15) This is thus also a possibility for the customers.

Although there is generally not a lot of operational collaboration between the DSOs, the association Danish Energy provides a platform through which the DSOs can collaborate regarding the grid and technical planning (Pedersen 2/03/15). Furthermore, five large DSOs in Denmark own

CLEVER and it can therefore be said that they are in close collaboration with them; the DSOs make the investments for the charging infrastructure and, together with CLEVER, determine how and where the charging stations should be established. They are thus interested in promoting the use of PEVs, however, they have not focused a lot on it as it has not been a major issue. (Langvad 26/02/15)

EvolvDSO is a report formed between numerous DSOs, TSOs and other actors in Europe with the purpose of defining the roles of DSOs in the future. From this report, it is concluded that it is generally not expected that the main responsibilities of the DSOs will change significantly in the future, however, it is expected that the management will be more complex. DSOs are expected to have the capability of incentivising their customers to provide flexibility to the grid in order to optimise the integration of RE. It is stated in the report that, *"The role could provide … optimal options for the adaptation of the tariff structure (e.g. placement of peak/off-peak hours) and tariff components in order to make them more cost-reflective."* (evolvDSO 2014, p. 4, 2014, p. 47) Furthermore, in the report, DSOs are considered to be one of the main actors regarding the implementation of a smart grid. They already collaborate with the TSO and are expected to have a close collaboration with the aggregators regarding the activation of the flexibilities in the grid. (evolvDSO 2014, pp. 24–25) Similarly, in the Nikola project, the DSO is expected to collaborate with the aggregator as shown in Figure 6.2.

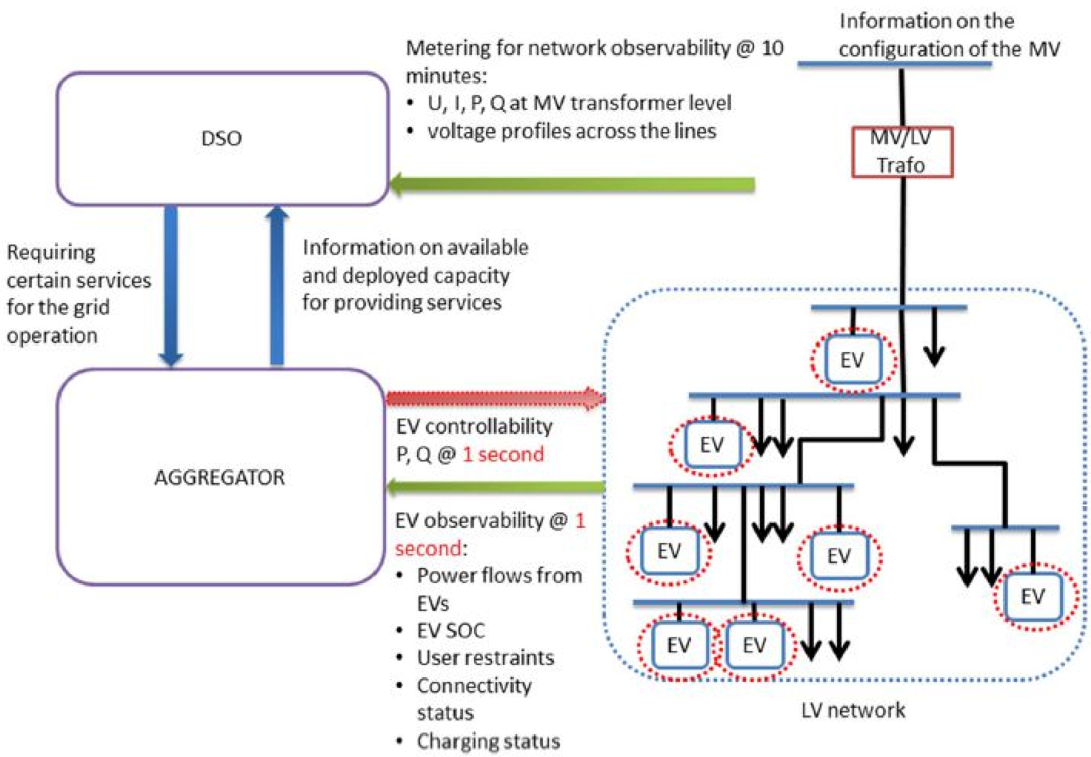

Figure 6.2: Collaboration between DSO and aggregator (Andersen et al. 2014, p. 4)

As shown in the figure, the DSO and aggregator communicate in order to determine what services the DSO requires by the aggregator and what can be provided by the aggregator through the PEVs.

From this section, it can be concluded that although DSOs do not currently experience major problems in the grid due to PEVs, they foresee the need for solutions in the future. Generally, the DSOs are interested in looking into smart grid solutions and are forming tools for this. Furthermore, they are responsible for gathering data from the smart meters that have been installed, which is required for smart charging. The DSOs are expected to enable the customers by encouraging them to provide flexibility to the grid, as they are interested in creating more value for the electricity that they provide. This can be done by using the grid as optimally as possible, where the infrastructure is used in a smart way. It is also expected for them to collaborate with the aggregators in order to provide the needed flexibility.

6.1.5 Danish Government

The Danish government has, through its policies, regulations and support schemes, the possibility to promote the development of RE. Their influence can, for example, be seen in their set goal of converting the energy and transport sectors into 100% RE based systems in 2050. Energy plans, such as CEESA and the DEA's report, use this goal as a basis for their analyses. The government can, furthermore, come with suggestions for initiatives that can be done to promote the integration of RE, and support projects with the same purpose. An example of this last point is the financial support given through the new finance law for different projects relating to RE. (Erhvervsstyrelsen 2015)

Another example of their influence can be seen when Anders Fogh Rasmussen became prime minister in 2001. He was not convinced by the climate ideas that were being discussed at the time, and therefore did not support the transition towards a green energy system fully. This impaired the development of the energy system significantly at the time. (Klimadebat.dk 2011)

Currently, there is uncertainty regarding the development of the energy taxes and taxes within the transport sector. On a general scale, the government has stated a concern for the rising PSO-payments, which are used to support, among other things, wind power and the development of RE systems. Furthermore, the government has decided to prolong the tax exemption for EVs to 2016, however, there is still uncertainty about the further development of this exemption. (Melgaard 4/05/15) The decision that is to be made by the government and the parliament regarding these taxes is expected to have a large influence on the expansion of RE, and in this case PEVs in Denmark in the future.

Another factor to consider regarding the government, is that they are often presented with a dilemma when trying to promote RE. They often have to find a balance between decreasing costs for end users and/or supporting RE projects, while ensuring that they still gain from tax incomes. This is seen, for example, when promoting energy savings or decreasing taxes for RE systems.

6.1.6 European Union (EU)

The EU is already supporting several projects related to the smart use of PEVs, such as the SmartV2G EU project, by making funds available (SmartV2G 2015). This type of support can be of great aid to demonstration projects that are trying to determine the right set-up for PEVs in a SES.

Another role for the EU is standardisation. When different parties are trying to design a system where PEVs are part of the energy system, communication protocols and charging infrastructure standards are required. In the case where this is not done properly, it may limit the potential for PEVs in a SES. (Hansen 1/30/2012) This could be the case if, for example, not all PEVs can be pooled together due to different communication protocols, or if not all types of charging infrastructure enable PEVs to connect to the electricity grid in the same way.

The EU is furthermore involved in all sorts of legislation that can affect the transition towards PEVs in a SES. Regarding emissions in the transport sector, for example, more strict regulations can increase the level of electrification of vehicles and thereby the amount of PEVs that can be pooled together to aid the energy system (European Commission 2015).

