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E-mobility charging sites

Assessment of power system impacts, consumption patterns and feasibility aspects to explore a new business opportunity

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Abstract

Electrification of energy demand is seen as one of the key elements of energy transition toward decarbonisation. E-mobility is one main side of the electrification process, and it is considered as a crucial way to reduce the emissions of the transport sector. A core element for a widespread adoption of electric vehicles (EVs) is the deployment of the charging infrastructure, and installing a microgrid can the best way to integrate a charging site in the main power grid. The research project has being developed in collaboration with Volvo Penta to support the exploration of this new business opportunity. For the possible stakeholders the knowledge gap concerns the economic feasibility of charging sites/microgrids, and also which data and information are needed to properly assess it. The present research project has then the objective to gather and analyse information and data to deliver a semi quantitative assessment of different alternative charging site/microgrid configurations, to evaluate which could be the most economically viable and under which conditions. Three research questions (RQ) focused the work toward the aim of the study: 1) which are the main impacts and implications for the power system? 2) Which can be some potential consumption patterns? 3) Which are the main technical, economic, regulatory feasibility aspects? A mixed research method was adopted: qualitative, with a thorough literature review and a number of interviews, for all the three RQs; and quantitative, performing a levelised cost of energy (LCOE) comparative analysis for different cases, for the third RQ. The work finds that e-mobility can entail a number of issues for the power system, but they will become relevant only when a higher degree of penetration will be reached, when it will also become important to provide some solutions to cope with them. A common assumption, also adopted in the present research, for the assessment of potential charging profiles is that, at least at the beginning, the use patterns of EVs will be in line with use of internal combustion engine vehicles (ICEVs). The work also concludes that although today the main feasibility problems for charging sties/microgrid are still related to the costs of the involved technologies, in the mid-long term the need to update the regulation and the adoption of new business models could be the main hurdles. The LCOE calculations show how the results vary substantially according to the configuration, but in general the economics are not yet favourable for microgrids in the considered cases. In the best case the LCOE for the microgrid configurations is 1.2 times higher than the one for the grid dependent solutions, while in the worse cases they are more than 10 times higher. The detailed comparative analysis illustrates the cost compositions in the different cases. Further research should be conducted in particular regarding the feasibility aspects. Different elements can radically change these results, such as possible needed grid upgrades or the evolution electricity tariffs. Possible investors and researches should bear in mind those aspects related to the charging sites when delving into e-mobility. In the future specific business cases will need to be assessed by Volvo Penta in order to get more exact results and insights.

Executive Summary

Electrification of the transport sector is expected to be one of the main pillars of the energy transition toward decarbonisation. Electromobility (e-mobility) will challenge both the automotive world and the power system. The transport sector will increasingly draw upon the power system, and progressively become an integral part of it. The e-mobility actors will also need to learn how to play according to the power system rules and how to deal with traditional power system actors and new entrants.

The crucial element for a really widespread adoption of electric vehicles (EVs) remains the deployment of the charging infrastructure. It should allow recharging the EVs' batteries in a manner analogous to the fossil fuels refuelling system, and to use EVs in a manner analogous to the internal combustion engine vehicles (ICEVs) within the different transport needs.

The charging process is also a central part of e-mobility value chain. This is where the interaction with the power system takes place and where e-mobility will affect the economic and technical operation of the power system. It is a new phase for the transport value chain, for which the technical, economic and regulatory feasibility and barriers need to be assessed, and the possible role of different market players defined.

Installing a microgrid can be an effective and economically viable way to integrate a charging site in the local distribution grid. This possibility becomes particularly interesting for EVs with high energy capacity batteries: heavy-duty trucks batteries can have a capacity of hundreds of kW, while cars usually are around few dozen kW. This means that it requires a much higher charging power rate to full charge batteries for heavy vehicles – as this charging should take place in a similar frame time as for cars.

The charging infrastructure is then critical for the integration of the EVs in the power system, and as such, it represents a (relatively) new business opportunity for companies in the power and transport sectors, as well as for new market players.

Problem definition

This thesis project has been developed in collaboration with the Swedish company Volvo Penta (a member of the Volvo Group), which has traditionally had its business in engines and complete power solutions for marine and a variety of industrial off-road and power generation applications. The overarching aim of the thesis is to support Volvo Penta in the exploration of the new business opportunities related to electrification, and in particular to charging sites/microgrids for e-mobility.

But, e-mobility charging sites, and indeed also other "traditional" microgrid applications, represent a new business area for both Volvo Penta and Volvo Group, hence exploring this new opportunity and then making an eventual investment decision must be backed with a deep and targeted analysis.

Exploring this new business opportunities for a company like Volvo Penta requires gathering and analysing a lot of data and information that are beyond the perimeter of their current activities. Beside that it also entails delving into the power system, with its regulations and market players. In particular the company needs data and analyses to explore the different possible configurations of charging sites and to evaluate their economic performance under different conditions and for different cases.

Such work will also likely provide useful insights to other stakeholders and potential investors, and, more in general, it will add knowledge to the discussion and ongoing research in the e-mobility charging issues field.

Based on interviews and discussions with Volvo Group people as well as with other relevant stakeholders it became progressively clear to the author how there still is a general knowledge gap for market players like Volvo Group and other e-mobility possible stakeholders. And so far this knowledge gap does not "only" concern the economic feasibility and profitability of delving into the charging sites/microgrids business opportunity, but it is also about how to assess it and which data and information are needed to assess it, and which new business models will prevail.

E-mobility stakeholders need to have more clarity about the relationship between the charging sties and the powers sector, and eventually how to deal with the power system and which are the impacts of charging on the power system and how to cope with them. Then a broad set of data and information is needed to fully assess the costs of a charging site, like: the costs and expected evolution of the involved technologies in a microgrid, the usage rate and load profiles of the charging sites, the cost of the alternative solutions to the microgrid, and many others.

This knowledge is not yet widespread; today most of the charging site/microgrid solutions are still just pilot projects, and the electric truck (e-truck) market is still at very early stages of its development. But things are happening quickly and this new knowledge is needed fast to have a competitive advantage and to successfully delve into the e-mobility opportunity.

The present research project has then the objective to gather and analyse information and data to deliver a semi quantitative assessment of the different alternative charging site/microgrid configurations, with the final target to support the assessment of which could be the most economically viable and under which conditions. The target is to provide Volvo Penta with: an analysis of the main expected impact of the charging sites for the power system and how to cope with them; an assessment of possible consumption patterns of the charging sites; a comparative quantitative assessment of the costs of different charging sites configurations.

The specific focus of this work is on charging sites configured as microgrids with a total peak power[1] in the MW order of magnitude, for commercial freight[2] vehicles. The microgrids studied here are to be able to work islanded from the main grid at least for few hours, or even eventually completely islanded.

Research questions and methodology

The research questions (RQs) addressed so as to deliver against the aim of this study are as follows:

- ✓ **RQ-1.** Which are the main impacts and implications of the charging infrastructure for the power system (main power grid)?
- ✓ **RQ-2**. Which can be some potential consumption patterns of charging sites/microgrids?
- ✓ **RQ-3.** Which are the major technical, economic and regulatory elements that can be challenging for the development of charging sites/microgrids?

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[1] The peak power is the maximum total power rating of the charging site, which is equal to the sum of the maximum power rating of all the charging ports installed in the site (total maximum electrical power possibly required)

[2] Also refuse operations & material handling equipment can be relevant and have similar characteristics

The research was conducted based on the following steps:

- a thorough literature review and analysis addressing aspects of all three RQs;
- interviews with different stakeholders within Volvo Group and also other companies and organisations, mainly focused on RQ-2 and RQ-3 topics;
- a quantitative assessment of some potential consumption patterns (RQ-2) based on Volvo Group's own data and elaborations on journeys (and relative energy consumptions) of a number of internal combustion engine heavy-duty trucks; two potential charging patters were selected and used for the following analysis, a "High-Energy – H-E"[3] and a "High-Power – H-P"[4] profile;
- a quantitative analysis of different cases and configurations, based on the results of the consumption patterns analysis, to compare the costs of a islanded microgrid and of a grid connected microgrid with the costs of a completely grid dependent charging site in Sweden and Italy (RQ-3)[5]. For the microgrid configurations thee alternatives were considered for the main electricity generation sources: only solar photovoltaic (PV), only wind and solar PV and wind together; the other components are: stationary batteries and diesel electricity generators.

As such, the research is based on mixed methods, where qualitative and quantitative data was gathered and analysed to address the research aim.

The qualitative part of the analysis was firstly performed with the literature review, and in parallel, with the interviews to relevant stakeholders, which were used to enhance and broaden knowledge of key topics.

The quantitative part of the work represents a 'deeper dive' into two of the RQs. The analysis is a comparative study of different possible alternatives rather than being focuses on a specific case study. Thanks to this approach it was possible to elaborate and provide some data and figures with high value in an explorative context, when it can be more important to have some numbers and methodologies applicable to different cases, rather than very detailed case-specific data. This represents one of the key contributions of this research as it supports the investigation of this new business opportunity in the e-mobility field.

Main findings from literature review and interviews

This analysis indicates strongly that e-mobility will entail different issues for the power system. Among other things the findings show that these can include: an additional electricity demand; (in)compatibility of EVs charging profiles with intermittent RES-E penetration; electrical power system losses; overload/saturation of power lines and transformers; voltage profile disturbance, phase unbalance, and harmonic distortion. However, the work also shows that all of those potential impacts will generally start to happen, and are thus be relevant, only with a significantly higher penetration of e-mobility in the market compared to what we have seen so far.

Further, the literature review and interviews show considerably consensus that as the number of EVs increase and the charging infrastructure develops, it then becomes increasingly important, and, in the long term even possibly mandatory, to provide some solutions to cope with the related impacts and issues. Different types of charging can be adopted, and they are

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[3] with a high peak load in the middle of the day, lasting for 3 hours, and then a pretty flat consumptions for the rest of the day

[4] with high energy consumption spread on a number of hours all over the average weekday

[5] Sweden and Italy are examples of two different European power systems (with different electricity generation mixes, different solar irradiation and wind speed conditions, different electricity tariff structures) for which the data needed for the analysis where easily available to the author and/or Volvo.

associated with different (increasing) levels of involvement in the power system, and also of implementation and management complexity. Generally speaking a shift from "dumb" charging to increasingly "smart" charging is foreseen.

Regarding the assessment of potential charging profiles, the work indicates that where enough relevant data is available, the preferred methodology is based on EVs and electric vehicles supply equipment (EVSE) use data and technical specifications. However, in many cases, as e-mobility is still at the early stages of deployment, it is not possible to have such data. In this case, many research efforts have assumed that, at least at the beginning and probably for a while, the use and journey patterns of EVs will be coherent with the use and journey patterns of ICEVs.

Evidence gathered strongly suggests that regulation can be one of the main possible elements that in the mid-long term can hinder, or at least slow down, the development of e-mobility charging sites and microgrids. Regulation can affect, among other things, the way electricity tariffs are designed (the costs of charging), who has to bear the eventual grid upgrade costs (grid manager or the company who's investing in the power solution?), grid connection costs and fees, and who is allowed to do what.

For instance, stakeholders report that microgrids as energy distribution systems are still within a grey area in terms of regulation and legal status in many countries: electricity distribution is a local natural monopoly, and in Europe managing a local distribution grid represents a regulated activity, so that there are specific rules about in which cases microgrids are allowed and who (which market actors) can deal with these configurations. The way electricity tariffs are designed could represent an important barrier for e-mobility penetration: charging stations are not energy but power-intensive loads, and this issue can become very relevant especially when a number of high power chargers are clustered together in the same location; under this condition the capacity fees can represent a relevant barrier for e-mobility.

From the discussions with relevant actors the author found evidence that e-mobility also calls for new business models, where traditional market players from the transport and energy/power sectors together with new entrants will have new roles in the value chain. With the rising of "mobility as a service" concept, (Maas), which is challenging the traditional model centred on vehicle ownership, automakers will probably need to expand/change their business and find their collocation over the new EV value chain, where the competition with new entrants can be very intense.

But if regulation can have an impact in the mid-long term, today the main feasibility problems are still related to the economics, and in particular the costs of the involved technological solutions. Fast charging infrastructure has much higher capital costs than the slow one, and also, possibly, higher grid connection costs (grid upgrade costs and/or need to set up a microgrid or at least to install some stationary batteries, but also higher network charges based on the peak power availability requested to the main grid). The costs of batteries (for stationary power solutions as well as for EVs) has sharply decreased the last years, but they are still too high to make them a widely diffused technology.

Meanwhile, there is clear evidence that the availability of proper technological solutions and their performance should not be per se as a problem or a possible barrier for the development of e-mobility and microgrids. While the costs have been decreasing, the battery energy density has been increasing over time, which means more energy in less volume. Ultra-fast charging (350 kW, 450 kW) is an already existing option, and in 2017 several ultra-fast charging standardisation bodies released new descriptions or official protocols to charge at up to 200 kW. Those developments happened pretty quickly during the last few years, and continuous improvements are expected and will be needed to allow to charge e-truck with a battery size of few hundred kW in a time span similar to the refuelling time of ICEVs (considering that it would take at least one hour to fully charge a 200 kWh battery with a 200 kW charger).

Quantitative assessment results

The final results of the comparative quantitative assessment are the LCOEs values for the different charging sites cases and configurations. Coherently with the literature review and interviews outcomes, the LCOE results shows that generation of electricity in a microgrid configuration in Sweden and Italy is more expensive than taking it from the main grid.

On average the LCOE of all the microgrid configurations (completely islanded as well as grid connected) were 3.5 times higher than the ones of the grid dependant solutions. But the results vary substantially according to the cases.

The worst results are for the solar PV only configurations in Sweden, where the LCOE is on average more than 10 times higher than the grid dependant cases. But the PV only configurations are the ones with higher LCOEs also in the Italian context: 2 times the LCOE of the grid dependant case on average.

Without considering the PV only configurations the average differences decrease considerably:
- For Sweden on average the microgrid configurations LCOE are 2.4 times higher than the grid dependent cases
- For Italy on average the microgrid configurations LCOE are 1.3 times higher than the grid dependent cases

This differences between the two countries are mainly due to the higher electricity tariffs in Italy compared to Sweden, which results in higher LCOEs for all grid connected configurations, and in particular for the completely grid depended cases.

Comparing the results for the two selected consumption profiles, the LCOEs for the "H-P" profile for the grid dependent sites are higher than the "H-E" ones because of the higher impact of the capacity fees on the total electricity consumptions (+35% in Sweden and +13% in Italy on the LCOE). But dealing with an H-P profile, with a high peak demand lasting few hours and then relatively very low for the rest of the day, brings about higher costs also in the microgrid configurations compared to an H-E profile (+17% in Sweden and +13% in Italy on the LCOE on average).

Conclusions and recommendations

The present research project adds a comprehensive view to the academic body of knowledge in the e-mobility charging site/microgrid field, contextualizing transport electrification in the broader energy transition topic and highlighting how complex the relation between e-mobility and the power sector can be. The comparative analysis also provided useful insights, showing which are the main costs are and how things can significantly change according to aspects like the geographical location and the load profile.

The LCOE results imply that microgrids are relatively more economically reasonable solutions where the solar irradiation and/or the wind speed local conditions are more favourable, and also where the final costs of electricity from the main grid is higher and the structure of the electricity tariffs design is less favourable to high power loads.

Considering the LCOE results with a forward looking, and possibly long term, perspective, it is important to point out how the cost of technologies (solar PV panels, wind turbines, battery energy storage systems) have decreased markedly in the last few years, and are also expected to further decrease in the next years, so that, ceteris paribus, microgrid configurations should become more and more economically feasible. At the same time in the past few years in Europe the final retail electricity prices have increased because of the network and taxes and levies components, and also for the future the expectations are for increases. Do all these expected trends will lead to an improved economic feasibility for microgrids in the considered countries?

But as different studies shows, microgrids are already cost-effective in places where the main grid is less reliable and less widespread than in Europe, and where the local conditions are favourable to renewables generation, such as in India or the South East Asian region.

Possible investors and researches should bear in mind those aspects when delving into e-mobility, since, differently from transport based on internal combustion engine technologies, the refuelling/charging is going to be a crucial element of e-mobility business models and value chains.

Further research should be conducted in particular regarding the feasibility aspects. Studies can be focused on how the regulation could develop to support the energy transition and e-mobility. Then scenarios to study the e-mobility penetration level that would cause issues and costs for the power systems can be elaborated. Assumptions and analyses about the possible business models and roles of different actors can be conducted.

The LCOE comparison can be refined including more data (costs and eventually revenues, like incentives) and more detailed data (more specific solar and wind profiles) in the calculations, and also cost optimization techniques/models can be used to size the different components. A possible follow-up to the quantitative analysis could be to assess, starting from the journey/consumptions of the vehicles, if and how the load profiles could be modified with the final target to reduce costs – the LCOE – without modifying the vehicles' use (implementing smart charging). Following that, it could also be analysed if, when and how it could make economic sense to modify the vehicle's' use to reduce the costs.

In the future specific business cases, with all their relative specifications and data, will need to be assessed by Volvo Penta in order to get more exact results and insights.

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Abbreviations

(Alphabetical order)

Battery electricity storage - BES

Capital expenditures - CAPEX

Carbon dioxide - CO2

Demand side response – DSR

Distributed energy resources – DER

Distribution system operator – DSO

Electric vehicle supply equipment –EVSE

Electric Vehicles – EVs

Electromobility – E-mobility

Energy storage systems – ESSs

European Commission – EC

European Union – EU

Greenhouse gas – GHG

Internal combustion engine – ICE

Internal combustion engine vehicles – ICEVs

International Energy Agency – IEA

International Renewable Energy Agency - IRENA

Levelised Cost of Energy - LCOE

Operating expenses – OPEX

Original Equipment Manufacturer – OEM

Photovoltaic – PV

Plug-in hybrid electric vehicles – PHEVs

Regulatory asset base - RAB

Renewable energy sources – RES

Renewable energy sources for electricity generation - RES-E

Total cost of ownership – TCO

Transmission system operator – TSO

World Energy Outlook – WEO

1 Introduction: e-mobility & the energy transition

In 2009 the European Union (EU) set itself an ambitious objective for the long term: reducing the greenhouse gas (GHG) emissions of the EU economy by 80-95% compared to 1990 levels by 2050, in the context of necessary reductions according to the IPCC[6] by developed countries as a group (EC, 2011c).

Two years later, the 2011 "Roadmap for moving to a competitive low carbon economy in 2050" showed how, according to the European Commission (EC), the power sector is going to have a crucial role in the 2050 low carbon economy. It has the potential for almost totally eliminating carbon dioxide (CO2) emissions by 2050 for electricity generation (Figure 1-1) (EC 2011a).

Based on the "EU Reference Scenario 2016" data in 2015 power generation & district heating accounted for more than 33% of the total EU 28 energy related CO2 Emissions, while the transport sector 29%, industry 14.3%, residential 12%, tertiary 7% and other energy branches 4.2% (EC, 2016b).