6.1.7 Electricity Producers

Electricity producers can basically sell their electricity in two ways; on the Nord Pool market through a trader or through a PPA.

When the PEVs are operating on Nord Pool, they increase the electricity demand in the hours that they are charging. This increases the Elspot prices in these hours due to the merit order effect. As smart charging in this project is done in hours with either low Elspot prices or hours with a high wind share (and generally also low Elspot prices), the prices in these hours can be increased by utilising demand response from the PEVs through the aggregator. This way, the revenue for electricity producers increases in these hours. In the case where the electricity production is based on RE such as wind power, the amount of required PSO-payment decreases due to the higher Elspot prices[22].

An aggregator can make agreements with electricity producers to purchase electricity for the PEVs through a PPA. This can, for example, be done to cover all the planned charging for which a fixed price can be negotiated. Another reason for a PPA between the aggregator and an electricity producer can be to ensure that only wind electricity is used for the PEVs. However, these PPAs limit the flexible use of the PEVs as they are not responding to the market price fluctuations when under such an agreement.

PEVs that aid in the balancing of the national grid might be a threat to the electricity producers who are currently providing regulating electricity. In case the PEVs are able to offer the same service for a better price, some of the current suppliers of the service are pushed off the market, which then decreases their revenue.

[22] Outside the scope of this project.

6.1.8 PEV Manufacturers

A small questionnaire was sent out to five of the main PEV manufacturers, however, only Nissan responded to it. This section is therefore based on the answers from Nissan Denmark and are related to the new models of the Nissan Leaf (Høj 18/05/15) as well as a seminar about the future of PEVs (Thomsen 14/04/15).

At the moment, PEVs are still more expensive than conventional vehicles, which combined with limitations like the range, prevents customers from purchasing PEVs, resulting in a small market share at the moment. PEVs are expected to become more cost competitive within a decade, which could be assisted by governmental support.

Most manufacturers sell their vehicles through a dealer. When alterations are required on PEVs in order to make them, for example, ready to be used for smart charging, PEV owners have to stop by their dealer, even for small updates, which is an extra hurdle. Some PEVs like the Tesla Model S enable 'on the air' updates through their internet connection.

The current PEVs have on-board charging timers that enable the user to pre-set the moment of charging. This feature can already be used as a simple smart charging system by, for example, having the vehicle only charging in the night, or in the hours with most wind power production. However, to use the PEV for smart charging, improvements on the side of the charging infrastructure are required in order to, among other things, allow for changes in the charging load or respond to signals from the aggregator.

Nissan also developed charging infrastructure that enables their PEVs to discharge with 6 kW to provide electricity to homes, businesses or the grid, without required alteration on the vehicle. The charging infrastructure allows for charging of PEVs from other brands who have a similar charging plug.

Regarding the warranty on the battery, this is not affected by engaging in V2G services. Testing has been done on the effect of V2G on the batteries without significant effect on the capacity of the battery.

This shows that PEV manufacturers are making considerations and developing new technologies to allow for smart charging and V2G. It seems that some of the current PEVs would already be capable of smart charging in a SES, given that the charging infrastructure is improved.

6.1.9 Charging Infrastructure Companies

The main charging infrastructure companies in Denmark (CLEVER and E.ON) were contacted with questions regarding the role of PEVs and the development in charging infrastructure. However, they did not have the opportunity to answer the questions or did not respond. The following section is therefore primarily based on a previous interview with the Dutch foundation originating from grid companies and responsible for the first steps in charging infrastructure in the Netherlands, ElaadNL (Wargers 30/09/14).

ElaadNL started from a Dutch grid company in 2009 because no actor at the time was responsible for the charging infrastructure for PEVs. The increasing amount of PEVs in the Netherlands was noticed by the grid companies, as well as their potential threat to the distribution grids due to their high electricity consumption. Since then, the possibilities for smart charging (and discharging) have been examined and tested, as it is assessed that smart charging is required to avoid peak loads, as well as to aid in the integration of RE in the future.

15% of their charging points offer the possibility of variable charging loads and upgrading of the remaining charging points is being planned. The requirements for the infrastructure to provide smart charging are already currently known. The technology of charging points, communication and ICT is not expected to be the issue towards smart charging (and discharging). However, standardisation and regulation is considered important, and lobbying is required to ensure that the best options are supported, for example, through the right regulations.

Trading the flexibility of PEVs that are connected to public charging points is considered a possibility to improve the business case for the public charging points, as it is noticed that most PEVs are parked (and plugged in) for a longer period of time than is required to charge. An important condition for having the PEV owners' accept that their vehicles are used flexibly is that they receive the right compensation, and they should not be able to notice that the flexibility of their vehicles has been used; it should not jeopardise their driving needs.

6.2 PEV Owners

The stakeholder analysis for the PEV owners is based on the results from the survey made in the project. It should be noted that respondents who lease their PEVs are also included in the results and are referred to as PEV owners. A more detailed presentation of the results can be found in Appendix C. As a reminder, there are 105 respondents in the survey, corresponding to over 3% of the PEV owners in Denmark in 2014.

PEV owner characteristics

A significant fraction of the respondents from the survey are in the higher income groups, and the majority live in or near a city centre; only 5% of the respondents live further than 20 km from a city centre. This could be due to multiple reasons such as the range of the PEVs and the distance to the nearest charging stations. The majority of the users have full ownership of the PEV, however it is seen that not all of these respondents have full ownership of the battery. This point is returned to later in this section.

Current charging behaviour

It can be assumed, based on their charging behaviour, that the majority of the PEV owners are parked and charging at least once a day. This is done through home chargers, public charging points or chargers at work; 72% of the respondents own home chargers, 26% of the respondents charge at work and 36% use public charging points regularly. It should be noted here that some respondents charge through more than one of these mentioned options. For the respondents with home chargers, 63% of the ones that have the possibility to charge at work do so, and 32% of them use public chargers. On the other hand, for the respondents who do not have a home charger, 77% of the ones that have the possibility to charge at work do so, and 48% of them use public chargers. Although more questions are asked in the survey about charging at work and public points, focus is here put on the charging that occurs through the home chargers, as this is the focus in the model. More information about charging at work and through public points can be found in the appendix.

Of the PEV owners that own home chargers, only about half of them currently adjust their charging so that it is done at specific desired moments[23]. This is despite the fact that 80% of the owners with home chargers have the possibility to adjust their charging through, for example, a mobile app. Certain factors regarding the reasons for adjusting are asked about, the results of which can be seen in Figure 6.3.

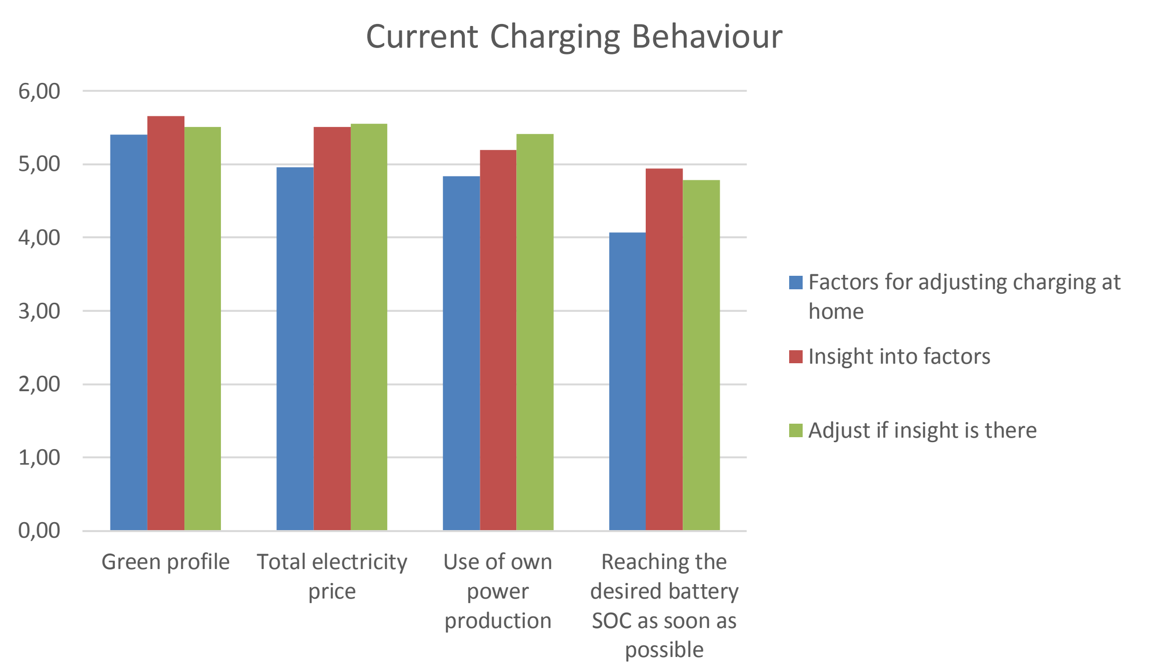

Figure 6.3: Current charging behaviour of PEV owners

Here, three things are asked about regarding each of the factors; to what extent the PEV owners currently adjust their charging at home based on these factors, to what extent they have insight into the factors, and finally, to what extent they would adjust their charging if they had insight into these factors. It should be made clear that the first question is only asked to owners with a home charger, while the last two questions are asked to all respondents[24]. The owners set a value between one and seven for these questions, where one corresponds to 'Low extent' and seven corresponds to 'High extent'. The average values from the results are shown in the figure.

[23] This can be done through, for example, a mobile application or by choosing when to plug in the PEV.
[24] This is excluding the respondents who answered 'Not relevant'. This is not expected to significantly change the results, as only a few respondents chose this option.

It is determined that the main reason for choosing to adjust the charging of the PEVs is to gain a green profile. About half of the respondents that adjust their charging also state that the total electricity price is an important factor to consider. This is interesting, as the price is assumed to be constant for the majority of the respondents, regardless of when charging is done. It is clear from some of the comments, however, that some of the respondents are on the Elspot market. Thus, it is assumed that if the prices are not constant throughout the day, the electricity price is a factor that would be considered by more of the PEV owners. From the comments, it can also be seen that some of the respondents have knowledge on the wear of the battery; some adjust their charging to ensure that the battery is not completely charged. It is, however, not assumed that this consideration is made by the majority of the respondents. The main reasons for not owning a home charger are that they are too expensive, due to lack of parking spaces and due to the opinion that they are not necessary. This last point mainly relates to the respondents who use regular outlets to charge their PEVs.

There is a general high level of insight regarding charging with a green profile, as well as the electricity prices on the market. For both of these factors, a majority of the respondents state that this insight would make them adjust their charging, however, despite this, the insight is not always put into action; as mentioned previously, only half of the owners with home chargers actually adjust their charging. Through the comments it is shown that some of the respondents decide to charge when convenient for them, which is generally when they return from work, or when it is otherwise practical. This relates to the dumb charging strategy analysed in the project. For others, what is missing is not the insight, but automatic solutions that would allow for the PEV owners to connect their vehicles to a SES without it being inconvenient for them. Furthermore, there are some of the respondents who do not believe that using PEVs in a SES is a feasible solution. This shows that there is still a variety of opinions regarding the flexible use of PEVs.

Perspective regarding flexible use of the PEV

A large part of the respondents had already heard of intelligent charging before the concept was brought up in the survey. This supports the assumption that these respondents are the first movers within this area, which is further supported by their high interest in RE. This could affect the stated preferences of the respondents. The majority of the respondents state that they are interested in charging their PEVs intelligently, however, their main concern regarding doing this is that the driving demand for unplanned trips or emergencies is not met. This is interesting, as other concerns such as meeting the daily driving demand for planned trips, the effect on the battery lifetime and the extra costs involved, are not major concerns for the PEV owners.

When the respondents are then asked about giving control of their PEVs to an aggregator, who can both charge and discharge the vehicles, the interest evens out; there is change from a clear interest (81%) in flexible charging to no major interest (40%)[25] in flexible use of the PEVs through an aggregator, as can be seen in Figure 6.4. Here, the average value set by the respondents can be seen, where one corresponds to 'Not interested' and seven to 'Very interested'.

[25] The respondents are considered interested if they set an answer above 4.

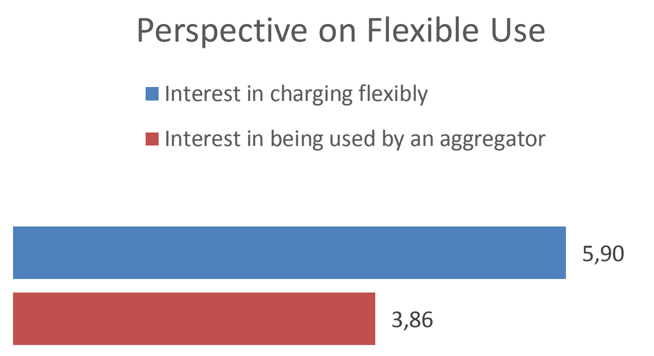

Figure 6.4: Perspective on flexible use of PEVs

In this case, the concern increases for all the factors that are also considered for the case of only flexible charging. This can be seen in Figure 6.5, where the average values from the results are shown. One corresponds to 'Not concerned' and seven to 'Very concerned'.

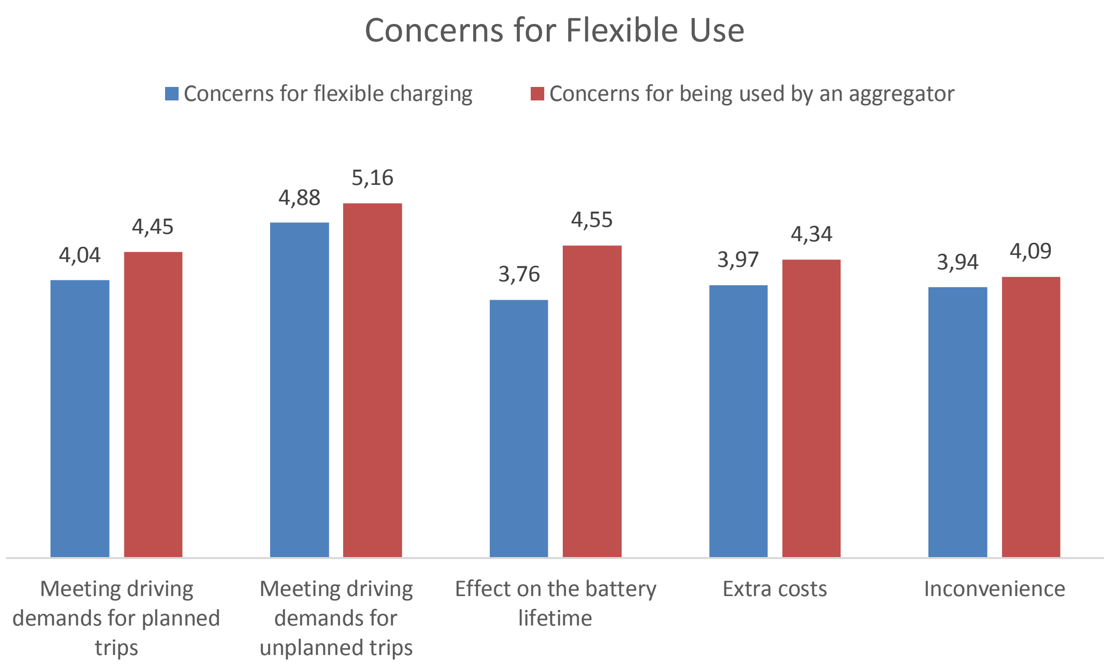

Figure 6.5: Concerns for flexible use of the PEVs

When considering the number of respondents who are concerned about the factors[26], the increase is especially seen for meeting unplanned or emergency driving demands and the effect on the battery lifetime. It is assumed that this is mainly due to the possibility of discharging, as the

[26] The respondents who have stated values above 4.

respondents maybe do not feel that they have as much control of what happens with the battery, and are wary of the effect on the battery lifetime from a potential increase in the charging cycles. From the comments, it is clear that there would have to be an economic incentive in order for many of the respondents to allow flexible use of their PEVs. This could, for example, be in the form of a compensation for the wear of the battery. Other concerns like always having to be connected when parked, and the protection of personal information, are not major concerns.