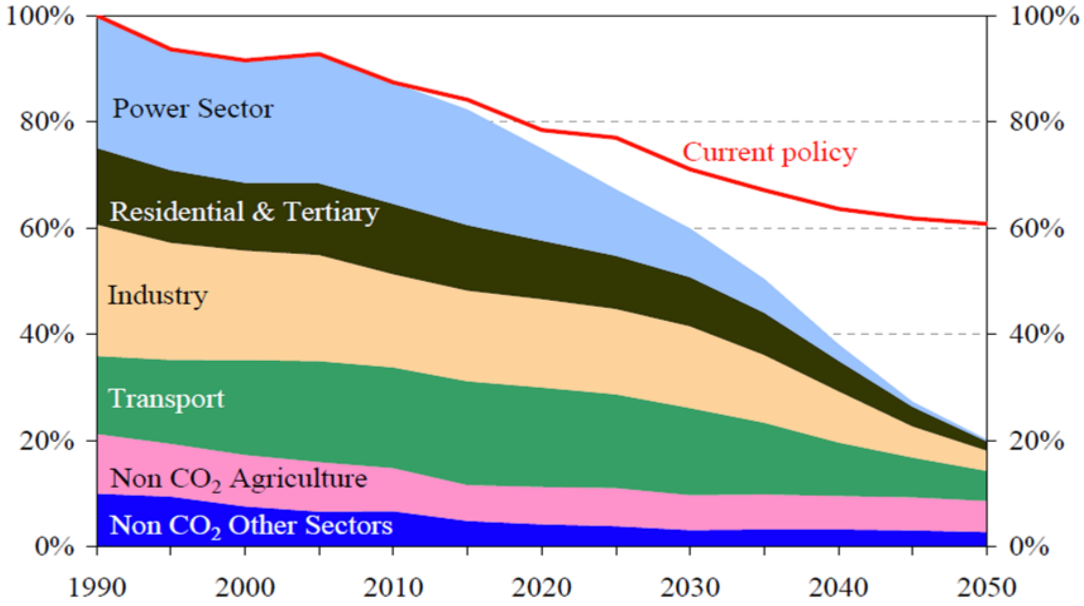

Figure 1-1. EU GHG emissions towards an 80% domestic reduction (100% =1990) – current policy scenario vs long term sectorial targets

Source: EC, 2011a, page 5 - (c) European Union, 1995-2018

The possibility to switch from fossil fuels to electricity for the energy consumptions of transport end heating could effectively reduce the emissions of the two sectors with the highest final energy demand in Europe. In 2015 the transport sector accounted for almost 32% of the total EU 28 final energy demand, while the residential sector for 26.4% (EC, 2016b), where heating and hot water alone accounts for almost 80% of the total final energy

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[6] The Intergovernmental Panel on Climate Change is the international body for assessing the science related to climate change. It was set up in 1988 by the World Meteorological Organization and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

use. More in general heating and cooling in European buildings and industry accounts for half of the EU's energy consumption[7].

Based on the EC "Energy Roadmap 2050" an increasing share of final energy demand will be covered by electricity, in particular from renewable energy sources (RES) (EC, 2011b). Two "current trend scenarios"[8] and five "decarbonisation scenarios"[9] were developed and:

"All scenarios show electricity will have to play a much greater role than now (almost doubling its share in final energy demand to 36-39% in 2050) and will have to contribute to the decarbonisation of transport and heating/cooling. Electricity could provide around 65% of energy demand by passenger cars and light duty vehicle (…). To achieve this, the power generation system would have to undergo a structural change and achieve a significant level of decarbonisation already in 2030 (57-65% in 2030 and 96-99% in 2050)." (EC 2011c, page 6).

The expected changes and challenges were then better detailed with the formulation of the 2020 and 2030 climate and energy frameworks and targets, which were designed as necessary and binding milestones to finally get to the longer-term ambitions (EC, 2008; EC, 2014a; European Council, 2014; European Council, 2007). In this context, the EC policy choices are primarily based on the "EU Reference Scenarios"[10], which are periodically updated key benchmark quantitative tools to assess the impact of new targets and policy proposals. They show expected trends for the future of the European energy system based on the current policy framework, and the level of consistency with the 2050 targets. They answer questions like: Where are we going? What do we need to do to meet our commitments? Which intermediate targets are better suited to achieve the long-term decarbonisation goal?

The EU Reference Scenario 2013[11], used to formulate the 2030 climate and energy framework[12], clearly shows the expected increasing role of electricity in the European energy system. This is driven by an increasing penetration of electric appliances and an increasing use of heat pumps and electromobility (e-mobility) (Figure 1-2).

At global level, also the International Energy Agency (IEA) World Energy Outlook highlights the growing electrification of the energy system, both as an increased access to energy and as the switching to electricity from other energy sources in end-uses (electric vehicles – EVs - for transport, heat pumps for heating and digital control technologies for information and communication technologies) (IEA, 2017b).

"Electricity is becoming the energy of choice in most end-uses. Electrification is driven by many factors: accelerating adoption of EVs and heat pump proliferation see passenger vehicle and heating energy demand increasingly turn to electricity; the evolution of industrial production and processes requires more electricity, millions of new middle-income families in developing countries add appliances and install cooling, and electricity progressively reaches those without access. Digitalisation can facilitate the electrification of energy demand." (IEA, 2017b, page 234).

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[7] https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling

[8] One including only the current trends and projections on population and economic development in 2010 (when the strategy was finalized), and the other also including policy initiatives adopted after March 2010 or already planned and some technology assumptions.

[9] With five different combinations of the four main decarbonisation options assumed by the EC (energy efficiency, renewables, nuclear power, carbon capture & storage).

[10] https://ec.europa.eu/energy/en/data-analysis/energy-modelling

[11] https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2050_update_2013.pdf

[12] https://ec.europa.eu/clima/policies/strategies/2030_en

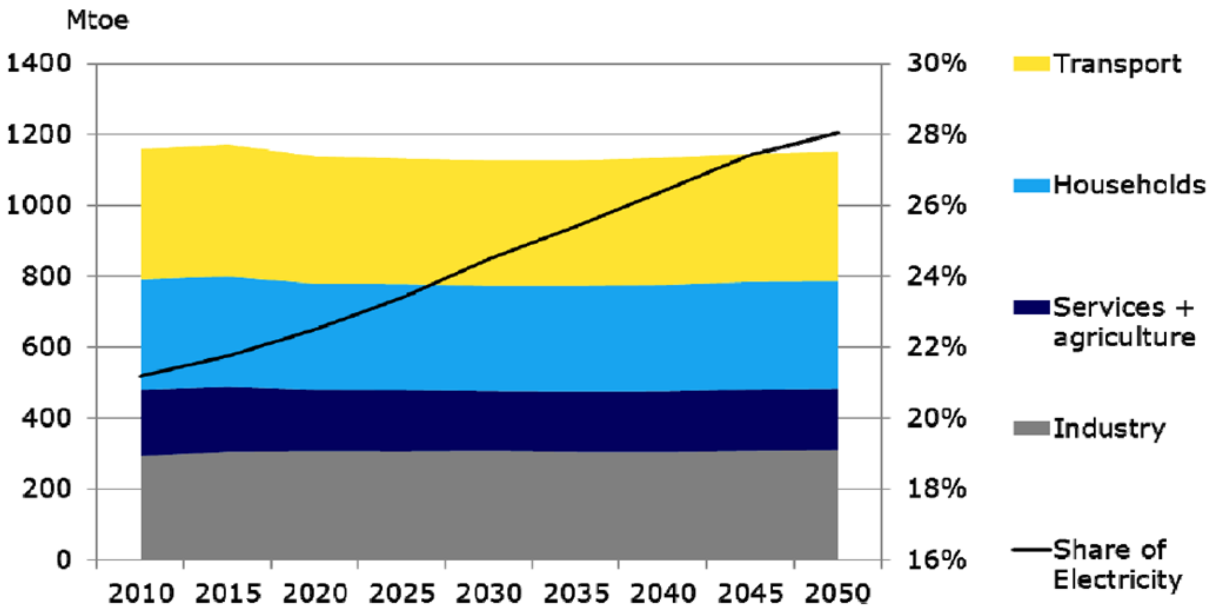

Figure 1-2. EU-28: Final energy consumption by sector and share of electricity in the EU Reference Scenario 2013

Source: EC, 2014b, page 145 - (c) European Union, 1995-2018

"The integration of the transportation and electricity sectors, in combination with EVs and renewable energy, offers the potential to significantly reduce the world's dependence on fossil fuels and the consequent emission of greenhouse gases" (Richardson, 2013, page 248).

Decarbonisation policies are thus completely transforming the power systems and markets. Electrification requires a fast increasing share of renewable energy sources for electricity generation (RES-E) in order to progressively lower the power sector emissions. Furthermore, a number of game changer technologies and new market and regulatory features are already reshaping the economics and the physical operations of power systems and markets, and their impacts are expected to become more and more evident in the future. According to the EC and the IEA some of the likely changes that are expected to impact the power sector include: microgrids, batteries, extensive deployment of small scale photovoltaics, a large availability of cheap renewable electricity at certain times, EVs, and many others (IEA, 2017b; EC, 2014b).

All these long-term goals and expected changes make up the so-called energy transition, which is envisioned as a long-term structural change of the energy system toward a low carbon economy. It will not only require technological improvements, but also some combination of economic, political, institutional and socio-cultural changes (Berkhout et al., 2012). The power sector will play a crucial role in the transition toward decarbonisation, and in particular, the e-mobility could be a very important enabling factor.

1.1 Four interlinked focus areas for the future of the power system

The focus of the thesis is on e-mobility, and in particular about assessing different aspects of the charging infrastructure, with the final target to provide useful information to explore this new business opportunity. For this purpose the author deemed important to properly contextualise e-mobility in the power sector and in its transition, since with the electrification process transport is going to be a complementary part of it.

As shown above, electrification is seen as of the key trends for the energy sector, and together with other elements it is expected to reshape European and global power systems. In an earlier work the author conducted a research with the aim to find which key technological and market elements are expected to transform the power systems/markets in the long term. For this purpose, the author analysed a limited number of different possible sources (key stakeholders) within the European perimeter which are listed in Appendix I.

The author sought for the expected power sector evolutions that were mentioned in all the documents reported in Appendix I, and that were discussed and seen as relevant for the future development of the power systems by all the considered stakeholders. The aim was to verify if there is a general agreement about which are going to be the main expected changes, finding out which are the key aspects, shared by all the different stakeholders, generally acknowledged as expected to be relevant for the future of the power system. Following this first analysis, a further literature review was conducted in order to get some more insights about the identified key concepts and their interrelations.

The main result of this study is depicted in Figure 1-3: four focus areas deeply interconnected and mutually dependent that are expected to change and challenge the power system. The future evolution of any of them depends of the evolution of the others, so that they are enabling each other to achieve the main target, which is the transition toward a decarbonised energy system.

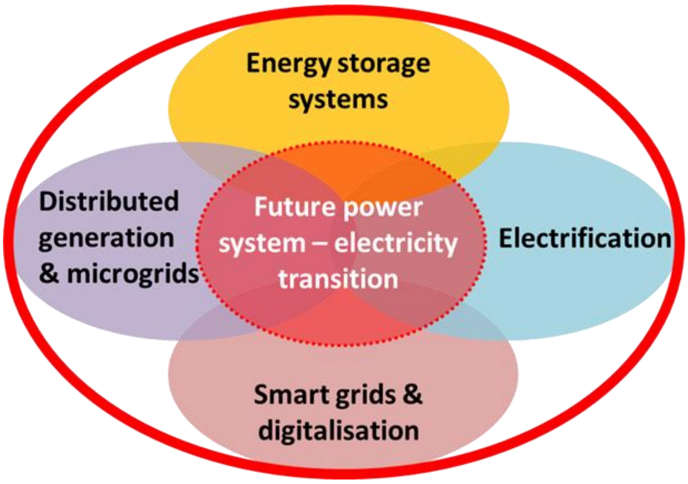

Figure 1-3. The four interconnected and mutually dependent focus areas for the power system transition: the building blocks of the future power system

Source: Author's own elaborations based on the literature review

Energy storage systems (ESS) will allow an improved and greater exploitation of RES-E, granting the possibility to store the excessive electricity generated by intermittent sources and providing flexibility to the system (Cebulla et al., 2018; Haas et al., 2017). In particular they will have a role to support the evolution of distributed generation, with the exploitation of local RES, allowing consumers to become "prosumers" and to create microgrids that will be only marginally dependent on the distribution/transmission grid (IEA, 2017b).

Smart grid will allow using ESS (and other electric devices and generation units) in a much more efficient way (Fang et al., 2012; Gungor et al., 2013; Su et al., 2012). Vattenfall identifies energy storage as one of the most salient market trends that are driving the transformation of the energy and power systems. *"One challenge for the energy system as a whole entails finding a solution* *that can handle storage not only short-term (from one day to another) but also seasonally (from summer to winter)"* Vattenfall, 2017, page 13.

Grid scale battery storage systems can enhance the distribution and transmission grid stability, and provide ancillary services to the power system while accommodating the increasing intermittent renewables (Brenna et al., 2017). ESSs include a varied spectrum of batteries, flywheels, pumped-hydro plants, compressed air and hydrogen (Cebulla et al., 2018; Divya & Østergaard, 2009). The electrification of consumptions is heavily depended on the cost and technological evolutions of batteries for the transport sector. Thanks to smart grids vehicle batteries can also help smoothing the load curves and provide stability to the systems, and the electricity stored in car batteries could also function as a buffer, leading to further energy efficiency (EC, 2014b; Marra et al., 2017; Shemami, et al., 2017).

Distributed generation and microgrids are central apscts of the energy transition. The expected future role of distributed generation, mainly based on intermittent RES, and the issue of integration in the distribution grid, is giving raise to discussions both at policy and technical levels, in particular about its impacts on the existing grid operation (Bunda, 2016; Georgilakis & Hatziargyriou, 2013; Veldhuis et al., 2018).

The heavily centralised power systems with few big generators and a multitude of consumers with little or no control and knowledge of the system itself will progressively be transformed into decentralised systems where all the actors will be much more empowered and responsible. This is needed in order to take advantage of all the distributed RES-E, and to support the energy efficiency of the system (IEA, 2017b; EC, 2014b). In this context ESS and smart grids will be essential to gather the benefits of distributed generation and microgrids. Furthermore electrification of energy consumptions can be better and more sustainably managed thanks to distributed RES-E: on-site electricity generation could indeed be one of the ways to support EVs penetration, reducing the charging stations grid impacts and ensuring the use of RES-E for recharging the batteries (Gallo, 2016).

Smart grids and digitalisation will accommodate an increasing share of renewables and especially distributed power sources, enable an effective and efficient demand side response (DSR), and will allow the integration of ESS, EVs and other devices in the grid (EC, 2014b). Smart grids are considered to be the electricity grids of the future: they use *"two-way flows of electricity and information to create a widely distributed automated energy delivery network"* (Fang at al., 2012, page 944). Smart grids and digitalization will empower producers and consumers and will become crucial in a context of increasing decentralisation of the generation, renewables and ESS deployment, where it will be necessary to properly manage all the new empowered and highly diffused actors and devices (Fang et al., 2012; Gungor et al., 2013; Su et al., 2012).

For e-mobility smart grids will allow to charge (and eventually discharge) EVs' batteries when it is more economically convenient (low electricity market prices), more environmentally sustainable (hours with high RES-E generation) while avoiding issues for the main grid (RSE, 2013; Gallo, 2016; IEA, 2017b; Yong et al., 2015)

Electrification of consumptions is seen as one of the main ways to support the energy transition, with specific focus on the transport sector and the heating/cooling energy needs of the residential and tertiary sectors. A sustainable and efficient electrification requires an increasing share of RES-E integrated in the power systems: the development of batteries and massive deployment of distributed generation is then crucial in this context, and also smart grids to efficiently manage the new loads and to allow the vehicle batteries to provide grid services (EC, 2014b; Yu et al., 2012). A proper and intelligent integration of the EVs can indeed provide important services to the grid: for instance, as the number of EVs increases, and with that also the number of dedicated parking lots, "EV aggregators", new market entities activing as intermediators between the EVs and the grid operator, could deliver so called grid to the vehicle (G2V) and vehicle to grid (V2G) integration services (Marra et al., 2017).

1.2 Problem background: e-mobility in the power system

E-mobility charging infrastructure research area is interesting first of all because of the expected increasing relevance of the electrification of the transport sector to achieve the long term decarbonisation targets.

But there are also other aspects that make this field interesting on a wider scale and for many different stakeholders. Policy makers are interested in low carbon transport and low carbon electricity generation to reduce local pollution and tackle climate change. They also want to improve energy security and independence, and to create new local industries, business opportunities and new jobs. Electrification of the transport sector can indeed bring economic benefits for companies, for users of clean transport systems, and for the society in general, since this is a new business opportunity is usually supported by the policy makers.

E-mobility can also support social equity, improving the life quality of people living close to transport corridors, close to polluted and noisy areas, or working in the transport sector. In general, the (massive) electrification of the transport sector will impact the whole society, from people, to companies, to public administrations, increasing the sustainability and energy security of the sector and creating new business opportunities.

The electrification of transport is indeed considered by many researchers and stakeholders as a crucial way to reduce the emissions of the sector, but its success is highly dependent upon the battery technology and recharging infrastructure developments (EC, 2014b; Sbordone et al., 2015; Yu et al., 2012).

Transport accounts for roughly a third of all final energy consumption in Europe, and apart from accounting for more than a fifth of the GHG emissions, it is also responsible for a large share of urban air pollution as well as noise nuisance[13]. Transport is responsible for more than half of all NOx emissions and road transport, in particular, continues to make a significant contribution to emissions of all the main air pollutants (with the exception of SOx)[14]. Furthermore if in 2016 the total GHG emissions in the EU decreased by 0.4%, the transport emissions slightly increased for the third consecutive year (EEA, 2018).

However, as already pointed out above, to properly understand and analyse this topic it is important to contextualise it in the broader discussion about energy (electricity) transition, especially if a forward looking and long term view is required or desired. With e-mobility the transport sector becomes part of a new complex system, the power system, with different players, stakeholders and rules compared to the traditional transport sector based in internal combustion engine vehicles (ICEVs).

The fuel that propels EVs, electricity, comes from a system that needs to be constantly monitored in order to be able to supply the required energy to all the loads. Electricity power demand and supply, that can come from a multitude of different sources (which are increasing

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[13] Source: European Environmental Agency website. https://www.eea.europa.eu/themes/transport

[14] Source: European Environmental Agency website. https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-5

in number and variety over time due to the electrification and decentralisations processes), require a continuous, real-time balancing in order for the system to work (van der Veen & Hakvoort, 2016).

If the transport sector has/wants to be part of the power system, it has to learn how to play its rules (power regulation) and how to deal with its actors. This learning and adaptation process becomes more challenging and convoluted when considering that the power system itself is rapidly evolving for the sake of energy transition.

Currently many studies and scenarios clearly illustrate that if e-mobility is really going to catch on, it could not help to be an integral part and an enabler of the energy transition, allowing more RES-E integration in the systems and providing services to the power grid (Coignard et al., 2018; Gago et al., 2016; IRENA, 2017; Marra et al., 2017; Nguyen et al., 2015; Tan et al., 2016). But the crucial element for a really widespread EVs' adoption remains the deployment of a charging infrastructure that will allow to recharge the EVs' batteries in a manner analogous to the fossil fuels refuelling system, and that will allow a use of the EVs suitable for the different transport needs.

"The ability to charge battery electric vehicles (BEVs) on a time scale that is on par with the time to fuel an internal combustion engine vehicle (ICEV) would remove a significant barrier to the adoption of BEVs. However, for viability, fast charging at this time scale needs to also occur at a price that is acceptable to consumers." Schroeder & Traber, 2012, page 136.

The charging infrastructure is then critical for the development of electric transport and for the integration of the EVs in the power system, and it also represents a (relatively) new business opportunity for companies in the power and transport sectors, as well as for new market players. E-mobility requires a new charging infrastructure that must be built, operated and maintained, which is one of the main reasons why the electrification of transport could lead to a new value chain where incumbents and new actors will play relevant and different roles compared to the existing ICEVs refueling infrastructure.

The charging process and the charging infrastructure is also the part of e-mobility value chain where the interaction with the power system happens and where e-mobility could affect the power system economic and technical operation. It is a new phase of the transport value chain, for which the economic, technical and regulatory feasibility and barriers need to be assessed, and the possible role of different market players defined. It entails new technologies with the related research & development (R&D), new cost structures and revenues streams, and new market and regulatory rules to be progressively defined.

At present most of the studies on EVs and their charging infrastructure still mainly focus on electric passenger cars (light-duty and medium duty passenger vehicles) (Burges and Döring, 2017; ESG, 2017; IEA, 2017a; IEA, 2018b; IRENA, 2017; Lo Schiavo et al. 2017; RSE, 2013; Tan et al., 2016; Yong et al., 2015). This is the segment where electrification was more realistically achievable at the very beginning of the e-mobility take-off due to economic and technical reasons: the high costs of batteries and the low available charging rating (which means high charging time) constitute huge barriers for vehicles equipped with higher power batteries.

But the transport sector, and, consequently, e-mobility is, is much more than just than cars, as portrayed in Figure 1-4.

In the last few years the possibility to electrify also other segments of the transport sector became appealing to different stakeholders. Key "new" e-mobility segments include buses, and now increasingly trucks and also water-borne transport. The rapid market penetration and relevance of this kind of EVs can be easily inferred comparing the IEA "Global EV Outlook" for 2017 and for 2018: the latest publication includes much more data and information about non-car vehicles, and also about the electric vehicle supply equipment (EVSE).

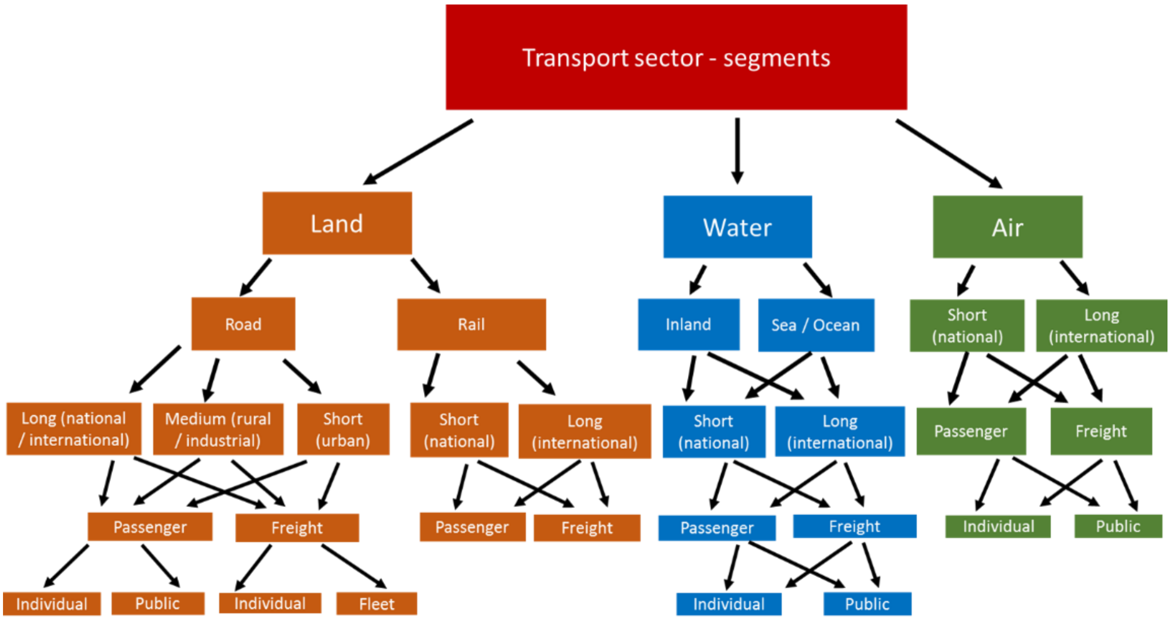

Figure 1-4. Different segments of the transport sector (freight also includes refuse operations & material handling)

Source: Author's own elaborations based on Burges and Döring, 2017

Electric buses represent a rapidly growing reality especially in China: *"By the end of 2017, the fleet of BEV*[15] *and PHEV*[16] *buses in China reached nearly 370 000 units (Sun,2018). This estimate exceeds half a million vehicles if buses are combined with other commercial electric vehicles (…). Cumulative sales available for other countries suggest that 2 100 additional electric buses are currently in circulation in Europe, Japan and the United States (…)." IEA, 2018b, page 29.*

One of the most interesting in a short/mid-term perspective is the road freight segment, in particular for short/medium distances in urban or densely populated areas. A key driver is that this segment - just like the buses that preceded it – is more sensitive to local pollution and noise issue, but in the longer term (2030 horizon) electrification of freight is expected also for long distances (Tryggestad et al., 2017, FREVUE, n.d.). In the US the National Renewable Energy Laboratory (NREL) has already conducted some researches and evaluations for electric and plug-in hybrid electric commercial fleet vehicles[17], while in the EU the FREVUE project[18] established test and demonstrations in eight European cities, and:

"By exposing over 80 Electric Freight Vehicles (EFVs) to the day to day rigours of the urban logistics environment, (…) aimed to prove that electric vans and trucks could offer a viable alternative to diesel vehicles,

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[15] Battery electric vehicle

[16] Plug-in hybrid vehicle

[17] https://www.nrel.gov/transportation/fleettest-electric.html

[18] https://frevue.eu/

particularly when combined with state of the art urban logistics applications, innovative logistics management software, and with well-designed (local) policy" (FREVUE, n.d.).

"City logistics not only has great potential for emissions reduction, it can also contribute to the uptake of electric vehicles, and the introduction of new concepts and business models" (FREVUE, n.d.).

A lot is going on in the commercial freight vehicles segment. Just to cite few examples: in 2017 Daimler Trucks and Tesla launched their first all-electric heavy-duty trucks, while in 2018 Volvo Trucks announced two electric truck models, and some delivery companies like UPS and DHL are exploring and investing in electric vans for their services ("Daimler Trucks", 2017; "Factbox", 2018; Henning, et al., 2018; "Premiere for Volvo", 2018; Tesla Semi, n.d.; Tryggestad et al., 2017; "Volvo Trucks", 2018).

Finally, also efforts to electrify ports and marine transport are going ahead, with some countries and Original Equipment Manufacturers (OEMs) already actively looking into this opportunity (Hockenos, 2018; Mullen, 2018; "Norway's efforts", 2017).

A lot has been happening in the last few years, and, especially when it comes to heavy-duty vehicles, the ability to rapidly transfer large amount of electricity becomes more crucial.

"Optimal planning of PEV[19] *charging infrastructure will promote the penetration rate of PEVs and minimize the negative impacts of PEVs on the electric power distribution system and transportation road network. Design of charging facilities with integrated distributed energy resources (DER) is considered a solution to alleviate strain on the grid, reduce the integration cost with the distribution network and the charging cost."* Abdalrahman & Zhuang, 2017, page 1

Charging sites for EVs can indeed be configured as microgrids (MG), which are: *"Electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded."* (CIGRÉ, 2015, page 9).

As already discussed in the previous section, microgrids are currently seen as one of the central tools for the energy transition, and expected cost reductions in key technologies will make them more and more economically viable. Microgrid can have different loads (energy consuming components), such as houses, offices, e-mobility charging stations, industries, farms, and others, and different energy generation technologies, such as RES-E, but also fossil fuelled ones, cogeneration units, diesel generators ("gen-sets", usually as back-up systems), and stationary ESS. All the microgrid components are grouped together, interconnected and controlled in an electricity distribution system configuration[20].

Although RES-E and storage will play an increasing central role in these systems, replacing technologies that have been more important in the past, such as combustion engine generator sets (gen-sets), the traditional combustion engines will continue to have a crucial role in the future, although increasingly as backup systems (EC, 2014b; IEA, 2017). For the remainder of this study a charging station is then defined as a single charging point (or outlet) for EVs, while a charging site is a location where a number of charging points are grouped together and

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[19] Plug-in electric vehicle

[20] Furthermore essential hardware components such as power inverters, smart meters, power lines, transformers, and circuit breakers which allow the electricity to be distributed and managed within the borders of the microgrid are necessary. Software is also needed to efficiently manage and optimize the operation and interaction between the components, and providing forecasts and historical data that can be used to optimise the system.

that can be part of a microgrid configuration, which is made up of also other components and possibly able to work islanded from the main grid for a reasonable amount of time.

Installing a microgrid can the best way to integrate in the local distribution grid a charging site, which can have a maximum total cumulative charging power of some MW, considering that 350 kW and 450 kW chargers are already existing ("ABB powers e-mobility", 2018; "BMW Group", 2016; Gallo, 2016)[21]. Under this conditions the high peak power requested to the local distribution grid could cause stress to the main grid, and it could also call for very expensive grid upgrading investments, so that investing in distributed energy resources and creating a microgrid[22] is increasingly considered a technically good and economic appealing option (Calstart, 2015; Bossart, 2015; Gallo, 2016; Lopes et al., 2011).

This possibility results particularly interesting for EVs with high capacity batteries: heavy-duty trucks batteries can have a capacity of hundreds of kW, while cars usually are around few dozens of kW. This means that it takes a much higher charging power rate to full charge the former than the latter in the same frame time ("Daimler Trucks", 2017; Kelly, 2016; Mahmud et al., 2018; "Premiere for Volvo", 2018; Tesla Semi, n.d.; "Volvo Trucks", 2018).

This new business area is set to open new interesting opportunities for different kind of market actors already existing and involved in the mobility/power fields as well as new kind of players that could fit into the developing e-mobility value chain.

For automakers it could represent the way to expand their traditional original equipment manufacturer (OEM) business, and progressively become a service provider ("mobility as a service" – Maas - concept), and not "just" a technology provider, while creating stronger and more direct relationships with the final customers. For energy companies (from multinational to local energy utilities to oil companies), e-mobility, and, in particular, the charging infrastructure, can represent a new business area to delve into, following the expected long term shrinking market relevance and margins from their traditional activities. New market players could just act as mobility service providers, without owning any infrastructure but just connecting the charging stations/sites with the final users.

This new potential opportunities will entail some significant and strategic and investment decisions, such as: establishing partnerships and contractual agreements, mergers & acquisitions, building/acquiring new competences and skills, developing/expanding the supply chain, disrupting a well-established value chain, R&D for new technological hardware (microgrid/charging site components) and software solutions (control systems, digitalisation).

1.3 Problem definition and aim: exploring a new business opportunity

This thesis research project has being developed in collaboration with Volvo Penta[23], which is looking into the new business opportunities related to electrification.

Volvo Penta is a global leading supplier of engines and of complete power solutions for marine ("at sea") and a variety of industrial ("on land") off-road and power generation applications (Volvo Penta, n. r.). Volvo Penta is part of Volvo Group, which includes, among others, Volvo Trucks, Volvo Buses and Volvo Construction Equipment, and the different

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[21] Or also in case a charging site with charging points of lower max power each (50 kW or less), but with many more charging points.

[22] Or at least installing some decentralised energy sources to support the charging station needs

[23] https://www.volvopenta.com/brand/en-en/home.html

companies of the group are investing resources in e-mobility projects and studies. The Group has strong internal communication and collaboration, and Volvo Penta benefits from being part of a global group with strong expertise in different sectors and a solid worldwide reputation. Different companies of the Volvo Group are currently exploring the new business opportunities that the electrification of the transport sector is opening up.

In recognition of the some of the key business activities of Volvo Group related to commercial vehicles (trucks), buses, construction equipment, diesel generations and marine engines/propulsion systems, the aim of the present research is then supporting Volvo Penta in exploring and evaluating the e-mobility charging sites/microgrids business opportunity. As a consequence it will also provide useful insights to other stakeholders and potential investors, and, more in general, it will add knowledge to the discussion and ongoing research in the e-mobility charging field.

The charging sites/micgrogrids opportunity represents a business area distant from the traditional and well established activities and competences of Volvo Penta and also, more in general, the automotive industry. In particular, it entails the need to delve into the power system and its market and operative rules, and to deal with the power system players. Exploring this new opportunity and making an eventual investment decision must be backed with a deep and targeted analysis. Volvo Penta, and the entire Volvo Group, such as most of the players of the automotive industry, still needs more insights, data and information about charging sites/microgrids for e-mobility to investigate this business opportunity.

The present research project has then the aim to gather and analyse information and data to deliver a semi quantitative assessment of the different alternative charging site/microgrid configurations, which the final target to support the assessment which could be the most economically viable and under which conditions.

Based on interviews and discussions with Volvo Group people as well as with other relevant stakeholders it became progressively clear to the author how there still is a general knowledge gap for market players like Volvo Group and other e-mobility possible stakeholders. And so far this knowledge gap does not "only" concern the economic feasibility and profitability of delving into the charging sites/microgrids business opportunity, but it is also about how to assess it and which data and information are needed to assess it, and which new business models will prevail.

E-mobility and the whole power sector are rapidly evolving and expected to have a much more important role in the transport and energy sectors of the future, and dealing with the power system represent a new challenge for all the transport stakeholders. This is true for all kind of EVs, and for all kinds of charging stations and charging sites, but if for electric cars the business is at a more developed stage, for other kind of vehicles, like trucks, it is still at the very beginning. And trucks are different from cars in many ways: they require more energy, they have different use and consumption patterns, different needs and requirements, so that the lesson learned with cars so far can only be partially applied to other segments of the transport sector.

The specific focus of this work is on charging sites configured as microgrids with a total peak power[24] in the MW order of magnitude, for commercial freight[25] vehicles. The microgrids

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[24] The peak power is the maximum total power rating of the charging site, which is equal to the sum of the maximum power rating of all the charging ports installed in the site (total maximum electrical power possibly required)

[25] Also refuse operations & material handling equipment can be relevant and have similar characteristics

studied here are to be able to work islanded from the main grid at least for few hours, or even eventually completely islanded.

More specifically the research will assess/analyse aspects of the e-mobility charging sites/microgrids:

- impacts and implications for the power system (main power grid) of the charging infrastructure;
- potential electricity consumption patterns (hourly electricity consumptions) of charging sites;
- technical, economic and regulatory feasibility (assessment of the main possible barriers and elements to consider) of charging sites/microgrids, comparing, in particular, a completely islanded microgrid solution with a charging station not configured as a microgrid.

1.4 Research questions

The research questions (RQs) are then the following:

- ✓ **RQ-1.** Which are the main impacts and implications of the charging infrastructure for the power system (main power grid)?
- ✓ **RQ-2**. Which can be some potential consumption patterns of charging sites/microgrids?
    - o Which are the main methodological assumptions needed to estimate these consumption patterns?
- ✓ **RQ-3.** Which are the major technical, economic and regulatory elements that can be challenging for the development of charging sites/microgrids?
    - o Which are the main issues, barriers, and elements to consider in order to assess the feasibility of charging sites/microgrids?

Most of the studies, articles, and various documents reviewed by the author are focussed on the cars segment[26], while for other EVs segments there is a much more limited body of literature already existing. In particular the author could not find any study where

- The possible consumption patterns of a charging site were assessed without analysing a very specific business case (a single vehicle/few vehicles under very local specific conditions), or a macro (a nation/region) case.
- The possible feasibility issues were assessed in a comprehensive fashion in order to elaborate a framework suitable for different geographical and socio-economic contexts, and the quantitative economic assessment involved the comparison between different cases and configurations.

Finding out and analysing which are the main impacts and implications for the power grid and the power system in general, represents a preliminary and background information needed to understand and contextualise the consumption patterns and the feasibility issues analysis.

Assessing some potential consumption patterns, and the technical, economic and regulatory feasibility of these charging sites will contribute to Volvo Penta assessment by giving more insights about different kind of relevant information. In particular estimating the consumption patterns represent a key information to plan a microgrid configuration and evaluate the involved CAPEX and OPEX, while assessing the feasibility aspects is important to be aware of the possible barriers and elements to consider when setting up a specific business case.

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[26] Also for the city buses segment there is a pretty consistent literature already existing.

Further researches, assessments, data gathering and analysing will be needed in order to provide all the involved stakeholders (from transport and power sectors traditional market players, such as automotive OEMs and energy utilities, to new market actors, such as e-mobility service providers) with all the information needed to properly assess this business opportunity and eventually make their investment decisions.

1.5 Limitations and scope

The research aims to provide an analysis that can be replicable and suitable to different contexts and specific cases. Therefore the research is not focused on a real specific case (specific location, specific configuration…), but is meant to study the topic at a more general / higher level, in order to give more generalisable insights to support the exploration of a new business opportunity.

If on one side this approach has the benefit of trying to provide an as much as possible comprehensive view of the issues, on the other side it could lack granularity and specificity. As a result, further and more detailed evaluation will be needed when using the results in a real case.

Regarding the assessment of the potential consumption patterns, it is going to be based on a number of hypotheses that may be contested, as other sources can be used and other researches may have different views. Beside this, data and information provided by Volvo Group entail disclosure and privacy issues, so that their use for the research and visibility for the public is, at least partially, restricted. This can then limit the soundness and reproducibility of the study.

Furthermore, the research will not delve into and discuss:

- Technical aspects of EVs
- Technical aspects of the charging stations /charging sites
- The possible configuration of microgrids / charging sties
- E-mobility penetration scenarios and forecasts
- Socio-environmental and geopolitical issues of rare earths and metals used in batteries and other technologies

The main geographical scope of the analysis is the EU, which is the region of the world the author is more familiar with and an area of the world of interest for Volvo Group. Europe is also a region with advanced legislative and regulatory standards, and old, diverse and complex power systems, which makes it an interesting case study also when looking at other regions of the world.