Factors for convincing PEV owners

In order to convince the majority of the respondents to allow for an aggregator to use their PEVs, it is determined that the aggregator would have to focus on the integration of RE, as well as in making Denmark more self-sufficient. This can be seen in Figure 6.6, where the average values set by the respondents can be seen. One corresponds to 'Low extent' and seven to 'High extent'.

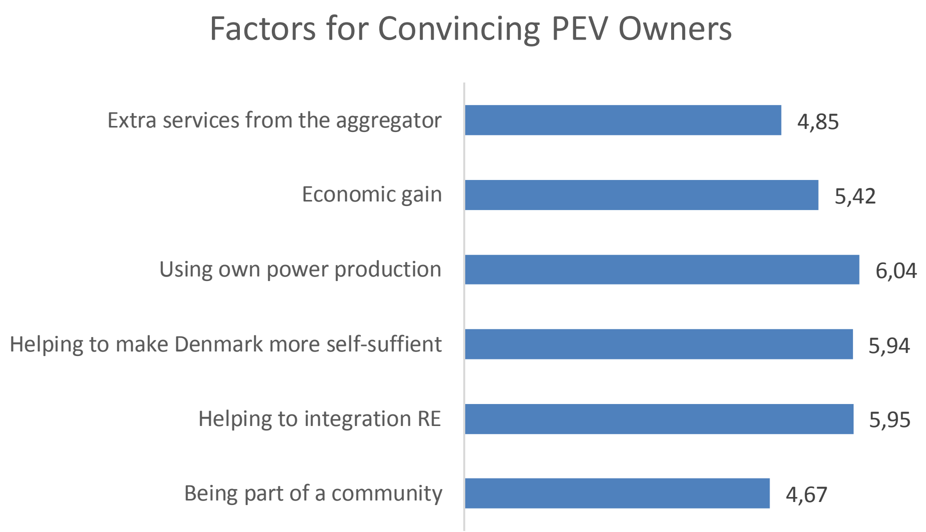

Figure 6.6: Factors for convincing PEV owners to allow for involvement of an aggregator

Providing an economic benefit and optimising the use of their private electricity production units are also aspects that can convince a significant part of the respondents to give up control of their PEVs. Regarding the economic benefits, an optional question is asked in the survey about the required monthly benefit in order to convince the respondents. Only about a third of the respondents provided an answer, and therefore care must be taken when concluding on the results from this question. Having said this, from the answers, it is calculated that for those that state that they are interested in having an aggregator use their PEVs flexibly, the average monthly economic benefit is about 350 DKK/month. The average is about 570 DKK/month for those who are not initially interested. When taking all the respondents into consideration, the economic benefit required is concluded to be in the range of 260-400 DKK/month for being used flexibly. This is calculated based on cases where the highest and lowest values stated by the respondents are omitted respectively, as these values can be considered to be unrealistic. All these values can be compared to the stated values that the respondents currently pay for charging (total cost of charging, including taxes); on average this is about 560 DKK/month for respondents with home chargers and about 500 DKK/month for all respondents.[27] Questions are, however, not asked about how the price settlements are made.

Extra analyses

As mentioned previously, not all the respondents that have full ownership of the PEV have full ownership of the battery. When comparing the two possibilities, it is shown that in general, a higher percentage of the respondents with leased batteries are interested in both charging their PEVs flexibly, as well as allowing an aggregator to use the vehicles. Furthermore, a lower benefit is required by the aggregator for these respondents compared to the respondents with full ownership of the battery. It should, however, be noted that when doing these types of comparisons, fewer respondents are included due to the filters, and therefore, the results are not necessarily representative of PEV owners in general. Having this in mind, it is possible to say that leasing the battery can potentially increase the incentive for the PEV owner to allow for flexible use of the vehicle.

A separate analysis is made for the respondents that also have electricity producing units such as PV and residential wind turbines. This corresponds to 33% of the respondents in the survey, so care must again be taken here, due to the relatively small amount of answers. It is seen that these respondents generally have a high level of insight regarding the use of their units. Despite this, only slightly over half of them adjust their charging based on the insight. As with the general results, the majority of these respondents are interested in charging flexibly, but only 48% of them are interested in involving an aggregator. Furthermore, the average required price for flexibility is similar to that stated by the respondents that are not initially interested in being used flexibly by an aggregator. From this, and again bearing in mind the small amount of respondents, it is possible to say that owning electricity producing units does not have a large impact regarding the incitement to involve an aggregator.

To conclude on this section, it can be said that PEV owners are important actors regarding the intelligent use of PEVs, as they are the ones that ultimately decide whether their vehicles can be used flexibly with or without an aggregator. The current owners are first movers, which can both be an advantage and a limitation; first movers often do not need as much evidence to test something, in this case the use of PEVs in a SES. However, a lot more people than just the first movers are required to start purchasing and/or using PEVs in order to make a significant difference in the energy system. From the survey, it can be concluded that there are already PEV owners that adjust their charging when connected to their home chargers, mainly to obtain a green charging profile. Furthermore, the majority of the respondents are interested in charging flexibly, and have

[27] Also an optional question. Here, some respondents responded with values of 0 DKK/month. These were excluded from the calculation, as it could have been due to a misunderstanding of the question.

the insight to do so, but the insight is not currently leading to action. When involving an aggregator, concerns increase, especially for meeting driving demands for unplanned trips and for the battery lifetime. Here, more would be required to convince the PEV owners; proof that using the PEVs are helping the system, as well as an economic incentive; for example, a compensation for the wear on the battery or lower tariffs for charging in specific hours.

7 System Design and Recommendations

In this chapter, the system design and recommendations for the project are described. These topics can be seen as conclusions to the analyses made in the project for the model, as well as the relevant stakeholders.

The proposals for the system design are based on the results and findings of the Excel model made in the project. Here, different charging strategies are analysed for PEVs, which are assumed to be controlled by an aggregator. From this, a design can be made that takes into consideration the economic aspects for the PEV owners, as well as the benefits for the electricity grid and the integration of wind power in Denmark.

The recommendations are made based on both the model and stakeholder analysis, and relate to how the system design can be implemented in Denmark. These cover a broad spectrum of topics, including the required policy changes, as well as how to incentivise PEV owner engagement.

7.1 System Design Proposal

It is clear that there are benefits for both society and the private user, if solutions are found for integrating the increasing amount of wind power, as well as phasing out conventional units that are currently used for balancing the electricity grid. PEVs can potentially be part of solving these problems through a SES, and the transition into a largely electrified transportation sector is already expected in Denmark. Therefore, a system design is proposed, in which the expected PEVs are utilised for the factors previously mentioned; integrating more wind power and aiding in the balancing of the grid.

The Excel model mainly considers two strategies that result in the flexible and intelligent charging of the PEVs. The strategies focus on low prices for the PEV owner and high wind integration respectively, and these are compared to a reference strategy, which represents a case in which the PEVs are not charged intelligently. As an addition to the focus, both strategies involve the participation of the PEVs in different parts of the Nord Pool electricity market. An extra strategy is also briefly considered, in which the focus is on the benefits for the electricity grid; the use of the PEVs in the RPM. When considering the results, care should be taken as some of the input parameters and set criteria are based on assumptions. Changes in these parameters and criteria may alter the final results. Furthermore, the design choice of the model has a direct effect on the results. From this, the system design should be seen as one possible proposal.

From these strategies it is clear that for both the current and future cases:

- Both smart charging strategies decrease costs and increase wind integration compared to dumb charging.
- PEVs can be used beneficially in the RPM and the primary reserve, where they can play a substantial role in the primary reserve for both smart charging strategies. The role in the RPM is mainly for the future case.

- Both smart charging strategies shift the peak hours of charging so that they do not coincide with the current peak hours in the grid, and distribute the charging throughout more hours in the day.
- Decreasing the minimum bid size in the RPM to 5 MW has a substantial effect on the role PEVs can play in this part of the market, mainly in the current case or with small pools of PEVs.
- Focusing on the RPM can increase the role that PEVs play in this market, however, this is at the expense of the savings for the owners, as well as the integration of wind power.

Depending on the preference of the PEV owner, or the aggregator, one of the two strategies can therefore be implemented, and result in benefits for society and the PEV owners. Furthermore, if it is chosen to continue with the dumb charging strategy, there can potentially be extra costs for society due to the distribution grid problems that could occur from the extra consumption during peak load hours. To optimise the strategies, certain points should be ensured:

- There should be enough PEVs in the aggregator's pool that can be used flexibly in order to be able to make bids in the electricity market.
- The aggregator should be able to gather the necessary data regarding the market and wind data to implement the strategies, as well as be able to communicate with both the PEV and the PEV owners. Furthermore, they should be able to participate in the Nord Pool market.
- The first priority should be given to meeting the driving demand of the PEVs. The participation of the PEVs in the primary reserve should then be given second priority. In the case where balancing the market is the focus of the strategy, RPM should be given third priority.
- Small changes in the market requirements, such as decreasing the minimum bid size in the RPM, could increase the role PEVs can play in this market.
- The aggregator should give the PEV owners the option of choosing a strategy. Alternatively, there should be different aggregators with different focus points that the PEV owners can then choose from.
- The aggregator should ensure a certain spread in the amount of charging over the cheap hours, to avoid high grid loads.
- The aggregator could be played by different stakeholders, which could focus on different strategies. This could, for example, be a commercial player, or a non-profit organisation.

7.2 Recommendations

In order to successfully implement the system design, recommendations regarding the relevant topics for the design are presented in this section, which are based on the analyses made in the project. A summary of all the recommendations is presented after all the individual descriptions.

7.2.1 Market Development

It is shown through the model that data which is already available can be used in order to implement the strategies in the design; data on the market prices, as well as wind production data, is used to determine when charging and regulation is done by the PEVs. This is beneficial for the system, as minimal resources are required to create better signals for the aggregator. If the strategy focused on integrating surplus wind power instead, clearer signals, for example, from the TSO, are assumed to be necessary in order to implement the strategy, making this strategy more complicated to use.

The primary reserve should be given high priority, however, this is mainly due to the high availability fees that are given for being available. If these fees or required volumes were to decrease, this would decrease the economic benefits for the PEV owner, making the reserve less attractive to participate in. It is, therefore, important to ensure that it is still attractive for the PEVs in the future. A possibility, apart from the high fees, is to allow for the PEVs to play a substantially larger role in this part of the market in the future. This could result in significantly higher savings for the PEV owners, which is not seen to a high extent in the model due to the limitations set through the market criteria.

Participating in the RPM provides regulating alternatives for the electricity system, which is necessary in order to ensure the security of supply of electricity. The TSO plans on decreasing the RPM bid size, which potentially makes it easier for PEVs to participate in this part of the market; less vehicles need to be pooled together to make a bid in the market, and in hours where the available charging capacity is low, some bids can still be made. Decreasing the bid size has a larger effect with a smaller amount of vehicles, and so it can provide possibilities to have smaller pools of vehicles in the future, to allow for more trading in the RPM. This can also provide the aggregator with some more flexibility. It is, therefore, recommend that the bid size is decreased even further, and that smaller pools of PEVs are used by the aggregator.

Charging in the intraday market (Elbas) does not play a large role in the charging strategies included in this project. This is due to the way that the market works, and from the model, it can be seen that when removing the additional charging that is done in the day-ahead market, more charging is generally done in Elbas. Thus, if Elbas should play a larger role in the future, the aggregator should consider the gains from doing this compared to charging additionally in the day-ahead market. Another possibility would be for the costs for imbalances to increase, to make Elbas more competitive with the RPM, as was originally intended.

In the model, the aggregator trades volumes in the different markets and reserves. Another possibility could be for the aggregator to make PPAs with suppliers. This could remove the uncertainty of the volatile prices in the Nord Pool market, however, it limits the flexibility of the aggregator, which can otherwise be used to optimise the charging strategy. PPAs can be made with, for example, small land-based wind turbine owners in order to guarantee charging with RE, which could also potentially increase the revenue for these wind turbine owners. If PPAs are made, it has to be determined how the electricity consumption settlement should be organised between the supplier, aggregator and PEV owner in order to provide benefits for all parties.

7.2.2 Policy Proposals

The Danish government can promote the transition to an electrified transport sector through, for example, tax reforms and subsidy schemes. Currently, the tax exemption on PEVs is expected to be prolonged to include 2016, however, it is uncertain what will happen to the tax after this point. It is expected that the inclusion of the tax will significantly affect the decision to purchase PEVs, as it would make them considerably less price competitive with conventional cars. It is, therefore, recommended that instead of completely removing the tax exemption, that it is gradually decreased throughout a period of more years. Alternatively, the whole taxing system can be redesigned to promote the use of PEVs and other environmentally friendly[28] vehicles to a larger extent. For example, the registration tax can be applied on the CO_2-emissions of the vehicles instead of on the costs of the vehicles. It is expected that this will help to incentive the purchase of PEVs. The electricity taxes, as well as the PSO-tariffs, can also be re-evaluated in order to promote RE and use of PEVs. Here, the government should find a balance between supporting RE and obtaining the required tax incomes.

The EU also has the influence to promote the implementation of RE systems in Europe. This is already seen in the energy goals set by, for example, Denmark, which use the EU goals as a standard. In order to enable and optimise the pooling of the PEVs, it is considered important for the standardisation of the relevant technology to be put on the agendas of, not only Denmark, but all the countries in the EU. Especially with the additional bidirectional communication and charging technologies required by the aggregator, complications arise if the PEVs use different platforms. Standardising also makes it more attractive for consumers to own PEVs, as potentially all charging points can then be used and planning for longer trips becomes less complicated.

In order to allow for the implementation of the strategies and to enable demand response from PEVs, it is required that the electricity tariff is at least on an hourly basis. This can be done using the smart meters, which are currently being installed in all homes around Denmark. Having flexible prices is considered an imperative requirement for incentivising PEV owners to allow for flexible use of their vehicles. These possibilities are discussed in this subsection.