Also studies and cases from other regions are considered, since when it comes to some economic and technical aspects the geographical location is less relevant then, for instance, when analysing regulatory aspects (although also for the regulation it can be interesting to analyse which are the issues faced by other countries). As pointed out previously, the electrification of some segments of the transport sector represents a quite new business opportunity. Expanding the geographical scope can then be relevant since today (according to discussions with Volvo Penta and external researches and the research and analysis conducted by the author) there are not many examples of these kind of charging sites worldwide, and most of them are pilot projects.

For the regulatory aspects, the author first considered the EU directives, and then analysed more specifically the Italian case, due to personal knowledge of the Italian system derived from a six years working experience as a consultant in the field, and a personal network of contacts already in place and easily extendable. Moreover, thanks to Volvo Group and the International Institute for Industrial Environmental Economics (IIIEE) networks, some very valuable contacts and insights from the Swedish context were possible, allowing adding alternative perspectives, although a proper comparative study was not conducted.

1.6 Ethical considerations

The research has been conducted for and in collaboration with Volvo Penta, which has a business-oriented interest in the topic. Volvo Penta asked the author to provide the company with specific research results, which were then discussed together in order to fit them in a thesis project coherent with the academic requirements and the EMP Master programme. Following this the author was free to contact and interview whoever might have relevant information within the Volvo Group and network and also outside that, and to find the most appropriate way, in her opinion, to answer the RQs.

For the purposes of the thesis project the author was subject to a contractual agreement with Volvo Penta, which entailed a non-disclosure agreement regarding the company confidential data and information and an economic compensation for the thesis work.

All the interviewees where informed via e-mail and during the personal interviews or the mobile/skype interviews about the collaboration of the author with Volvo Penta.

1.7 Audience

The primary audience is the New Business Development unit of the Volvo Penta company, but the study is also meant to support the Volvo Group endeavour in e-mobility. This study will also provide useful information and perspectives to other e-mobility stakeholders, like other OEMs, utility companies, e-mobility service providers, charging sties /microgrids operators, TSOs, DSOs, regulators, policy makers and researchers at different levels.

1.8 Thesis outline

Chapter 1 introduces the e-mobility / charging sites topic, helping the reader to understand its relevance and complexity, and contextualising it in the energy transition and electrification research areas, with a specific focus on European trends and scenarios. Furthermore, in Chapter 1 the research gap and problem definition is addressed, formulating specific RQs.

Chapter 2 details the methodology adopted to answer the previously identified RQs. It provides a description of the literature review, interviews and quantitative assessments methodological steps adopted by the author. Chapter 3 reports a thorough literature review and analysis divided into three main different sections, one for each RQs.

Chapter 4 shows, discuss and analyses the results of the literature review together with the outcomes of the interviews conducted by the author, and the results of the quantitative assessment. Chapter 5 finally sums up and provide some conclusions to the present thesis research project.

2 Methodology

This research effort follows on from a project conducted with Volvo Penta in April 2018 (in the context of the "Strategic Environmental Development" course of the IIIEE's EMP MSc. Programme). This earlier project (hereafter referred to as the Microgrid Project) explored different aspects of the global microgrid market, in order to provide Volvo Penta with a pertinent information/analysis addressing this strategic business opportunity (IIIEE, 2018)[27].

Following the Microgrid Project, the author and the accountable Volvo Penta representative (Niklas Thulin, Director Electromobility) evaluated options for a thesis research project in collaboration with the company. The author proposed a focus on key issues and aspects of stationary power solutions for the transport sector, since these resulted to be one of the most appealing business areas for the company based on the Microgrid Project.

Discussions with the Volvo Penta representative supported the definition of the priorities and of the most relevant aspects under a private company perspective. The specific foci (the three RQs) and also the aims of the project and how this research would support the exploration of a new business opportunity for the company were discussed. At the same time the research foci and aims were reviewed by the IIIEE thesis supervisor in order to contextualise and formalise the Volvo Penta needs and requests in a form consistent with an IIIEE thesis[28].

The research was conducted based on the following steps:

- a thorough literature review and analysis about all the three RQs
- a number of interviews with different stakeholders within Volvo Group and also other companies and organisations, mainly focused on RQ-2 and RQ-3 topics
- a quantitative assessment of some potential consumption patterns (RQ-2) based on Volvo Group own data and elaborations
- a quantitative analysis of different cases and configurations to compare the costs of a islanded microgrid with the costs of completely grid dependent charging site (RQ-3).

As such, the research is based on mixed methods, where qualitative and quantitative data was gathered and analysed to answer the RQs. An underlying motive for the entire work has been to provide Volvo Penta with information that can be utilised in exploring a new business area – this in turn requiring an intellectual property agreement between Volvo Penta and the author (see limitations for further discussion).

The qualitative part of the analysis, was performed as a literature review and, in parallel to that and also following that, through interviews with relevant stakeholders. Interviews enhanced the author's knowledge providing insights, information, and data about the topic.

The quantitative part was a deeper dive into two of the RQs. Although the analysis is not focused on a specific case study, it was possible to elaborate and provide some data and figures which can have a high value in an explorative context. A guiding logic being that it can be more important to have some numbers and methodologies applicable to different cases, rather than very detailed case-specific data. This represents one of the main items of value and

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[27] The Microgrid Project was conducted by the thesis author together with three other EMP master's students: Angélica Rivera Díaz, Corey Stewart, David Helsing; Philip Peck, Professor at the IIIEE, and Niklas Thulin, Director Electromobility at Volvo Penta, and Gunnhildur Ísaksdóttir, New Business Development Manager at Volvo Penta, supported and supervised the team.

[28] Research aims and outputs were also adjusted throughout the thesis project in collaboration with supervisors, as new knowledge and insights emerged.

contributions of this research as it strives to support the investigation of this new business opportunity in the e-mobility field.

The qualitative and the quantitative analyses can give more insights to possible investors and examines different kinds of relevant information:

- the parameters to consider when proposing a charging station/site solutions to potential e-mobility clients (in order to have a more informed discussion with the client);
- main components needed and better suited for the charging station/site;
- the relative dimensioning of the different components;
- operating expenses (OPEX) of the station/site;
- capital expenses (CAPEX);
- grid connection costs;
- relationship with the grid;
- possible grid integration issues/barriers;
- main other actors involved;
- business model to apply, and relations with other market actors;
- how to manage the relation with the main grid (economic and technical aspects);
- today's technical, economic and regulatory barriers;
- anticipated future technical, economic and regulatory barriers and requisites.

2.1 Literature review

The literature review was first conducted searching for the key words and concepts listed in Table 2-1 on LubSearch, the Lund University Libraries shared search engine, and on Google Scholar, the Google web search engine for scholarly literature. For both search engines only documents published from 2010 onward and only the first 50 results of each search were considered.

Table 2-1. First list of key words and concepts used for the literature review

Electric vehicles	Electromobility /e-mobility	Transport electrification
Electric buses	Industrial electric vehicle	Fast charging
Electric trucks	Fast charging infrastructure	Electromobility /e-mobility barriers
Charging patterns	Commercial / freight electric vehicles	Regulation charging
Charging behaviour	Regulation electric vehicle	Charging station microgrid
Charging stations	Charging stations regulatory aspects/issues	Charging facility microgrid
Charging consumption	Electric vehicles regulatory aspect/issues	

Source: Author´s own elaborations

The same key words and concepts were also searched in Google Search, the Google "generic" web search engine. Particularly via Google Search, non-academic material of relevance was found. This category included: press releases, articles, reports, information on projects and researches from different stakeholders (automotive and microgrids/charging infrastructure OEMs, energy utilities, consultancy companies, local public authorities, research centres, sectorial journals and online newspapers and magazines…).

The snowballing search approach was another important part of the literature review: the reading and analysis of the main body of academic literature and non-academic documents selected as above described were utilised to find additional sources based on the reference lists and various kind of organisations and projects mentioned in the documents.

Interviews with stakeholders was also useful to find further sources, specific data/information and to know about ongoing or completed projects about transport electrification. Furthermore, some sources were based on the author´s previous working experience as an analyst and consultant for an Italian research and consultancy company focused on the Italian and European energy field (ENTSO-E, Terna, the Italian TSO, ARERA, the Italian Energy Authority, European targets and policies, RSE, ENEA, Energy Strategy Group).

Finally, during the literature review process and writing, ongoing ad hoc searches were conducted for additional key words and concepts that arose during the work process. Table 2-2 reports the main more specific searches done on LubSearch, Google Scholar and Google Search, while Table 2-3 lists the different kind of documents and stakeholders included in the literature review.

Table 2-2. Second list of more specific key words and concepts used for the literature review

Smart charging	Solar panel /photovoltaic costs
Demand side response	Wind energy costs
Vehicle to Grid (V2G)	Energy storage systems costs
Time-of-use / real-time energy pricing	Battery costs
Distributed energy resources and charging	Diesel generators / gen-sets costs
Load management and charging	Electricity tariffs / bills / fees in Sweden / Italy
Electric vehicles and the grid	Electricity costs / prices in Sweden / Italy
Coordinate charging	European statistics/data on electricity prices
Charging station location	Renewables generation profiles in Europe
Assessing / estimating electric vehicles charging consumption / patterns	Electromobility / e-mobility business models
EVs charging infrastructure deployment projects / plans	Electromobility / e-mobility value chain
Stationary batteries / solar PV / wind turbines / diesel gen-sets sizing for a microgrid	Electromobility / e-mobility market actors
Grid upgrading / reinforcement costs	Mobility as a service

Source: Author´s own elaborations

Table 2-3. List of documents and kind or organisations used for the literature review

List of type of sources /documents		**List of type of stakeholders / organisations**
Academic literature (Journal articles)		Academia
European Commission plans and reports		Research Institutions
European Directives		International Organisations
National legislations and regulations (Italy)		European Union bodies
Online news and articles		European Organisations
Press releases (mainly from OEMs)		National Energy Authorities / Agencies (Italy and Sweden)
Reports		Consultancy companies
Outlooks		European and national (local) energy utilities
White papers		OEMs (automotive sector + other relevant industries)
Project documents and outcomes		Online websites, newspapers, magazines
Presentations (conferences)		Industry associations
Excel sheets for data (electricity tariffs…)		

Source: Author´s own elaborations

2.2 Interviews

The author contacted a number of different stakeholders in the power/microgrid/e-mobility fields, with the idea of gathering information, insights, opinions and, when possible, also relevant data for the quantitative analysis.

In the planning stage the key topics that the author wanted to address in the interviews were: how e-mobility can affect the power system and how this deal with e-mobility impacts on the main grid; methodologies and typical assumptions to assess potential consumption patterns of charging stations/sites for EVS; which can be and why the most relevant feasibility aspects and barriers for charging sites/microgrids (technical, economic and regulatory).

The stakeholders were all initially contacted via e-mail, and then skype/mobile calls or meetings were planned. In total the author sent around 130 e-mails; in most of the cases the recipients were physical persons, while in very few cases the e-mail were sent to the generic e-mail accounts of companies (in particular to the Swedish Transport Agency, the City of Gothenburg, the Swedish Energy Agency, the Norwegian Water Resources and Energy Directorate, and two Italian energy utilities, Enel and A2A). In total 70 out of 130 e-mails were headed to Volvo Group people, the rest to external stakeholders.

The e-mails had a quite standard format and content: the author briefly introduced the master programme and herself, always stating that the thesis project was in collaboration with Volvo Penta; then the specific thesis focus areas (the RQs) were briefly described, giving, in each case, more details and asking direct questions on some aspects according to the kind of stakeholder and the author´s expectations about her/his competences; finally the author asked if it was possible to arrange a call or a meeting to discuss the above mentioned aspects or if the person had some more proper contacts to suggests within the same organisations, or eventually documents and data sources.

The author tried to interview different kind of organisations outside Volvo Group: European and local energy companies (utilities), energy agencies /regulators, research centres & institutes, universities, municipalities, e-mobility service providers. The specific contacts were mainly either suggested by or found thanks to: Volvo Group network, IIIEE network, author´s own web searches and author´s own contacts.

A list of all the organisations that the author contacted via e-mail can be found in Appendix II. Since the thesis was not focused on the technology itself, the author deliberately decided to not try to get in contact with OEMs in the automotive industry or in the hardware (and software) components for microgrid and the charging infrastructure. Furthermore, the author expected that eventually talking to other automakers could have been difficult because of possible completion and conflict of interest issues.

In total the author interviewed (calls or meetings) thirteen people within the Volvo Group[29] and thirteen external people from eleven different organisations (see the Interviews list for the details).

To a large extent, the interviews were conducted based on an unstructured approach, with spontaneous questions drawn from a guidance list held by the interviewer, more than determined in advance. Just in few cases some specific pre-set questions were asked. Before

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[29] The ongoing discussion with Niklas Thulin is not included in this thirteen interviews, as well as few occasional discussions with Volvo Penta people working in the same business unit.

every interview the author reviewed and took note of the role and expected knowledge and competences of the interviewees, and wrote down a list of main topics to discuss with them.

The interview were usually conducted as follows:

1. The author better introduced herself and the aim of the thesis, and why she thought that talking to the specific person/organisation could be relevant to the work. For the interviews conducted in August the author also summarised some of the main preliminary results of the research and the ideas and views she progressively gathered and gained with other interviews and the literature review and analysis.
2. The author asked the interviewees more insights about themselves, their competences and knowledge, and about the organisations they worked for.
3. The author started asking questions based on the previous steps / discussion. In many cases the interviewee asked for more details and clarifications about the project during point 1 and also point 2, also pointing out about which topics she/he could probably provide valuable information. The discussion usually started smoothly as a follow-up of point 1 and 2, based on the common ground between the author´s research areas and the interviewees´ knowledge.

The author opted for unstructured interviews after the first two interviews, when she approached the persons with a semi-structured interview, but then the conversation went on in more unstructured way, pursuant to the background and views of the interviewee. After that point in time, the author decided that it would probably be better to have a more spontaneous conversation, trying to let the interviewees talk as much as possible and explain their views about the topics of interest and according to their background and competences. This choice was also driven by the fact that in most instances, it was difficult to understand the exact competences of a person just based on her/his job position/title, not least due to a lack of specific information about her/his background. These factors usually became clearer during the interview process.

At the end the interviews main outcomes were some highly valuable insights and opinions about methodological aspects and assumptions on RQ-2 and RQ-3 topics. The final target was to validate (or challenge and change) the author´s ideas, understanding and analysis according to the literature and other interviews.

The main issues discussed in the interviews were the following:

- methodological aspects related to the quantitative analysis to be performed in the thesis;
- relevant data sources and ongoing projects;
- the main possible barriers for a massive deployment of e-mobility;
- what is and will be needed to support transport electrification;
- how different market actors are looking into the e-mobility business opportunity;
- the possible role of different market actors in the e-mobility business opportunity;
- feasibility issues related to micgrogrids.

2.3 Quantitative analysis

All the quantitative analyses and calculation were conducted using Microsoft Excel sheets and Excel's embedded functions.

2.3.1 Potential consumption patterns of charging sites

The quantitative assessment of potential consumption patterns of e-mobility charging sites has been based on Volvo Group own data. These include elaborations of actual journeys (and relative energy consumptions) of a number of ICE heavy-duty trucks all over Europe during one year[30].

Volvo experts (I8; I16) identified a number of hypothetical charging sites and their related average hourly consumption profiles for every day of the week according to trucks journeys. The profiles are based on a "dumb" charging hypothesis. That is: the trucks start charging if their stops last enough time and they keep on charging till the battery is "full"[31] or till they leave for the rest of their daily journey (see the Literature Review chapter for further details about "dumb" and "smart" charging).

The main assumption behind these elaborations and the identified charging sites is that e-trucks will be used in the same way ICE trucks are currently used. As shown in the Literature Review, this is a very common methodological first hypothesis whenever data on the use/journeys of EVs are inexistent, or too limited to be representative. The author's further choices and elaborations are then based on "dumb" charging patterns compatible with some current representative use/journey of a number of heavy-duty trucks in Europe.

This is a methodological approach that is also adopted in order to verify the compatibility of the current ICEVs journeys/consumptions with EVs technological constraints. Following methodological steps (for further researches in the field) can then be aimed to: 1) identify "smart" charging patterns compatible with the current journeys of the trucks; 2) adapt, whenever possible and whenever makes economic sense, the journey to smarter charging habits.

The author selected two of these profiles according to the following criteria in order to have two different and relevant potential consumption profiles for the cost comparison elaborations.

1. Selection of hypothetical charging sites with at least 1000 stops per year (the more used ones, which consumptions are assumed to be more statistically significant).
2. Comparing weekdays and weekends: maximum, minimum, average hourly consumptions and totals. Since in most of the cases there are differences between the weekdays and weekends[32], only weekdays were considered.
3. Checking the hourly consumption over the different weekdays to verify if there are "typical" hourly patterns. Since in most of the selected profiles the weekdays tend to have similar hourly consumption profiles the author[33] calculated the average hourly consumption of the "average weekday", and used this hourly profiles for the economic comparison calculations.
4. Checking the differences between the maximum and minimum hourly consumption over the average weekday. Only the profiles with at least 300 kW of difference were selected (more "extreme" daily profiles).
5. First selection of 5 average weekday profiles out of 22 remained at this stage. Since some different charging sites resulted to have very similar profiles (a peak in the middle of the day, a peak in the evening…), only 5 charging stations with diverse profiles were selected.
6. Based on internal discussion with the Volvo Penta the two final profiles were chosen:
    a. A "High-Energy – H-E" profile – with high energy consumption spread on a number of hours all over the average weekday

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[30] Data from Electronic Logging Devices (E-Log). Elaborations based on the journeys of few thousand trucks.

[31] 80%

[32] Weekends usually have lover total and average consumptions and also lower differences between the maximum and minimum hourly consumption over the day – the profile tend to be more flat

[33] In this step the charging stations with one or more weekdays hourly consumptions very different from the rest of the days or the average were excluded.

b. A "High-Power – H-P" profile – with a high peak load in the middle of the day, lasting for 3 hours, and then a pretty flat consumptions for the rest of the day.

Figure 2-1 summarises some relevant data within the two selected profiles, while Figure 2-2 shows the two selected profile shapes over the 24 hours of the average weekday.

Charging site	Total consumption per average weekday kWh/d	Average hourly conusumption per average weekday kWh	Maximum hourly conusumption per average weekday kWh	Minimum hourly conusumption per average weekday kWh	Maximum - minimum houly consumption difference kWh	Total annual consumption* GWh/y
H-E	15 500	650	1 100	250	850	4.5
H-P	4 100	170	670	50	620	1.3

Figure 2-1. Data about the two selected consumption profiles

** The total annual consumption is calculated based on the total daily consumption reported in the Figure for the weekdays, while for the weekends the specific average consumptions of Sundays and Saturdays were included.*

Source: Author´s own elaborations based on Volvo Group data

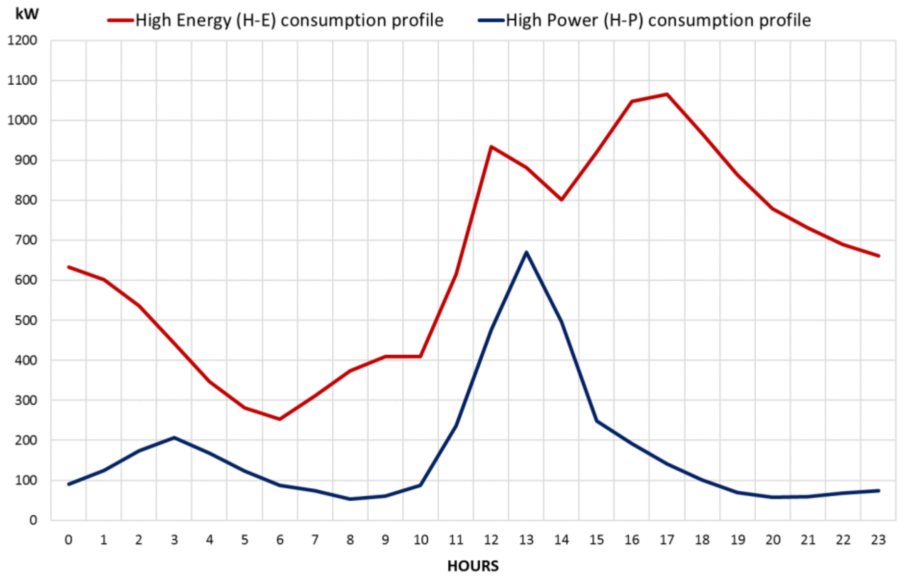

Figure 2-2. The two selected consumption profiles (H-E and H-P) over the 24 hours of the average weekday

Source: Author´s own elaborations based on Volvo Group data

2.3.2 Economic comparison: microgrids versus grid dependent charging sites

To assess the economic feasibility of a charging site configured as a microgrid, the author calculated the Levelised Cost of Energy (LCOE) of three different cases for a charging site: a completely islanded microgrid, a grid connected microgrid, and a charging site completely dependent on the grid for the electricity supply. For all cases the elaborations were conducted using the two profiles (H-E & H-P) selected according to the above described methodology.

The geographical scope of the analysis is Europe. For the photovoltaic (PV) and wind generation profiles, and for the electricity tariffs and fees, two national cases were considered and analysed: Sweden and Italy. For the charging profiles, all CAPEX and OPEX, LCOE calculation assumptions, and other methodological assumptions were the same between the two national cases.

For the two microgrid cases the following three alternative configurations were considered:

- solar power PV as main electricity generation technology, stationary lithium-ion battery energy storage (BES)[34], diesel electricity generator set as back-up ("emergency") system;
- wind power turbines as main electricity generation technology, stationary lithium-ion batteries, diesel electricity generator set as back-up system;
- solar power PV and wind power turbines as main electricity generation technologies, stationary lithium-ion batteries a diesel electricity generator set as back-up system.

Figures 2-3 and 2-4 summarise and show all the different cases and configurations analysed, and Table 2-4 reports the main data used, sources and assumptions for the LCOE calculations.

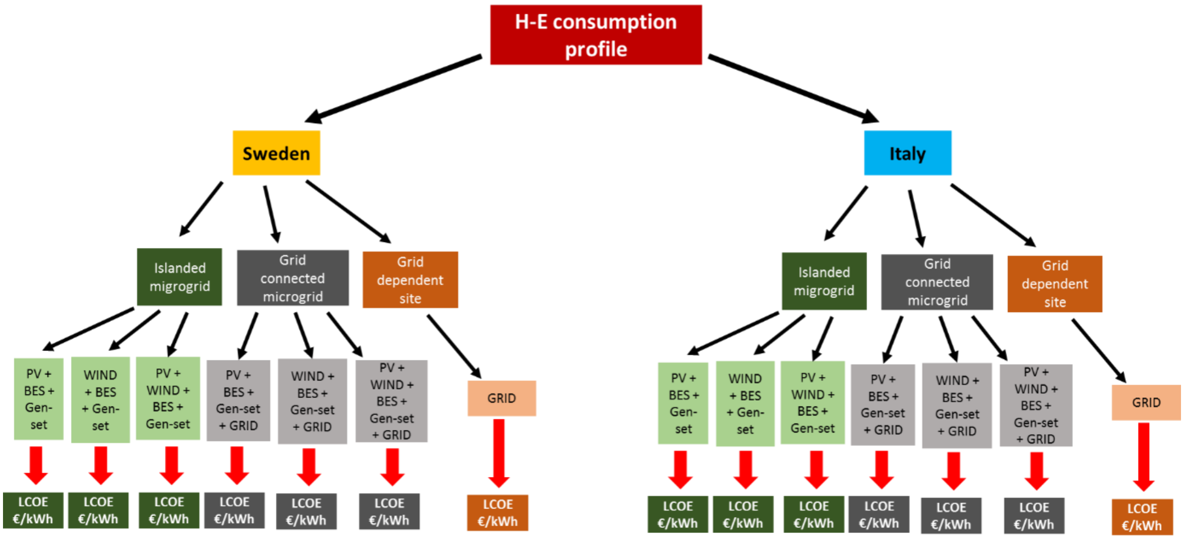

Figure 2-3. LCOE analyses performed for the H-E consumption profile

Source: Author´s own elaborations

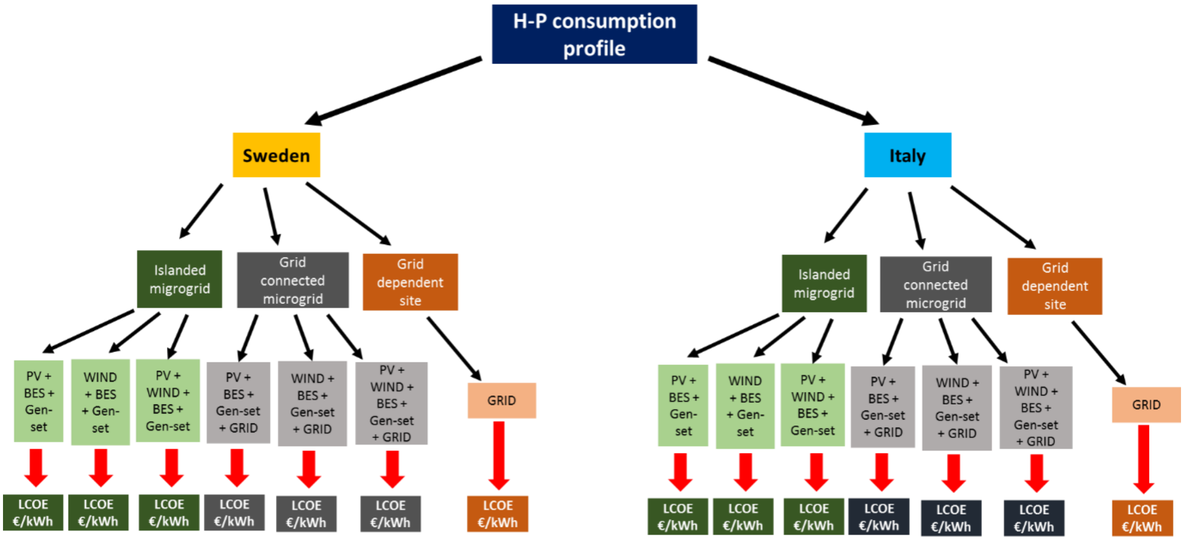

Figure 2-4. LCOE analyses performed for the H-P consumption profile

Source: Author´s own elaborations

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[34] Used to shift the RES generation over the 24 hours of a day when according to the charging site load profile

Table 2-4. Data used, sources and main assumptions for the LCOE calculations

Data used for LCOE	**Data used & sources**	**Methodology & assumptions**
Average PV generation profiles in winter and summer, Sweden	> PV hourly generation profiles - Svenska kraftnät statistical data > Total annual PV electricity generation - Swedish Energy Agency > Total PV generation installed capacity – Swedish Energy Agency	> The national hourly generation profiles were divided for the total installed capacity to identify the average hourly generation profile of 1 MW of installed capacity > If the sum of the hourly total yearly stated generation of the reference year was lower than the total yearly generation (due to difficulties for the TSOs in measuring or acquiring precise data about the generation of power plants connected at the local distribution grid), the profile was re-proportioned based on the stated total. > The average daily generation profile of 1 MW was calculated per each month > Due to high seasonal differences, in particular for PV, two different profiles for each technology and each country were calculated considered: winter (average between November, December, January and February) and summer (average between May, June, July and August) > Reference year considered for both countries to calculate the profiles: 2016 – since this was the latest year for which was possible to find all the data needed for the calculations for both countries > National average profiles were considered, although the author is aware that there are significant differences according to the latitude. Considering different zones/regions would probably be especially relevant for Italy, because PV is widely spread all over the peninsula, while in Sweden most of the capacity is installed in the southern regions. Considering local profiles could be a way to improve the accuracy of results.
Average Wind generation profiles in winter and summer, Sweden	> Wind hourly generation profiles - Svenska kraftnät statistical data > Total annual wind electricity generation - Swedish Energy Agency > Total wind generation installed capacity – Swedish Energy Agency	
Average PV generation profiles in winter and summer , Italy	> PV hourly generation profiles - Terna actual generation data > Total annual PV electricity generation – Terna statistical data > Total PV generation installed capacity – Terna statistical data	
Average Wind generation profile in winter and summer, Italy	> Wind hourly generation profiles - Terna actual generation data > Total annual wind electricity generation – Terna statistical data > Total wind generation installed capacity – Terna statistical data	
PV CAPEX	€/kW - IRENA, 2018a; REN21, 2018; ESG, 2018	> Different costs according to the size of the installation (total MW of the power plant) > Same CAPEX in Sweden and Italy
WIND CAPEX		
PV and WIND O&M	€/kW/year - ESG, 2018	> Same in Sweden and Italy
PV and WIND technical lifetime	Years – IRENA, 2018a	> Same in Sweden and Italy: 25 years > Average reference values, not based on the load factor or other usage and external actual factors
Lithium-ion battery CAPEX	€/kWh - IRENA, 2018c; REN21, 2018; ESG, 2018	> Lithium-ion battery technology > Reference €/kWh costs selected: average between the maximum and the minimum central estimates for the different Lithium-ion technologies
Lithium-ion battery technical lifetime	Years – IRENA, 2018c	> Same in Sweden and Italy: 13 years; new battery investment in 2030 assumed (with a system's life of 25 years) > Average reference values, not based on usage and external actual factors
Diesel gen-set CAPEX	€/ unit – American Generators website & Volvo Penta	> Same in Sweden and Italy

Data used for LCOE	Data used & sources	Methodology & assumptions
Diesel gen-set energy conversion efficiency	% (energy output / energy input) - American Generators website & Volvo Penta	> Energy conversion efficiency at maximum power
Diesel fuel costs	€/l - EC (n.d.) (Weekly Oil Bulletin)	> Same reference value in Sweden and Italy all over the LCOE calculation period – 1 €/l > Taxes not included
Diesel fuel calorific value	GJ/t – IEA, 2005	> Reference standard value adopted
Exchange rates	$/€ - ECB, n.d. €/SEK - 1€ = 10 SEK standard HP	> Same reference values all over the LCOE calculation period
Electricity costs and fees, Sweden	Göteborg Energi, SCB (statistics based on Swedish Energy Agency data)	> 2018 tariffs and fees used for all the all over the LCOE calculation period (so specific scenario assumptions regarding the evolutions of the electricity prices) > For the energy component the prices on electricity for industrial consumers were considered
Electricity costs and fees, Italy	ARERA	> 2018 tariffs and fees used for all the all over the LCOE calculation period (so specific scenario assumptions regarding the evolutions of the electricity prices) > For the energy component the final prices for non-household consumers in 2016 were considered (more recent data was not available)
LCOE parameters & formula	Weighted Average Cost of Capital (WACC) - IRENA (2018a); ESG, 2018; Lotfi & Khodaei, 2016	> Investment lifetime of 25 years > Investment in year 0 (which is 2017), and then electricity generation from year 1 to year 25 (from 2018 to 2042) > WACC (or discount rate) of 7.5%

Source: Author´s own elaborations

The cost of the electric vehicle supply equipment (EVSE) is not included in the calculations since it is assumed to be the same in the different considered configurations for the same consumption profile.

The solar PV and wind summer and winter generation profiles in Sweden and Italy used to size the microgrid components and calculate the costs and, finally, the LCOE, are shown in Figure 2-5, while Figure 2-6 all the prices/costs and other data used can be found.

For Sweden the electricity tariffs of the Gothenburg local energy utility, Göteborg Energi, which vary according to the level of power subscription (grid voltage connection), while for the electricity prices, including the related taxes, the latest prices published by SCB (which are based on Swedish Energy Agency data) for industrial consumers were used.

For Italy the electricity, tariffs, fees and prices published by ARERA, the Italian Energy Authority, which vary according to the level of consumption, the power subscription, the grid voltage connection and the type of consumer, were considered. For the electricity price the lasted data available is the 2016 one, which was used as reference value.

All costs and prices are expressed in nominal terms. The Value Added Tax (VAT) is not included in the calculations.

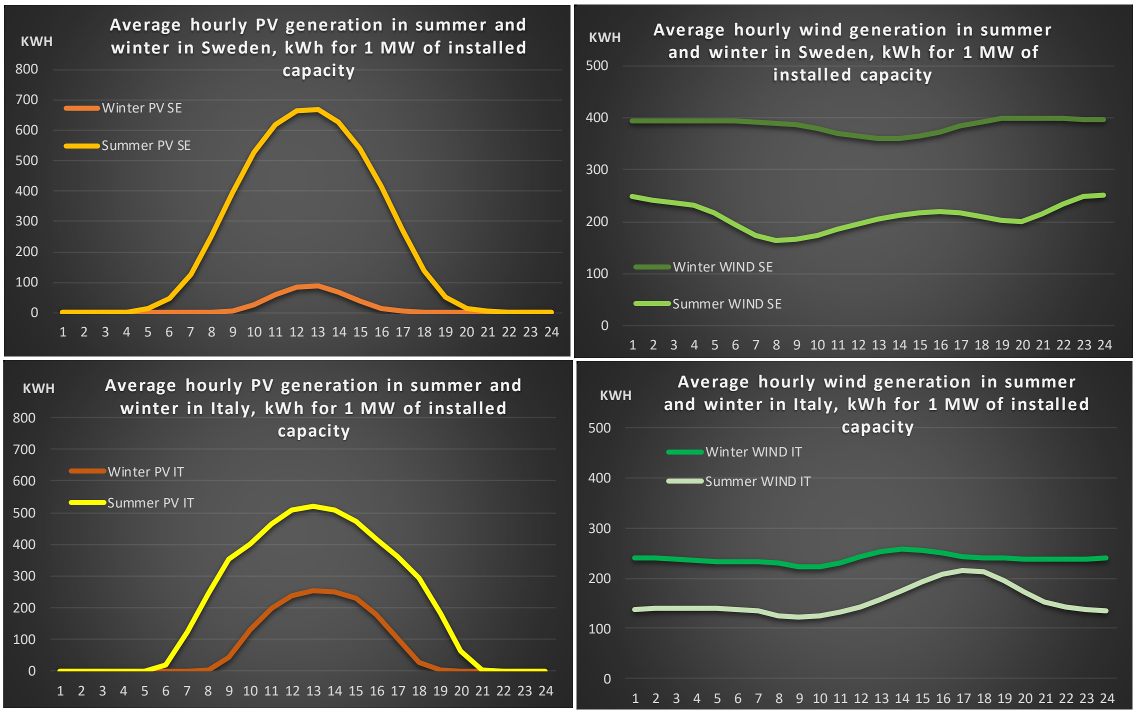


Figure 2-5. Solar PV and wind summer and winter generation profiles in Sweden and Italy

Source: Author´s own elaborations on Svenska kraftnät, Swedish Energy Agency & Terna data

	Size / cost element / tech spec	Cost / price	Referece year for the cost / price
Solar PV	P > 5MW	800 €/KW	2017
	1 MW < P < 5 MW	1 050 €/KW	2017
	200 kW < P < 1 MW	1 300 €/KW	2017
	O&M	20 €/KW	2017
Wind	P > 1MW	1 530 €/kW	2017
	500 kW < P < 1 MW	1 700 €/kW	2017
	P < 500 kW	1 840 €/kW	2017
	O&M	20 €/KW/year	2017
Diesel gen-set	500 kW	70 000 $/unit	2018
		61 728 €/unit	2018
	275 kW	40 000 $/unit	2018
		35 273 €/unit	2018
	230 kW	35 000 $/unit	2018
		30 864 €/unit	2018
	Efficiency at full load	40%	2018
	Fuel price	1 €/l	2018
	Fuel net calorific value	43.38 GJ/t	2018
Stationary battery	Utility scale lithium-ion	700 $/kWh	2016
		632 €/kWh	2016
		313 $/kWh	2030
		273 €/kWh	2030
Exchage rate		1.107 €/$	2016 AVG
		1.134 €/$	3 years AVG (31/08-2015 - 31/08/2018)

Figure 2-6. Prices/costs and other data used

Source: Author´s own elaborations on American Generators, EC, ECB ESG, IEA, IRENA, REN21 data

To size the different components of the microgrid cases the author adopted the following methodology.

- Based on the average summer and winter daily generation profiles for Sweden and Italy (hourly kW generation per 1 MW of installed capacity) the author calculated how many MW of installed capacity of solar and wind (summer and winter) are needed to be able to cover the daily electricity load of the charging site in summer and winter for both countries (assumption of load shifting with stationary batteries in the 24 hours of the day).
- Three different alternative configurations to cover the load were assessed:
  - solar PV only alternative - sizing based on winter solar generation profiles, when the generation is lower, which means extra generation ("overgeneration") in the summer, and which results in generation curtailments (solar PV system capacity is oversized for the summer);
  - wind only alternative - sizing based on summer wind generation profiles, when the generation is lower, which means extra generation in the winter, and which results in generation curtailments (wind system capacity is oversized for the winter);
  - solar PV and wind alternative – sizing based on an energy efficiency view, in order to avoid oversizing and energy waste. The sizing was then calculated imposing the total daily generation to be equal to the total daily load both in summer and winter, which means solving the following system of equations in two unknown variables for each charging site consumption profile and each country

$$\begin{cases} Sp * X + Sw * Y = a \\ Wp * X + Ww * Y = a \end{cases}$$

  Where:
  Sp = average daily summer load factor (working hours per day) of solar PV
  Sw = average daily summer load factor (working hours per day) of wind
  Wp = average daily winter load factor (working hours per day) of solar PV
  Ww = average daily winter load factor (working hours per day) of wind
  a = total (average) daily electricity consumption of the charging site (daily load of the microgrid)
  X = unknown variable 1 - number of kW needed – solar PV
  Y = unknown variable 2 - number of kW needed – wind
- Battery energy storage capacity needed per each profile and generation alternative - when the generation is higher than the consumption the electricity is stored, otherwise it is used on real time. Since the electricity generation components (solar PV and wind) were sized based on the daily consumptions, over the 24 hours of the week day the stored energy is enough to cover the charging station load when the generation is lower than the energy required. The total battery energy storage capacity needed is equal to the sum of the hourly stored energy over the 24 hours. For the only solar PV alternative the winter storage capacity was considered, for the wind only alternative the summer storage capacity, and in the solar PV and wind solution the highest between the summer and the winter. It results that the battery capacity is sized subsequent to the matching of the consumption profiles and generation profiles.
- Diesel electricity generators - sized to be able to cover the maximum hourly load (kW of installed capacity at least equal to the maximum hourly load), and used only as back-up (emergency) generation. In the LCOE calculations it was assumed that the diesel gen-sets are used to cover the 2% of the total annual load (for the fuel cost calculation – rule of thumb).