Although it is not currently being considered, utility companies have the possibility of implementing dynamic tariffs for their customers. The introduction of such a tariff would, however, make it more challenging to determine the consumption pattern of the consumers, as it can be difficult to predict the reaction of the users to the price differences. This could result in more imbalances in the grid, the price of which ultimately would be passed on to the consumers. An aggregator could alleviate these challenges as it reacts more accurately to the price fluctuations and can communicate the charging strategies. The utility company interviewed for the project does not see themselves playing the role of the aggregator, however, they do see the possibility of acting as a link between the users and the aggregator. Currently, all customers consuming under 100 MWh of electricity in a year pay a set price for their consumed electricity.

[28] PEVs driving on electricity produced by conventional power plants are technically not environmentally friendly, however, it is assumed that in the future, a larger part of the electricity generation will come from RE sources.

This means that these customers would not acquire the benefits of a strategy focusing on low Elspot prices. In these cases, an agreement on a price settlement should be made between the utility company, aggregator and customer.

Dynamic tariffs can also be applied by DSOs for incentivising smart charging, as is already being considered by, for example, NRGi. This can be used to influence the behaviour in the market, in order to mitigate the investments needed for new cables to support the increase in consumption due to the PEVs. DONG Energy is already trying to promote the electrification of the transportation sector by setting low connection fees for the PEVs. This is thus also a possibility for the customers.

7.2.3 Technological and Infrastructure Development

In order to incorporate the different parts of the market into the charging strategies of the PEVs, there is a need to develop and implement the necessary infrastructure. This includes bidirectional charging and variable load capabilities in both the charging infrastructure and the vehicles, as well as bidirectional communication platforms to allow the aggregator to communicate with the PEVs. It should become a general priority among the different actors to ensure that this technology is both implemented in the charging points and the vehicles in the near future. For example, the EU can set standards for the technology so that all units become compatible, and the investments for the development and installation could partly be provided by the government or the DEA. CLEVER and E.ON could incorporate the necessary changes in all their charging units, and PEV manufacturers could ensure that the same is done in their PEVs. Doing this directly promotes the idea of smart charging, while at the same time demonstrating the possibility for it.

From the survey, it is clear that some of the PEV owners do not have home chargers, as they regard them as being unnecessary; they use normal outlets from their homes to charge their PEVs. In these cases, a possibility could be to incorporate the necessary technology mentioned previously into the PEVs, so that these outlets can be used to at least charge flexibly, or to shift the moment of charging; it is assumed that discharging would not be a possibility through this solution. The communication can then still be made between the vehicle and the aggregator. Otherwise, to incentivise the purchase of home chargers, solutions should be found regarding the price of the charger, as well as the problem regarding parking spaces. Alternatively, the charging unit can be leased through, for example, the aggregator or the infrastructure company; in the latter case, the infrastructure company could have a collaboration with the aggregator.

Apart from the necessary technology that needs to be installed in the PEVs, the manufacturers should also find solutions for providing better software updating services for the PEV owners. Currently, only the Tesla model S uses this service optimally, partly due to them not having to go through a dealer first in order to provide updates for the customer. Furthermore, in order to ensure that the required amount of PEVs are purchased, the vehicles have to become more affordable than they currently are, even with the tax exemption. This is, however, expected to happen in the future with the developments in the technology, as well as the expected support from, for example, the government.

Some of CLEVER's home chargers refund the electricity tax to the customers when charging. This creates an economic incentive for the PEV owners to use these chargers. A similar agreement could be made for PEV owners who charge their PEVs through an aggregator, independent of what charging unit is used; if the PEV is used through an aggregator implementing the strategies proposed in this project, the refund of the electricity tax can be seen as a compensation for the PEV owner for allowing their PEVs to be used. Alternatively, this refund can be given for specific parts of the market; if the PEV is being used to balance the grid or to integrate surplus wind electricity, for example.

Regarding the data from the smart meters, the DSOs have to find a way to efficiently use this for optimising the grid and integrating PEVs. They could, for example, collaborate with the aggregator to mitigate potential problems in the distribution grid, while still considering the dispatch principal. With this principal, customers are guaranteed unlimited access to the electricity, and it can therefore be argued that this principal is violated when intelligently charging the PEVs; the charging can be altered depending on the needs of the grid. In these cases, the customer would need some sort of compensation for not having unlimited access. The DSOs should generally encourage the customers to provide flexibility to the grid, as the DSOs are interested in creating more value for the electricity that they provide. This can be done by using the grid as optimally as possible, where the infrastructure is used in a 'smart' way. It is also expected for them to collaborate with the aggregators in order to provide the needed flexibility.

7.2.4 PEV Owner Engagement

The recommendations discussed in this subsection are mainly based on the responses from the survey made in the project. Some of the recommendations are also presented in the previous subsections, and are therefore not discussed in more detail here. These are:

- Most of the PEV owners in the survey are in the high income groups. In order to incentivise more people to purchase PEVs, they need to become more affordable for the general population.
- Solutions should be found to incentivise the purchase of home chargers to allow more PEVs access to the market through an aggregator. These should focus on the price of the chargers and the parking spaces. Alternatively, solutions can be found to be able to use the normal outlets at homes for this purpose.
- Flexible tariffs should be implemented in order to incentive the use of the PEVs during specific hours. For example, if the taxes and/or tariffs are lower during night hours compared to the day, this could cause a change in the charging behaviour of PEV owners; the insight into the different relevant factors will then lead to action.
- There should be a form of economic compensation for the PEV owners for being used flexibly. This compensation can be due to multiple factors, for example, the wear on the battery due to the increased amount of charging cycles, and for the violation of the dispatch principal.

Involvement of the aggregator

A third of the respondents in the survey stated values for the economic benefit that is required in order for them to allow for an aggregator to use their vehicles. It is calculated that this value is in the range of 260-400 DKK/month. From the model, the highest savings that can be gained is for the low price strategy in the 2012 current scenario, where, compared to the dumb charging strategy, the savings are about 330 DKK/month. The savings in the other scenarios and in the future are lower. From this, it can be said that the strategies analysed can just about provide the required benefits, if all the market criteria are applicable; for example that the PEVs can take up such a large market share of the primary reserve. It is therefore assumed that if economic incentives are necessary, this should be given supplementary by other actors such as DSOs. In addition other factors can be used to convince the PEV owners.

When involving an aggregator and the possibility to discharge, a significant part of the respondents who initially were interested in charging their PEVs flexibly were suddenly not interested in having their PEVs be used. It is assumed that this is mainly due to the concern of the effect on the battery lifetime of increased charging cycles. Thus, in order to convince more PEV owners, it is recommended that further studies are made regarding the battery and the data should be made more assessable for the PEV owners. Business analyses could be made to show the PEV owner what their battery costs are compared to what they gain from being used by an aggregator. As seen from the model, discharging as RPM upward regulation is assessed to be only a small fraction of the potential savings for the PEV owners. From this, it can be concluded that not participating in RPM upward regulation is also an option to mitigate the concern of the effect on the battery lifetime.

Another possibility is for the PEV owners to form an organisation, similar to the ones formed within district heating, that pool the PEVs together. The vehicles are then still controlled by the PEV owners, having their interests as the main focus. An option to provide an economic incentive for the PEV owner is in the form of a reward for ensuring the availability of the PEVs, when promised to the aggregator. For example, if, in a year, a PEV owner never or only seldom interrupts the charging strategy of the aggregator, that PEV owner can gain an extra economic payment.

There is a general concern about meeting driving demands for unplanned trips/emergencies when giving control to an aggregator. This should be the main priority of the aggregator, and as an extra precaution, the charging strategy could be designed to ensure that flexibly charging and discharging does not affect the SOC in the battery required for these trips. This is done in the model in the project, where priority is given to charging the battery so that there is always enough capacity for unplanned trips.