In the grid connected microgrid case the power connection with the main grid is based on the following rule of thumb: it is equal to the hourly electricity needed to cover half of the daily total load if the hourly consumptions were the same all over the day. The power grid subscription calculated in this way is not fully used only for few hours over the weekdays. Only the residual load that is not covered with electricity taken from the main grid has to be covered by the microgrid components; the sizing of the solar PV, wind and battery are based on the same methodology of the islanded microgrid.

Since the diesel generators are installed to support the reliability of the configuration, their sizing is the same in the islanded and in the grid connected microgrid cases.

Over the weekends the load is generally lower and has a more flat profile, so that the solar PV, wind and battery sized for the weekdays in enough to fully cover the Sundays and Saturdays hourly charging site consumption. Over the weekends, when the load is generally lower and has a more flat profile, the use of self-generation is maximised.

For the grid dependent case the grid power subscription is equal to the maximum hourly load of the H-E and H-P consumption profiles, while the total annual electricity withdrawn from the grid is equal to the total annual charging site electricity consumptions (weekends included).

Summing up, the sizing of components has been based on a linear sequential methodology (waterfall model): first the power grid connection (when present), then the solar PV panels together with the wind turbines and finally the battery energy storage capacity. The sizing of one element depend on the sizing of the previous ones (they are linearly dependent).

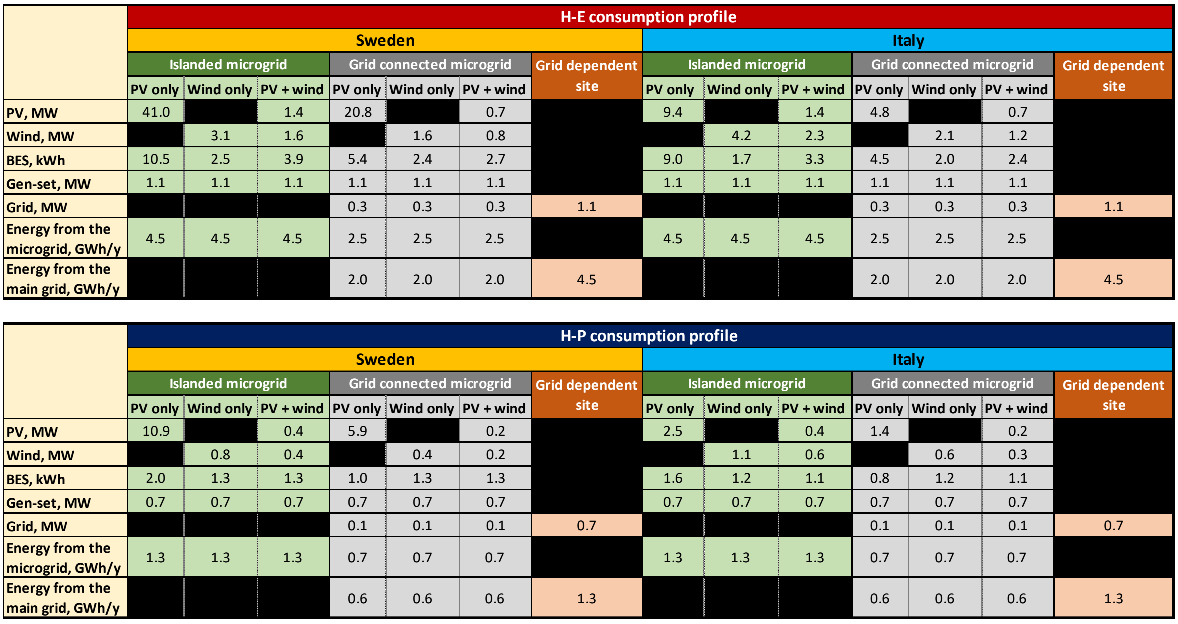
No overarching cost optimisation strategy has been implemented and analysed for assessing the components sizing. This choice is due to the complexity to implement a (cost) optimization process when many variables and many different cases are involved, and it will be discussed in the Results chapter. The objective of the study is indeed to provide a comparative analysis of different possible cases and configurations and not to pursue a cost optimization.

The LCOE calculations are based on the following formula:

$$\frac{\sum_{t=0}^{n} \frac{(CAPEX_t + OPEXt + O\&M_t)}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}$$

Where:
LCOE = levelised cost of energy (electricity) generation over the period n, €/kWh
t = reference year; t=0: year of the investment
n = life of the system, 25 years after year 0; year 0=2017, year 1= 2018, …, year 25 = 2042
r = discount rate, 7.5%
$CAPEX_t$ = investment expenditures in year t (solar PV, wind turbines, batteries, gen-set)
$OPEX_t$ = operating expenses in year t (fuel costs, electricity tariffs, fees and costs)
$O\&M_t$ = operation and maintenance costs in year t (for solar PV and wind turbines)
E_t = electricity consumption in year t (overgeneration excluded, because it is wasted/curtailed)

Figure 2-7 sums up the microgrid components sizing and grid power subscription required. The energy from the microgrid does not include the overgeneration. Table 2-5 lists some cost and revenue components that were not considered in the LCOE calculations but that could have a significant impact on the final results. Those components are very site and case specific and/or is more complicated to find/assume some standard reference values for them.



	H-E consumption profile													
	Sweden							Italy						
	Islanded microgrid			Grid connected microgrid			Grid dependent site	Islanded microgrid			Grid connected microgrid			Grid dependent site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind		PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
PV, MW	41.0		1.4	20.8		0.7		9.4		1.4	4.8		0.7	
Wind, MW		3.1	1.6		1.6	0.8			4.2	2.3		2.1	1.2	
BES, kWh	10.5	2.5	3.9	5.4	2.4	2.7		9.0	1.7	3.3	4.5	2.0	2.4	
Gen-set, MW	1.1	1.1	1.1	1.1	1.1	1.1		1.1	1.1	1.1	1.1	1.1	1.1	
Grid, MW				0.3	0.3	0.3	1.1				0.3	0.3	0.3	1.1
Energy from the microgrid, GWh/y	4.5	4.5	4.5	2.5	2.5	2.5		4.5	4.5	4.5	2.5	2.5	2.5	
Energy from the main grid, GWh/y				2.0	2.0	2.0	4.5				2.0	2.0	2.0	4.5

	H-P consumption profile													
	Sweden							Italy						
	Islanded microgrid			Grid connected microgrid			Grid dependent site	Islanded microgrid			Grid connected microgrid			Grid dependent site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind		PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
PV, MW	10.9		0.4	5.9		0.2		2.5		0.4	1.4		0.2	
Wind, MW		0.8	0.4		0.4	0.2			1.1	0.6		0.6	0.3	
BES, kWh	2.0	1.3	1.3	1.0	1.3	1.3		1.6	1.2	1.1	0.8	1.2	1.1	
Gen-set, MW	0.7	0.7	0.7	0.7	0.7	0.7		0.7	0.7	0.7	0.7	0.7	0.7	
Grid, MW				0.1	0.1	0.1	0.7				0.1	0.1	0.1	0.7
Energy from the microgrid, GWh/y	1.3	1.3	1.3	0.7	0.7	0.7		1.3	1.3	1.3	0.7	0.7	0.7	
Energy from the main grid, GWh/y				0.6	0.6	0.6	1.3				0.6	0.6	0.6	1.3

Figure 2-7. Microgrid components sizing and grid power subscription - summary

Source: Author´s own elaborations

Table 2-5. Further possible costs/revenues components not included in the cases and calculations

Cost / revenue component	**Relevant for**	**Possible impact**
Costs of buying, renting or opportunity cost for land (space) use (particularly relevant for PV and wind)	All configurations	LCOE ⬆
Taxes	All configurations	LCOE ⬆
Contractual agreements (power market operators, components providers, insurance…)	All configurations	LCOE ⬆
Soft infrastructure of the microgrid (control systems, etc)	Microgrids	LCOE ⬆
Hard infrastructure of the microgrid (power lines, transformers, inverters…)	Microgrids	LCOE ⬆
Use of other electricity generation technologies	Microgrids	LCOE ⬆⬇ - the final impact will depend on the final configuration
Grid connection costs (grid connection fees, public grid upgrade costs…)	Grid connected cases	LCOE ⬆
Restrictions on wind turbines location and on solar PV panels (usually when ground mounted and for MW sizes)	Microgrids	Limits on the kind/size of microgrid configurations that can be considered
Regulations on microgrids (possible limitations and restrictions)	Microgrids	Limits on micrgogrid installation, size, use
Regulations on diesel generators use (possible limitations and restrictions)	Microgrids	Limits on the kind/size of microgrid configurations that can be considered
Revenues from the overgeneration and net metering possibilities	Grid connected microgrid	LCOE ⬇
Providing services to the main power grid	Grid connected cases	LCOE ⬇
RES-E and energy efficiency incentives	All configurations	LCOE ⬇

Source: Author´s own elaborations

3 Literature review and analysis: three interrelated aspects of the same topic

The literature review on the three RQs brought the author to analyse a quire broad set of different sources: from academic articles to reports from international/supranational organisations, results of analyses conducted by research institutes or universities, papers published by consultancy companies, conferences presentations, company press releases, online articles.

As clearly resulted from the literature review the three RQs are interrelated, and many of the analysed documents gave valuable insights about the different aspects covered by the research. Notwithstanding this, it was possible to separate the literature review and analysis in three parts, to show how the different aspects are analysed in other works.

3.1 Synthesis of literature

The following three sections synthetise the literature review for the three RQs.

3.1.1 Impacts and implications for the power system

The battery charging process and patterns is the link between the transport and the power sector. Charging stations and charging sites are the physical meeting point of the transport and power sectors; their design, location, software and hardware configuration and use have impacts and implications for the power system, as well as for the transport system operation. In order for the electrified transport sector and for the power sector to keep on effectively and efficiently perform their jobs it is necessary to assess their current and expected interactions.

In particular, great attention was focused on analysing how e-mobility can affect the power system, since if EVs charging will have a relevant negative impact on the power system operation, e-mobility could have a short life, as EVs:

"(…) are connected to and dependent on the electricity system" (Chalmers, 2017, page 94).

For this reason a number of researches and projects analysed the impacts and implications/issues of e-mobility for the power system with the final target to assess their relevance and magnitude and how to cope with them.

The different possible impacts can be divided in four categories:

- Economic – affecting the economic performance of the power system (costs, revenues).
- Environmental – affecting the environmental performance of the power system (emissions).
- Operational – affecting the way the power system operates (energy generation mix, system capacity issues) – adequacy consequences.
- Technical – affecting the technical parameters/aspects that the power system must fulfil to operate (technical power system constrains) – quality consequences.

Table 3-1 summarises the main issues that e-mobility can implicate for the power system found in the literature. A specific impact may pertain to more than one category. Impact description is based on an "all other things being equal" situation: what can be the impact of EVs charging if no measures to accommodate and integrate it in the grid are implemented. The possible solutions are some possible ways to cope with the electrification of transport from a power system perspective.

Table 3-1. Main issues of e-mobility charging for the power system & power grid: RQ-1 literature review summary

Issue / impact	**Impact category/ies**	**Impact description**	**Possible solutions**	**Documents / sources**
Increased/ additional electricity demand (load impact)	Mainly operational, but also economic, environmental and technical	- Increased installed capacity - Increased electricity generation - Increased emissions - Increased costs for fossil fuels - Increased electricity prices - Increased grid costs - Grid stability, reliability, safety problems	- Smart charging (off-peak charging, , valley filling, peak shaving, DSR, V2G) - Couple charging stations with DER (PV, ESS… microgrids) - Real-time energy pricing	Gallo, 2016; IEA, 2017b; RSE, 2013; Yong et al., 2015
Compatibility of EVs charging demand with intermittent RES-E penetration	Mainly operational, but also economic, environmental and technical	*"Inclusion of electric vehicle charging in the power system demand represent yet another source of potential load variations which the electricity system need to manage"* Chalmers, 2017, page 106	- Smart charging (off-peak charging, , valley filling, peak shaving, DSR, V2G) - Stationary ESS - Real-time energy pricing	Chalmers, 2017; Coignard et al., 2018; Gallo, 2016; Richardson, 2013
Electrical power system losses	Mainly economic	EVs charging process increases the amount of energy flowing through transmission and distribution power lines, increasing the system losses	- Choose the proper physical location (with respect to the power grid) - Coordinated EVs charging and, in general, smart charging - Couple charging stations with DER (PV, ESS… microgrids)	Mahmud et al., 2018; Yong et al., 2015
Overload / saturation of power lines and transformers (mainly and firstly at distribution grid level)	Economic + operational + technical	*"(…) overloads can result in the accelerated ageing of grid infrastructure and eventually cause service interruptions, which could require investments for upgrading lines and transformers"* IEA, 2017b, pages 41-42	- Choose the proper physical location (with respect to the power grid) - Network and charging stations development planning - Couple charging stations with DES (PV, ESS… microgrids) - Grid investments (reinforcements, upgrades) - Smart charging (off-peak charging, , valley filling, peak shaving, DSR, V2G)	IEA, 2017b; Mahmud et al., 2018; Yong et al., 2015

Issue / impact	Impact category/ies	Impact description	Possible solutions	Documents / sources
Voltage profile, phase unbalance, harmonic distortion	Mainly technical	*"Large fleets of EV charging may make the network voltage violate the safe regulatory voltage requirements" (…) "The residential EV slow charging may cause severe phase unbalance problem if this kind of charging is not distributed evenly across all three supply phases"* Yong et al., 2015, page 374	- Smart charging (off-peak charging, , valley filling, peak shaving, DSR, V2G) - Coordinated charge scheduling - Load management (distribute the EVs loads between the three phases) - Voltage regulation equipment	Mahmud et al., 2018; Pinter & Farkas, 2015; Putrus et al., 2009; Torquato e al., 2014; Yong et al., 2015

Source: Author´s own elaborations on the selected literature

Most of the documents analysed point out how the impacts summarise in Table 3-1 are going to happen and/or being relevant only with a significantly higher penetration of e-mobility in the market compared to what we have seen so far (Chalmers, 2017; RSE, 2013; Lopes et al., 2011; Mahmud et al., 2018; Yong et al., 2015). *"When only a small percentage of the total energy demand of a network comes from electric vehicle charging, the vehicles will have negligible impact on the efficient and safe operation of the electricity network. However, as electric vehicles become a more popular and cost-effective technology, their usage will likely increase, motivating some alteration to the current operation infrastructure"* Chalmers, 2017, page 113.

As the number of EVs increase and the charging infrastructure develops, it then becomes increasingly important, and, in the long term even possibly mandatory, to provide some solutions to cope with the related impacts and issues. As shown and summarised in Figure 3-1 four different types of charging can be described, and they are associated with different (increasing) levels of involvement in the power system and also of implementation and management complexity (from "dumb" charging to increasingly "smart" charging).

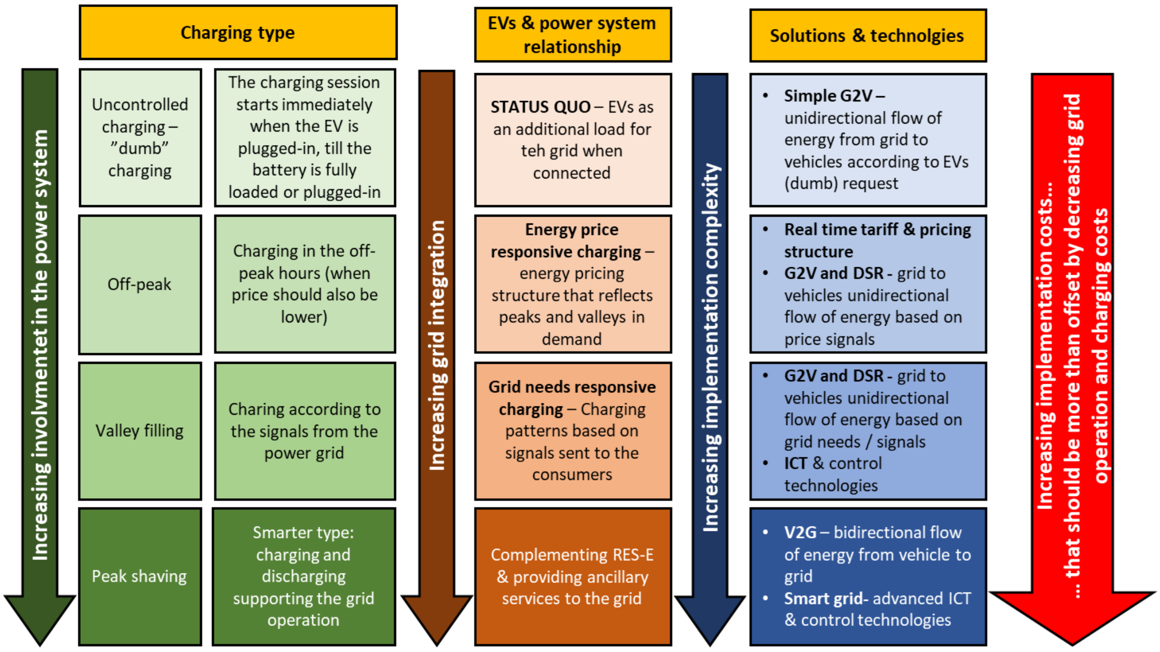


Figure 3-1. Smart charging and EVs - grid relationship

Source: Author´s own elaborations based on Chalmers, 2017; Mahmud et al., 2018; Yong et al., 2015; García-Villalobos et al., 2014

Figure 3-2 provides a possible theoretical representation of the different charging types.

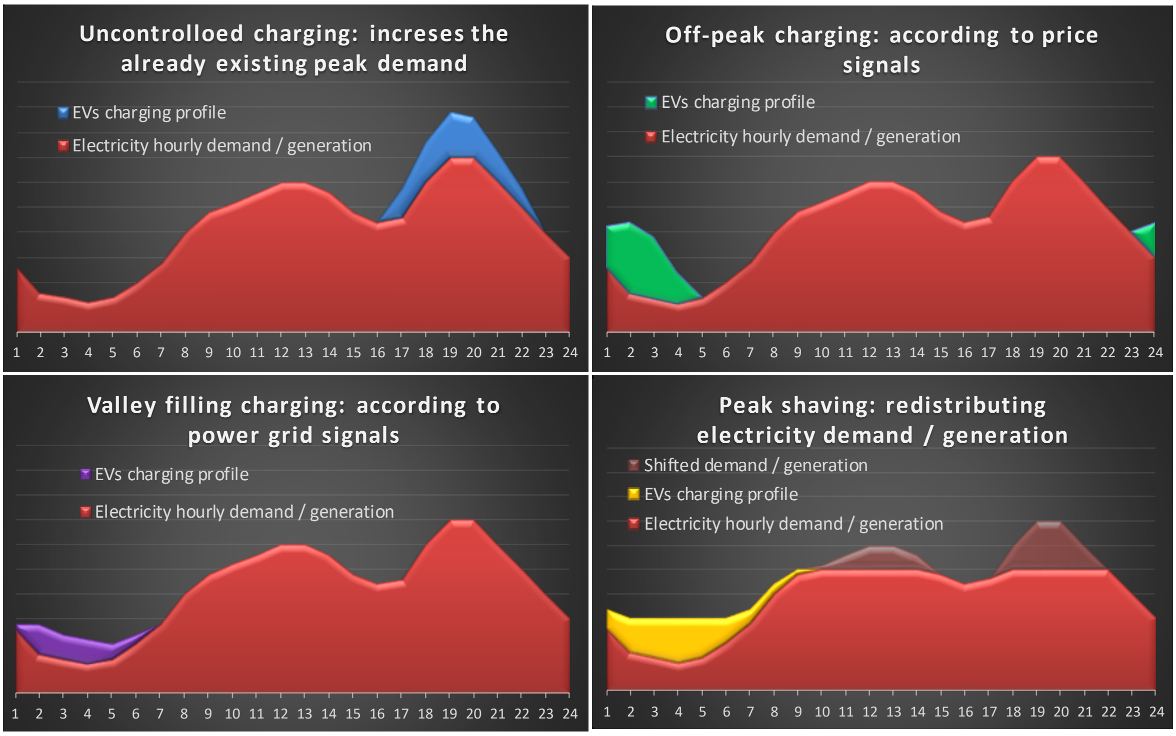


Figure 3-2. Different charging types theoretical representation

Source: Author´s own elaboration based on García-Villalobos et al., 2014

Peak shaving, which represents the "smarter" charging type, entails the use of EVs´ batteries to shift the grid load from peak hours to off-peak ones: batteries are charged when the rest of the system electrical demand is low, and then discharged when it is high, levelling out the demand and power generation needs (V2G). EVs smart charging can also support renewables integration shifting RES-E generation from low demand hours to high demand hours, storing the excessive generation from intermittent renewables and making it available for consumption when needed.

DSR, and all demand management systems can also be included in the various smart charging options, since they are supposed to reduce costs (charging when electricity is less expensive), and support the integration of e-mobility (as well as other loads) in the power system, allowing increase/decrease of the energy consumed according to the grid needs.

With the increasing integration in the power system EVs customers will lose their power and control over the vehicle use (or, more properly, over the battery use), *"giving-up the right to independently initiate charging"* (Chalmers, 2017, page 116).

EVs owners will require some economic benefits or incentives to allow this, and some kind of contractual quality-of-service agreement will be needed to guarantee the transportation needs of all customers, together with very advanced communication and control technologies. In general it is expected that the benefits will overcome all the costs and possible hurdles. On the other side, without the implementation of this new technical architecture and business models/relationships the power system won´t probably be able to achieve decarbonisation while meeting long term energy consumers' needs.

"Electric mobility is another step towards sustainability in modern society. Integration of PEVs in electrical distribution networks should be beneficial to all stakeholders, improving the efficiency of the system both technically and economically. In this context, smart charging is the key to achieve this ambitious objective" Villalobos et al., 2014, page 729.

"Implementing a system which includes vehicle-to-grid will require significant investment, both in terms of alterations to the current market structure to allow electric vehicle owning customers to potentially sell generation capacity, as well as development of the bidirectional communications infrastructure which would be required to support such a market. While vehicle-to-grid seems to be both infeasible and impractical for the current system, in future scenarios if there is substantial economic benefit to be yielded from avoidance of network investment or from retiring peak load generation units, it may warrant the implementation of such a system" Chalmers, 2017, page 119.

Aggregator entities will be needed to reach out a minimum "critical mass", able to provide services to the grid on a regular and stable basis without impairing the final customers charging willingness and "freedom". EVs aggregators will be in charge of managing the connection and communication of large amount of EVs with the grid and exploit economic opportunities on the energy markets (Eid et al., 2016; Lopes et al., 2011; Marra et al., 2017).

According to Zhao et al. (2016), electric delivery trucks may represent a better preliminary application of V2G technologies for providing grid services and enhanced smart charging, since they have: higher capacity batteries, a centralised coordination (for fleets), a more rational decision making process compared to car owners/users, less range anxiety problems (since they usually have no journey randomness or unpredictable operation patterns). For passenger light vehicles (cars) aggregators will indeed need to couple a bigger number or vehicles due to lower battery capacity, and coordination can be more complicated due to more diverse driving patterns and scattered location.

At the same time it is important to keep in mind the higher constraints that freight vehicles have compared to cars, and in general operators with more stable routes and mileage will probably be the ones who will benefit more from electric trucks, due to the lower operation flexibility of EVs (at least on the short-medium term) (Tryggestad et al., 2017).

"One of the main challenges posed by larger EFVs[35] *is the timing of charging events: both, large (over 12 tonnes) and medium (3.5 tonnes to 7.5 tonnes) EFVs within FREVUE tended to be charged only once a day in the late afternoon at the operator's depot. This differs from cars or light commercial electric vehicles where the diversity in charging patterns is high. The charging profiles of medium and large freight vehicles are less heterogeneous since most of them require to be charged at the same time every weekday with a sudden peak around 6pm"* FREVUE, 2017a, page 5.

"Truck and bus fleets work with the specific requirement to provide timely and regular service to their customers. As a result, E-Trucks & Buses will generally operate on set schedules mirroring business hours or commute hours. Time-Of-Use (TOU) pricing, where energy is more expensive when the electric demand on the grid is higher, has been effective at shifting light-duty EV charging off peak. But truck and bus fleets do not have the same flexibility to shift charging based on utility price signals. While TOU pricing can work for some delivery vehicles operating during business hours and charging at night, they can make it difficult when charging on route, during lunch breaks, between two shifts or after an early shift" Gallo, 2016, page 4.

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[35] Electric freight vehicles

An interesting alternative to TOU pricing, *"fixed electricity prices for different time blocks within a time period"* (Eid et al., 2016, page 18), can be Real-Time-Pricing, *"an hourly rate depending on the day ahead real-time price of electricity"* (Eid et al., 2016, page 18), to fully benefit from very low or even negative prices and accommodate and increasing level of intermittent RES-E into the grid (Eid et al., 2016; Gallo, 2016)

A last but not least possibly very relevant way to reach an extensive deployment of e-mobility without disrupting the main grid and while achieving economic benefits is installing and coordinating EVs charging with stationary ESS and on-site distributed generation (Gallo, 2016; Chalmers, 2017; Tryggestad et al., 2017).

In particular this can happen in a microgrid configuration, which is the focus of the present research and a kind of solution for e-mobility charging sites that is gaining a lot of attention from researches, with a number of studies focused on analysing how to configure and optimise the microgrid operation.

Integrating renewables and stationary batteries in a microgrid with plug-in EVs can have at least three economic benefits: reduce or eliminate the distribution/transmission upgrading costs; significantly reduce the maximum peak power requested to the local distribution grid through microgrid internal peak shaving process, allowing to have a much lower capacity charge in the electricity billing; reducing the electricity bill with less kWh taken from the grid thanks to self-production (Abdalrahman & Zhuang, 2017; Chalmers, 2017; Gallo, 2016; Lopes et al., 2011; Peças Lopes et al., 2010; Tan et al., 2016; Tryggestad et al., 2017 van der Kam & van Sark 2015; Wu et al., 2013; Yong et al., 2015).

3.1.2 Assessment of potential consumption patterns

To investigate how to assess the potential consumption patterns of an e-mobility charging site the author analysed the literature to find out

1. Possible alternative methodological approaches
2. Main data used
3. Main underlying assumptions

Moreover, it was important to understand the purpose and the scope/scale of the analysed researches in order to have a broader context and evaluate how and if a similar approach was applicable to answer RQ-2.

The consumption patterns and, more in general, the way EVs are used and they require charging, can be assessed for different specific objectives, but under a wider system perspective the final target usually remains providing some data and analysis to support the deployment of e-mobility and its integration in the power grid.

Many analyses have already been conducted, but, based on the author´s findings, no one provided an overview of the methodology and key data used and assumptions made.

Table 3-2 briefly summarises the literature review for the RQ-2.

Table 3-2. Assessment of e-mobility potential consumption patterns: RQ-2 literature review summary

Document / project	**Purpose**	**Scope - scale**	**Methodology**	**Key data used**	**Key assumptions /conditions**
Pasaoglu et al., 2013	Estimating expected national EVs grid level load profiles	- Privately owned cars - Data from six EU countries (national scale)	Estimation based on car-use profiles of ICEVs	Survey data on sample individual driving profiles	- EVs penetration degree - Charging stations availability - Same use of EVs & ICEVs
FREVUE project (FREVUE, n.d.)	Proving that electric fright vehicles could offer a viable alternative to diesel vehicles	- 32 partners - 80+ electric vans & trucks - 8 EU cities	Demonstration project based on data from EVs use under real-world logistics conditions	Data and information about the use of the EVs included in the project	Cooperation and management principles between local authorities and industry partners
Bryden et al., 2018	Assess the usage and power requirements of future fast charging points	- Privately owned cars - Dataset from the US - Long distance journeys	Estimation based on car-use profiles of ICEVs	GPS data from existing ICEVs	- Same use of EVs & ICEVs - Driving range - Fast charge usage
Serradilla et al., 2017	Building a business model for future investment and policy decisions in fast charging infrastructure	- Rapid Charge Network (RCN) project in the UK - 74 EVSE rapid chargers	Use and analysis of data and input parameters to evaluate an investment decision (CAPEX, OPEX, electricity costs a possible reselling mark-up)	- Data from the EVSE and EVs along the routes covered by the RCN project - Data from EVs manufacturers	New business models are required for e-mobility due to the differences between EVs and ICEVs transport
Liu & Wu, 2014	Estimation of level and patterns of EV charging demand in Nordic Countries	- Nordic Coutries (DK, FI, NO, SW) - Passengers ICE cars	Driving behaviour analysis to calculate the energy consumption and possible charging patterns	- National travel surveys data of the Nordic area	- Same use of EVs & ICEVs - 2 charging availability conditions - Dumb, timed and spot price based charging analysed
NREL, n.d.; NREL, 2014; Prohaska et al., 2015	Evaluation and documentation of the performance of electric and plug-in hybrid electric medium-duty trucks	- electric and plug-in hybrid electric medium-duty trucks - US companies (Navistar Inc.; Smith Electric Vehicles; Frito-Lay North America)	Comparing the electric and plug-in hybrid performance to conventional diesel trucks operating in the same fleets	- In-use data collected from the vehicles - Vehicles specifications from the involved US companies	- EVs adoption brings different benefits compared to ICE vehicles (GHG reduction, fuel costs reduction)

Document / project	**Purpose**	**Scope - scale**	**Methodology**	**Key data used**	**Key assumptions /conditions**
Karlsson, 2013; Karlsson & Kullingsjo, 2013	Gather and analyse a large amount of data on the movement patterns of cars to support electrification	- Sweden (cars registered in Västra Götaland county or Kungsbacke municipality) - 714 individual privately driven passenger ICE cars	- Request to a random selection of car owners from the motor-vehicle register - Data analysis	Measurement with GPS equipment	Relevant data and information from ICEVs movements to support the electrification of transport
Speidel & Bräunl, 2014	Analyse and discuss EVs and charging stations data to assess EVs impacts	- Electric vehicle trial in Australia - 11 EVs, 23 charging stations	Data gathering and analysing – driving and charging statistics	EVs driving and charging data	The data *"supply accurate and detailed EV driving pattern that are useful for EV charging grid modelling"*, Speidel & Bräunl, 2014, page 98
Robinson et al., 2013	Understand the recharging behaviours of EV drives to analyse the carbon content of EVs trips	- North-east of England - 65 drives, 31756 EV trips, 7704 EV recharging events	- EV trial project (Switch EV) - EVs leased to drivers recruited through media campaigns - descriptive statistics	EVs driving and charging data	Possibility to shift the charging events to reduce the carbon content (off-peak recharging, RES-E offsetting)
Shen et al., 2016	Analysis of ICE taxis trajectories to discuss how to locate public charging stations	- Beijing, China - data from 46756 ICE taxis	Time-series simulation to model PHEV´s operation and charging behaviours	Vehicle trajectory data	- Same use of EVs & ICEVs - Charging opportunity based on time window, charging demand, charger availability
Schey et al., 2012	Summarise the result of EV Project to support the assessment of early EVs adopters impact on the electric grid	EV project: collection of data from 5000+ electric cars in 18 US regions	Data collection and statistical analysis	Usage of residential charging units in the EV Project (2704 EVSE)	Possibility to shift the charging demand to off-peak hours to prevent an increase in peak system demand
Kamankesh et al., 2016	Studying the optimal energy management of microgrids with RES and PHEVs	Theoretical configuration – framework is tested	Stochastic framework based on Monte-Carlo simulation	EVs charging behaviours based on a series of assumptions, not actual data	Three different charging strategies considered: uncontrolled, controlled, smart

Document / project	**Purpose**	**Scope - scale**	**Methodology**	**Key data used**	**Key assumptions /conditions**
Li et al., 2018	Supporting the planning of new EVs charging stations based on usage data of existing ones	- Beijing, China - EVs charging data	Demand sensing and charging station planning algorithm to estimate charging demand and optimise siting and sizing of new charging stations	Actual charging behaviour data (from official Beijing mobile app and charging pile network usage data)	Charging needs of future EVs drivers can be inferred from today´s charging patterns
Corchero et al., 2014	Monitoring of a large collection of EVs and charging points data to support a large deployment of EVs	- 12 locations around 8 countries in Europe - Variety of EVs fleets and charging point locations	Data collection, study and statistical analysis	Static and dynamic relevant data on EVs and charging point use	- The results can be a benchmark to support higher EVs penetration - Possible differences between countries are not assessed
Mies at al., 2018	Supporting optimisation analysis of EVs smart charging schemes	- Amsterdam, Netherlands - 128 000 EVs charging sessions´ records	Regressions analysis to investigate how different factors (variables) influence the charging profiles	Charging sessions data and detailed meter values of the charging point	Selection of variables to test based on the literature and other assumptions

Source: Author´s own elaborations on the selected literature

As Table 3-2 shows the existence of a broad and extensive research activity for the assessment of charging patterns of EVs. This represent a fundamental kind of analysis for a massive planning and deploy of e-mobility at systems level (policy makers, regulators, national and international authorities and organisations) as well as to elaborate specific business plans (automotive companies, energy utilities, e-mobility service operators, hardware and software equipment manufacturers and service providers...).

Whenever enough relevant data is available, the preferred methodology is based on EVs and EVSEs use data and technical specifications. But in many cases, being e-mobility still at the early stages of deployment, it is not possible to have such data. In this case, many researches have assumed that, at least at the beginning and probably for a while, the use and journey patterns of EVs will be coherent with the use and journey patterns of ICEVs.

This general view comes from the idea that people want to be able to use EVs as they use ICEVs for switching to EVs, but also from the objective observation that at the very beginning there might be no other alternative actual data to rely upon. ICEVs use data can then be checked against EVs technical specifications and parameters, in order to create usage and charging profiles coherent with EVs working possibilities.

It is also important to notice that different studies imply the fact, which is probably going to a necessity or even a mandatory requirement in case of a massive e-mobility deployment, that the charging patterns will have to adjust to integrate EVs in the power systems and accommodate an increasing share of RES-E. Also for this reason assuming that the usage/charging behaviour and energy consumption patterns of EVs will be in line with the ICEVs ones could make sense on the short-medium term, but in the longer term, the smart charging potential economic and technical benefits and new regulatory requirements could lead to significant changes.

3.1.3 Technical, economic, regulatory feasibility

As pointed out in section "3.1.1 Impacts and implications for the power system", charging sites configured as microgrids, which is the focus of the present research, represent a solution to some of the issues that can arise from the integration of the charging infrastructure in the power system. Microgrids can indeed enhance the technical and economic feasibility of charging stations, since they allow to be less dependent on the main grid (local distribution grid, or, eventually the transmission grid for higher power configurations).

But they also increase the complexity of the charging infrastructure, since they entail to cope with the power system regulation on microgrids (and, more in general, distributed generation), and to deal/compete more directly and closely with the other power system actors, such as electricity distributors, suppliers, generators. They also entail investing in electricity generation technologies and grid related hardware and software components, and having the technical and economic knowhow to operate them and optimise their use.

Charging sites configured as microgrids sum up two of the main elements that are expected to reshape power systems in the long term: electrification (of transport) and distributed generation - microgrids (see section "1.1 Four interlinked focus areas for the future of the power system"). These two elements have a lot in common, such as the energy storage technologies, which are at the heart both of electromobility and microgrids, and which still constitute one of the main economic aspects/barriers for EVs as well as for stationary power solutions (Calstart, 2012; FREVUE, 2017b; FREVUE 2017c; FREVUE 2017d; IEA2017b; IEA 2018b; IRENA, 2018c).

The three areas, technical, economic and regulatory immediately appeared interlinked, but going through the literature review it become more and more clear that they are overlapping and mutually dependent. Regulation probably represent the more relevant topic: in can be the biggest barrier or element to consider in a business plan, and is also probably going to be the area that will require the longer time span to get properly updated in order to cope with the energy transition (Gallo, 2016; Lo Schiavo et al. 2017; Gómez, 2011).

Furthermore the literature reviewed showed how new business actors, relationships, approaches and models are being developed and will be needed, and also the power system regulation will need to evolve significantly to allow and support new technical configurations and market roles in the future (Chalmers, 2017; ESG, 2017; Serradilla et al., 2017; San Román et al., 2011; ARF, 2014). Regulation is going to have a pivotal role for the electrification of the power system, and the current regulatory framework, established and still mainly based on a centralised power system, will have to evolve to support the energy transition toward decarbonisation. The regulation (together with and driven by the legislation) will impact the shaping of the new business models, determining which market actors will be allowed, or better suited, to play different roles, and establishing the technical/operational requirements of the new solutions. Regulation can also provide a favourable context for the deployment of specific technological solutions while hindering some others. At the same time regulation (and legislation) developments can be supported and driven by the main market actors that are interested in having a role in this new business opportunities and that have a specific interest in certain technologies and business models.

Economics places second, cause although some technologies are still too expensive to already consider microgrids and charging stations as widespread economically attractive solutions, the main forecasts are for a continuous decease of costs (IEA2017b; IEA 2018b; IRENA, 2018c); other relevant economics aspects, such as grid and energy tariffs, could relate more to the law/regulation (taxes, systems charges, tariffs design) than to the evolution of "real" costs (Gallo, 2016; Lo Schiavo et al. 2017; EC, 2016a).