It is shown that the owners who lease their batteries generally are more willing to have their PEVs be used by an aggregator. From the respondents who provided an answer for the required economic gain, it is also shown that the respondents with leased batteries generally require a lower gain to be convinced. It is recommended, therefore, that solutions are found in which the batteries can be leased when entering into an agreement with the aggregator. It could, for example, be the aggregator who purchases the batteries and leases them to the owner, or a collaboration can be formed between the aggregator and the PEV battery manufacturers.

It should be easy and reliable for the PEV owners to inform the aggregator of their preferences regarding their PEV. This can be for their preferred charging strategy, driving demands, etc., and there should be a possibility for the owner to overrule the aggregator (at a cost) in case, for example, the owner suddenly needs the vehicle. A mobile application can be used for the PEV owners to communicate the information to the aggregator, also opening up the possibility for the PEV owners to have insight in the use of their PEVs. Some of the respondents already use mobile applications such as Energinet.dk's to adjust their moment of charging, and therefore, if the aggregator's application can show the same type of information, this could incentivise the PEV owners to allow for flexible use of the vehicle. This information can be used, for example, to show the PEV owners that they are integrating RE and/or making Denmark more self-sufficient and could also provide monthly or yearly overviews of savings and wind integration of their PEV. At the same time, the PEV owners can use the application to be notified about the SOC of their vehicles; this could aid in diminishing the concern regarding if there will be enough electricity in the battery to cover the driving demands.

7.2.5 Summary of Recommendations

To summarise the recommendations:

Market development

- It should be prioritised for PEVs to play a larger role in the primary reserve due to the economic benefits for the PEV owners, as well as to provide the necessary frequency regulation in the future.
- To allow for smaller pools of PEVs to play a role in the RMP, the bid size should be decreased.
- The possibility of establishing PPAs should be considered, to evaluate if they can bring benefits for the PEV owners, as well as the system.

Policy proposals

- The Danish government should find a solution for the tax exemption for PEVs, whether this is to gradually decrease it after 2016, or to re-evaluate the whole taxing system for vehicles.
- The EU should push the agenda of standardisation for PEVs and charging infrastructure in the EU countries.
- The electricity consumption should be considered at least on an hourly basis, to allow for flexible prices. Utility companies and DSOs should evaluate the potential of applying dynamic prices and tariffs for their customers, where especially the DSO can gain from this.
- Collaborations should be made between the aggregators, DSOs, utility companies and PEV owners to establish charging strategies, price settlements and make these factors transparent for the PEV owners.

Technological and infrastructure development

- Priority should be given to the inclusion of the required technology in both the PEVs and charging points, to allow for the aggregator to implement the charging strategies. This applies to multiple actors.
- Solutions should be found for the PEV owners who use normal electricity outlets for charging their PEVs. Alternatively, incentives should be given to convince the owners to purchase home chargers.
- PEV manufacturers should improve their software updating services, as well as ensure that the PEVs become more affordable in the future.
- There should be an economic incentive for the PEV owner to allow for the aggregator to control their PEVs. This could be in the form of a refund of the electricity tax.
- DSOs should use the data from the smart meters to collaborate with the aggregator to optimise the distribution gird. Here, a form of compensation should be given to the PEV owner.

PEV owner engagement

- In order to incentivise the PEV owners, more economic incentives than the ones provided directly through the charging strategies are required. This can, for example, come from the DSOs.
- Further studies should be made to show the effect on the battery lifetime of increased charging cycles. The data from such studies should be easily accessible by the PEV owners.
- It could be considered not to participate in the RPM upward regulation as it has a small effect on the savings and could mitigate concerns regarding the effect on the battery lifetime.
- An economic incentive could be given in the form of a reward to the PEV owner, when ensuring the availability of the vehicle when promised to the aggregator.
- Priority should be given by the aggregator to ensuring that unplanned/emergency trips can always be made.
- Solutions can be formed where batteries are leased. This can potentially increase the incentives to use the PEVs flexibly.
- It should be easy and reliable for the PEV owners to state their preferences to the aggregator. This could be done through a mobile application, where relevant information can also be provided to the PEV owners by the aggregator.

It is concluded that the presented system design and recommendations provide a solid basis for the promotion and implementation of PEVs in a SES, through the use of an aggregator.

8 Conclusion

The focus in this report is on the role PEVs can have in a Danish SES, by enabling smart charging strategies. The following research question is used in the project:

What role can plug-in battery electric vehicles play in the current and future Danish energy system?

In order to answer this research question, four sub-questions have been formulated, which are answered in the following.

What potential gains are there for the vehicle owners when smart charging is enabled by an aggregator?

Through an Excel model analysis, it is shown that PEV owners can save money compared to their current way of charging (dumb charging), by implementing smart charging strategies. Two smart charging strategies are analysed, where one focuses on low Elspot prices, while the other focuses on the integration of wind power.

In the current scenarios (2012-2014 with 2,000 PEVs), the annual savings compared to dumb charging are in the range of 2,600 to 3,900 DKK on average per vehicle for the low price charging strategy, assuming that the PEVs are able to participate in all parts of the Nord Pool electricity market[29]. Almost 90% of the savings come from the availability fees for providing frequency regulation in the primary reserve. In the future scenarios (2025 with 20,000 PEVs), the savings are less; between 1,200 and 1,550 DKK per vehicle per year, with a contribution of around 60% from the primary reserve. It should be noted that the amount of savings are sensitive to assumptions in the model, such as the allowed market share in the primary reserve and the market price developments.

To what extent can plug-in battery electric vehicles integrate wind power and provide balancing services to the electricity grid?

A wind integration strategy can be used to increase the wind share of the electricity used by PEVs from 39% up to 59% in the current scenarios and from 51% up to 73% in the future scenarios. Furthermore, the amount of surplus wind electricity that can be integrated by PEVs can be increase, however, the total volume remains limited to about 1% of the total surplus volume in the future scenarios. Differences between the two smart charging strategies can mainly been seen for the future scenarios, where the differences in savings and wind integration are around 10%.

The model is furthermore used to show that PEVs are able to provide balancing services in the electricity grid. This is mainly seen in the future scenarios with the wind integration strategy, where the PEVs' share of the annual volume traded in the RPM can increase up to 9.3% for downward regulation and 2.2% for upward regulation. Through alteration in the charging strategy, increased volumes of electricity can be offered as balancing service in the RPM; up to 17% of the

[29] With exception of the secondary reserve.

annual traded volume in the downward RPM, however, the savings and wind integration volume are decreased.

How should the involved actors be organised to enable this role?

From the stakeholder analysis, it is concluded that certain stakeholders are required within the transition towards PEVs in a SES. An aggregator is expected to be required to pool PEVs together, gather the necessary data, create charging strategies and trade electricity on the electricity market, in order to generate savings for the PEV owners. In order to fulfil this role, it is deemed necessary for the aggregator to gain access to the electricity market. It is assessed that this role can be played by different actors, such as a trader, commercial party or non-profit organisation. Utility companies and DSOs can support the transition by providing dynamic electricity and distribution tariffs respectively, in order to provide the required incentives to enable smart charging. Different stakeholders such as governmental institutions need to work on regulation to support PEVs and the smart use of them, and to improve standardisation. Collaborations should be made between the different stakeholders to establish charging strategies and price settlements.

What is the attitude of PEV owners towards having their vehicle used in a smart way?

The results from a survey amongst 105 Danish PEV owners show that PEV owners are positive towards the smart use of their vehicle. Creating a green profile is the main motivation for this actor to allow for flexible charging, followed by the costs for charging, however, it is shown that this motivation is currently not generally leading to action. The PEV owners seem more hesitant towards the involvement of an aggregator that takes control over the vehicle and allows for discharging. Their main concerns regarding this are meeting the driving demands for both planned and unplanned trips, as well as the effect on the battery lifetime. It is expected that these concerns can be mitigated through knowledge sharing of relevant aspects, such as the battery lifetime, economic compensation and the use of a user friendly mobile application. PEV owners can be convinced to have their vehicles be used by an aggregator mainly by helping to make Denmark more self-sufficient and helping to integrate RE. Other factors such as economic gains and using own power production to charge the vehicles are also considered important.

This project shows that there is a significant role for PEVs in a SES, given that the right conditions are created, such as the implementation of flexible tariffs and the required technologies, and the involvement of an aggregator, which collaborates with the other relevant actors. This way, savings for the PEV owners can be acquired, the wind share used to charge the PEVs can be increased and balancing services can be provided in the electricity system. It is assessed that PEV owners are in general positive towards having their PEVs being used in an intelligent way, however, it is uncertain if the estimated savings found through the model can be achieved and if they are sufficient to convince PEV owners to have their vehicle be used flexibly by an aggregator.

9 Perspective Analysis

Certain aspects are considered relevant to the topic presented in this project, but are not analysed due to the project limitations. In this chapter, some of these aspects are briefly reflected on. This analysis can be seen as an indication of what the next steps in the project would have been, given more time, as well as suggestions for further research.

9.1 Sensitivity Analysis

In order to further validate the model made in the project and assess its robustness, a sensitivity analysis can be made for the factors that are assumed to be significant, or that are set based on assumptions and predictions. Doing this allows for a better insight in how these factors affect the model, in order to better evaluate the results. As the charging strategies analysed in the model should be seen as being possibilities for the use of PEVs, doing a sensitivity analysis can also give an idea of how other strategies could be formed. For the strategies in the project, factors relating to the PEV characteristics, market criteria and distributions could be tested for sensitivity, as shown in Table 9.1.

	Sensitive factors
PEV characteristics	Battery capacity, charging capacity, energy used per km, driving demand, power loss
Market criteria	Minimum and maximum bid sizes, battery capacity reservations, price limits
Distributions	Availability, charging distribution

Table 9.1: Factors for sensitivity analysis

The sensitivity of these factors towards the total costs for the PEV owners, the wind integration and the balancing of the grid should be considered.

9.2 Public Chargers and Charging at Work

Although this project focuses on home chargers, it can be expected that public chargers, as well as chargers at work places, will also be used by aggregators in the future. In order to ensure that this can happen, the barriers towards the implementation of these chargers should be considered. From the survey results, some recommendations can be made.

Currently, to use different public charging points, different memberships are sometimes required. This can act as a barrier for PEV owners, due to the inconvenience and expenses brought from either being limited to only using certain charging points, or having to pay for multiple memberships. There should be a solution for this, to remove the inconvenience. For example, if standardisation of the charging infrastructure is pushed forward, all future PEVs should be able to physically charge at the different charging points, as long as the PEVs support the charging capacity of the unit. There could then be one membership fee for all these charging points, which is distributed among the charging infrastructure companies. Another option could be to completely remove the membership fees, which is assumed possible if the charging infrastructure is, for example, subsidised, or to remove them for PEVs who are used by an aggregator. This relates to another barrier, which is the general cost of charging through a public charging point. Regarding charging at work, under half of the survey respondents have the possibility of doing so. There is, therefore, a need for further implementation of charging points at work places if the aggregator requires a larger availability of PEVs during the day. Solutions should be found to promote this and to ensure the effective use of the infrastructure; currently a PEV could be parked at a charging point, but it is not necessarily charging all the time. This limits the possibilities for other PEVs to charge.

In order to evaluate the potential benefits of increased availability due to an increased use of both public charging points and chargers at work places, a scenario could be analysed through the model. For this scenario, the availability of the PEVs would be higher during the day than currently set. This would be a simplified scenario, as in reality, it is assumed that price settlements would be made differently than for home chargers.

9.3 Distribution Grid Analysis

In the project, the potential effects on the distribution grid from implementing PEVs are briefly mentioned. A main concern is found when the load from the PEVs would cause the overall consumption to surpass the grid capacity limitations. This is an important factor to consider, as the strategies analysed in the project do not directly take into account the potential need for upgrading the grid in order to integrate the PEVs. This topic has been researched in Denmark, but is not seen as an urgent problem, for example through the perspective of the DSOs. However, the growing number of PEVs, combined with the goals of electrifying a significant share of the transport sector, can be seen as a future problem for the distribution grid. By looking for solutions for this future problem now, potential over-investment in grid infrastructure can be avoided.

In the project, it is concluded that the smart charging strategies can aid in mitigating overloads in the grid by shifting and distributing the consumption to more favourable hours. It would be interesting to evaluate the actual effect of the PEVs and the strategies on a distribution grid, for example, through the use of the programme Power Factory. Here, the strategies can be tested, and changes can be made in order to optimise the use of the PEVs seen from the perspective of the grid. For example, limitations can be made for the charging strategy, so that charging in peak hours does not exceed the capacities of the grid. For this, a local distribution grid can be used as a case study, where the local supply and consumption are considered.

9.4 Real-time Market

The project EcoGrid EU is a demonstration project on Bornholm, where the residents of the island are part of testing ways of utilising demand response. The electricity price is used to try to influence the consumption, to shift it to hours where there is a lot of electricity production. The participants can react to the prices, as they receive continuous information about them. The flexible units, such as heat pumps, can then be set to automatically react to price changes, taking into account user preferences and the room temperature. (EcoGrid Bornholm 2015)

In this regard, the Danish TSO is testing the use of a real-time market, and would like the gain insight in the way consumers respond to such price incentives. The real-time market can be seen as an addition to the RPM, with a regulating price that is provided in five minute intervals, as can be seen in Figure 9.1.

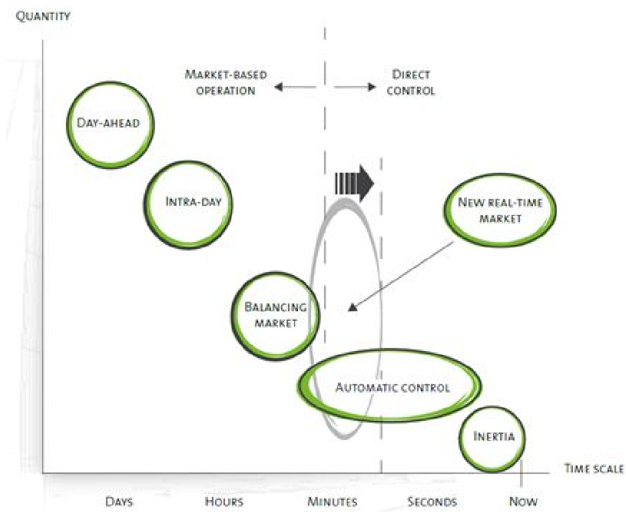

Figure 9.1: Real-time market, EcoGrid EU (EcoGrid Bornholm 2013)

For this, a market is made which is simulated with regulating power plants, consumption and wind turbines. This data is then based on actual measurements, for example, of wind forecasts and power production. This market could potentially provide solutions for the increased demand for flexibility by including demand response, also in the day-ahead market. (Nyeng 11/03/15) Therefore, it would be interesting to evaluate the benefits of implementing such a market in combination with PEVs, both seen from the consumer's perspective and a system perspective. It could be analysed if an aggregator is still required or what the change in its role is when a real-time market would be implemented.

Consideration should, however, be made regarding the applicability when evaluating the results of the demonstration project and/or model, as they do not necessarily correspond with what would actually happen in a larger perspective; the demonstration is done on the island, which has a different set-up compared to the whole of Denmark. (Nyeng 11/03/15) There are, however, (optimistic) predictions that such a real-time market can be implemented in the Denmark in the next ten years.

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