Regarding technology, based on the analysis of the selected academic literature and other documents from different private of public organisations, the availability of proper technological solutions and their performance are not perceived per se as a problem or a possible barrier for the development of electromobility and microgrids. But their deployment and implementation will be highly dependent on the development of software and smart grid technologies to optimise their operation and to properly integrate them in the power system, in particular as these solutions become more and more widespread in the system. A conspicuous number of studies are indeed focuses on modelling approaches and optimisation techniques for micgrogrids and for integrating EVs in the power grid via smart charging approaches. The main issues seem to be about finding out the best way to make things properly work according to a series of constraints and assumptions rather than questioning if things can properly work (Mahmud et. al, 2018; Richardson, 2013; Tan et al., 2016; Lopes et al. 2011; RSE, 2013; Attaianese et al., 2014).

Figure 3-3 schematically shows the author´s vision about the feasibility aspects before and after the literature review: from three interconnected but distant and equally relevant blocks to three highly overlapping and with different weights aspects where also new market features and actors/roles are key elements to consider. This new vision was also supported by a number of interviews the author conducted among different stakeholders within Volvo Group as well as other organisations.

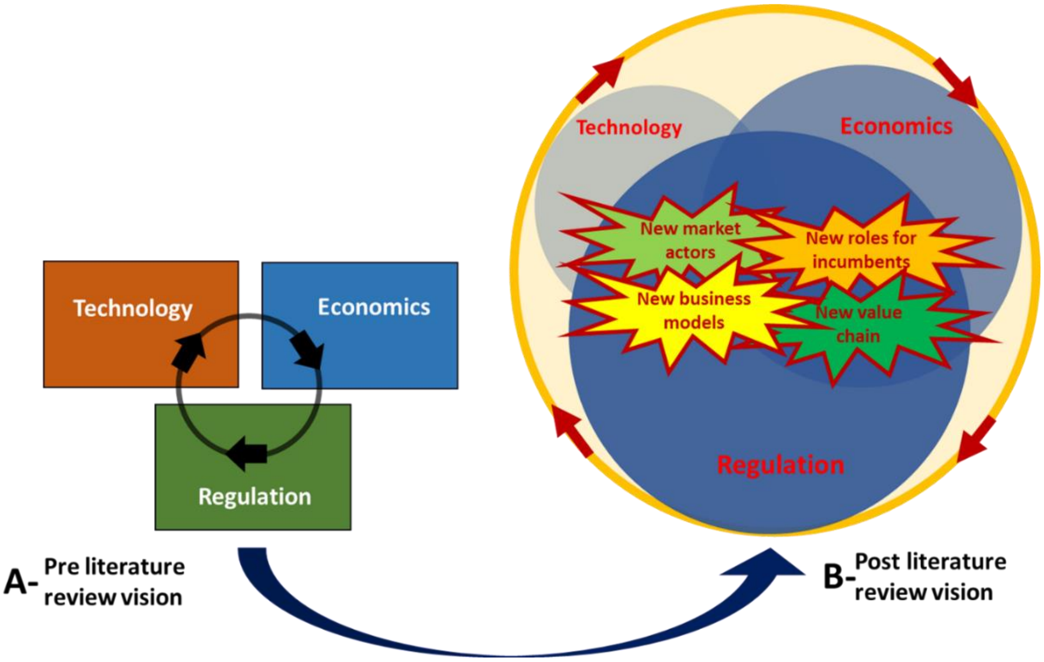

Figure 3-3. Author´s vision about technological, economic, and regulatory feasibility aspects of charging sites/microgrids

Source: Author´s own elaboration based on the literature review (and interviews)

In the following the main feasibility issues/barriers found in the literature will be briefly analysed. For RQ-3 the literature review was a way to start understanding which are the main barriers and issues for the deployment of charging sites/microgrids according to researches, and where the academia is headed toward about these topics. It was also needed for the author to be able to conduct more educated interviews with many different stakeholders, which results are shown in the Results chapter, together with the quantitative analysis outcomes.

Focus on microgrids: trends and challenges

Based on the findings of the Microgrid Project the deployment of microgrids is pushed forward by five main category of drivers that are all interlinked and tend to work in concert (IIIEE, 2018):

- Access to energy – microgrids can increase the access to electricity for remote areas, where expanding the main grid would probably be much more expensive.
- Affordability – microgrids solutions are becoming economically competitive with the rapid decrease of the costs of the involved technologies.
- Resilience – microgrids can enhance the capacity of a system to maintain or recover functionality in the event of a disturbance or disruption.
- Reliability - microgrids are potential solutions to help ensure the reliability of the social and production systems, especially in areas where the main electricity grid frequently experience disruptions.
- Sustainability – microgrids are a way to use and integrate more and more renewable distributed energy resources in the power system.

But notwithstanding the many benefits that microgrids can bring to the power system and society in general, there are a number of barriers to their developments which were clearly portrayed by Ali et al. (2017) in the scheme shown in Figure 3-4.

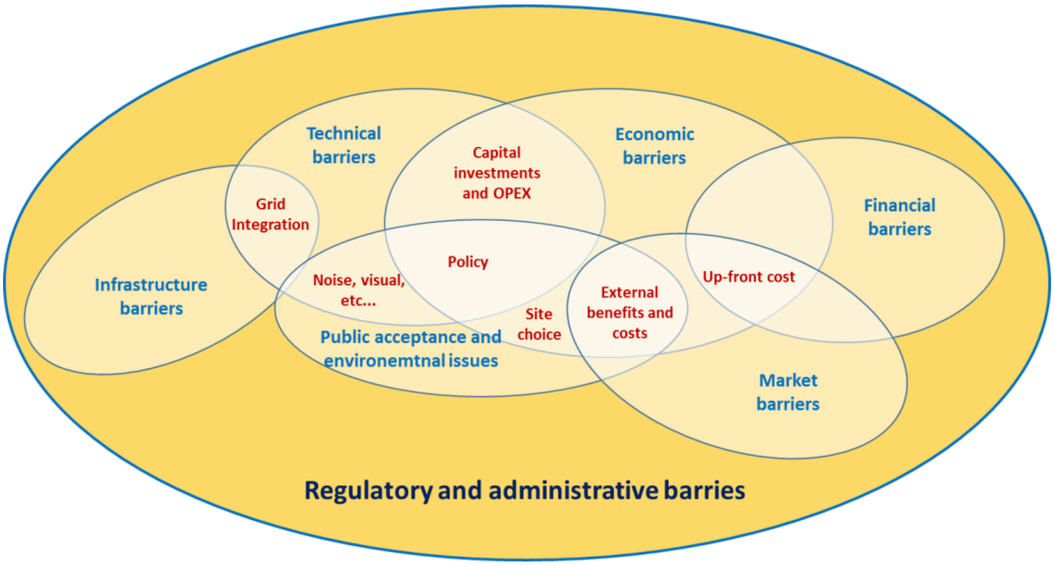

Figure 3-4. Synthesis of the barriers for microgrids (and distributed renewable energies) development

Source: Ali et al., 2017

Infrastructure barriers relate to the uncertainty of how microgrids/DER should connect to the grid. In some countries, such as in the US, different manufactures and project managers make arrangements with utilities (Hirsch et. al., 2018). As an attempt to overcome this barrier, the

IEEE 1547 standard has been developed, and rules for integrating DER to the grid in a safe manner have become more consistent (IEEE, 2018).

For the technical barriers, one of the main issues can be the technical platform which handles communication between the different microgrid components, and, more in general, the energy management system to control and optimise the energy flows with the behaviours of the different energy resources (Ali et al., 2017; Attaianese et al., 2014; Sandroni et al., 2016; Yong et at., 2015) This is an area where many research efforts are focused with test, pilot projects and simulations (Attaianese et al., 2014; Sandroni et al., 2016). RSE, who tests different aspects of microgrids in a test facility in Milan:

"Has successfully demonstrated the opportunities made possible by the synergy between power grid and information network. By means of the concept of microgrids, with their management systems, it is possible to aggregate various distributed energy resources, loads and renewable generation, in order to make their aggregate behavior more predictable, improving the quality of service and the network stability" Sandroni et al., 2016, page 5.

Financial and economic issues regard the up-front investments costs and the possible financial tools to overcome these barriers, such as the possibility to have a Power Purchase Agreement to reduce the risks for the investors, or the presence of adequate funding opportunities. Market barriers can be represented by: a pricing structure that disadvantages these solutions, or asymmetrical information, the market power of the different actors, existing subsidies for fossil fuels or other technologies, and the classical market failure about pricing and internalising social and environmental costs and benefits.

The costs of stationary storage systems, which represents one of the key components of a microgrid, especially in case of a completely islanded solution, are expected to decrease substantially. Figure 3-5 shows some data from the IRENA "Electricity Storage and Renewables: Costs and Markets to 2030" report, about the current and projected energy installation costs[36] for battery electricity storage (BES) technologies, with a focus on the lithium-ion systems for stationary applications, and some specific data for the home systems (behind-the-meter) price evolution in Germany. The numbers shown for Germany are in line with what is reported in the IEA World Energy Investments report 2018: the global *"average installed cost of a behind-the-meter-battery was estimated to be around USD 1 200/kWh, with around 40% attributable to the battery pack itself"* IEA, 2018c, page 67.

IRENA analysis includes:

- Five lithium-ion subtechnologies: lithium nickel manganese cobalt oxide (NMC); lithium manganese oxide (LMO); lithium nickel cobalt aluminium (NCA); lithium iron phosphate (LFP); lithium titanate (LTO).
- Two lead-acid subtechnologies: valve-regulated lead-acid (VRLA); flooded lead-acid (Flooded LA)
- Two high-temperature subtechnologies: sodium nickel chloride flow battery (NaNiCl); sodium sulphur (NaS)
- Two flow subtechnologies: vanadium redox flow battery (VRFB); zinc bromine flow battery (ZBFB)

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[36] The cost per installed kWh of storage capacity, in real 2017 USD

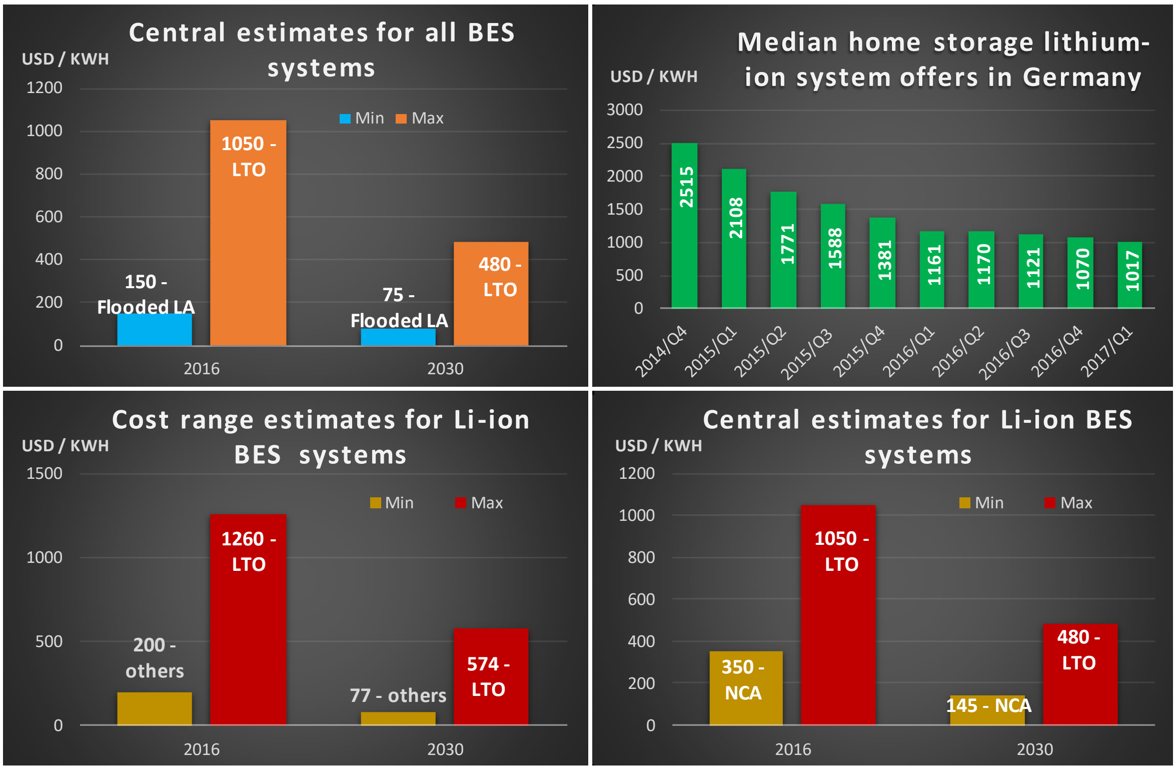

Figure 3-5. Stationary BES technologies costs from IRENA

Source: IRENA, 2018c

At the same time also the projections for renewable energy sources, the other typical component of a microgrid and one of the core elements of the power sector transition, are for a continuous decrease of prices (IEA, 2017b; IRENA, 2018a). As shown in Figure 3-6 the total installed costs[37] and LCOE[38] for solar photovoltaics (PV) and onshore wind technologies experienced significant reductions, and *"by 2020-2022, the LCOE of electricity from solar and wind technologies will fall solidly within the range of USD 0.03 to USD 0.10/kWh"* (IRENA, 2018a, page 57).

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[37] Which, in IRENA definition and calculation, represent all of the costs of developing a project, and includes which includes: Transport cost, Import levies (for the on-site equipment), Project development, Site preparation, Gird connection, Working capital, Auxiliary equipment, Non-commercial cost, Working capital, etc.

[38] Based on IRENA, 2018a "The LCOE of a given technology is the ratio of lifetime costs to lifetime electricity generation, both of which are discounted back to a common year using a discount rate that reflects the average cost of capital", and in the IRENA 2018a report "all LCOE results are calculated using a fixed assumption of a real cost of capital of 7.5% in OECD countries and China, and 10% in the rest of the world, unless explicitly mentioned. All LCOE calculations exclude the impact of any financial support". LCOE calculations includes the following costs and data (which are not included in the total installed cost): Operation & maintenance, WACC, Resource quality, Capacity factor, Life span.

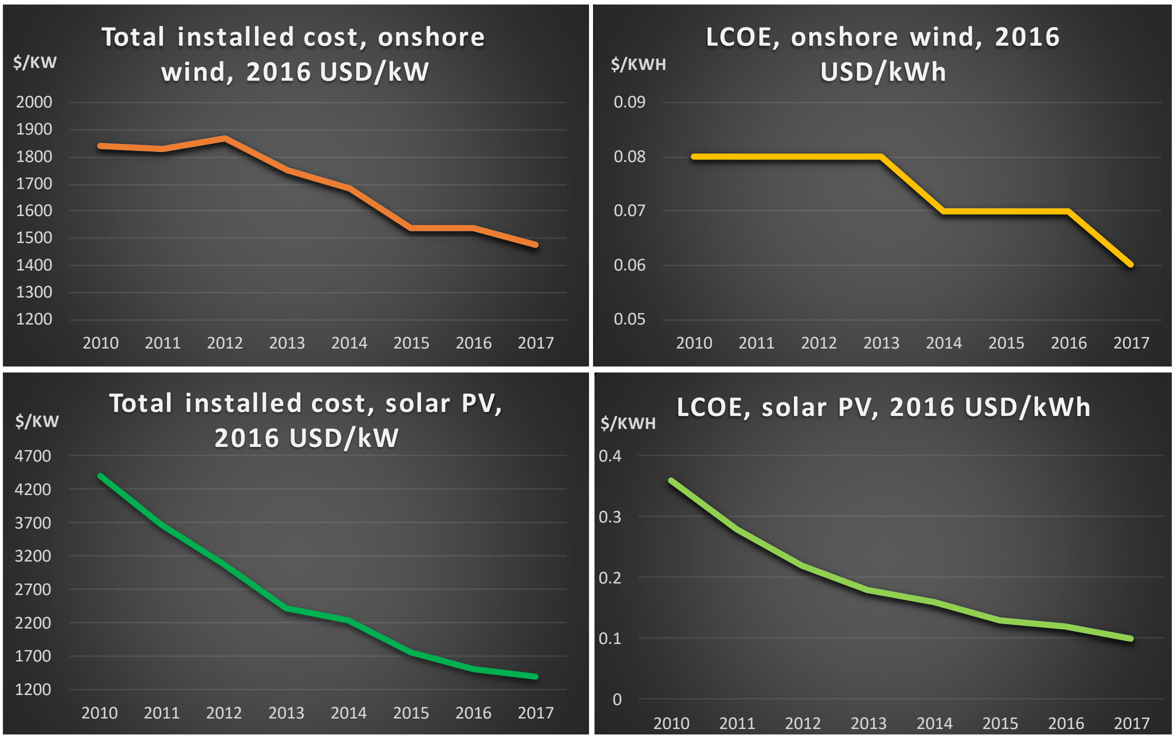

Figure 3-6. Global weighted average total installed costs and LCOE for onshore wind & solar PV, 2010-2017

Source: IRENA, 2018a; IRENA renewable cost database

Also public acceptance can be an issue, impacting the possible site choice and the penetration of new technologies, so that educating the public and demonstrating the reliability of the system can be important factors, while some environmental issues can arise from the local planning and construction regulations.

But regulation and administrative barriers remain the overarching issue for microgrids, which can also positively or negatively affect all the other barriers, reducing or reinforcing their impact on microgrid development. Administrative issues can arise from the length, complexity and non-transparency of permitting procedures, or from the lack of clear responsibilities and skills within the local and national authorities.

Microgrids as energy distribution systems are still within a grey area in terms of regulation and legal status in many countries: electricity distribution is a local natural monopoly, and in Europe managing a local distribution grid represents a regulated activity, so that there are specific rules about in which cases they are allowed and who (which market actors) can deal with these configurations.

Completely islanded or grid connected microgrids represent a tricky evolution for the energy regulators because they will entail updating the rules of the game, and in particular the need to completely reform the electricity tariffs system that has been established for a very centralised systems and that has been in place for many years.

Considering a specific national case, the Italian Energy Authority (Autorità di Regolazione per Energia Reti e Ambiente - ARERA[39]) has been working a lot on these aspects in the last few

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[39] https://www.arera.it/it/index.htm

years. In particular it has been analysing the impacts of and increasing share or renewable DER and electricity self-consumptions (in different kinds of microgrid configurations) on the allocation of electricity system charges on final consumers (ARERA, 2017). The main risk highlighted by ARERA is that with a decreasing number of electricity consumers who rely only on the main grid to satisfy their electricity demand the system charges (distribution and transmission charges but also other levies) will then weigh on less consumers, leading to an "unfair" increase of their electricity bills (ARERA, 2017; Bertani, 2016). At Italian level the legislative-regulatory discussion is then turning around a crucial point: if and eventually which system costs should be charged on all the electricity consumption, irrespective of whether the electricity is self-produced (in a microgrid or just thought the use of DER) or taken from the main grid (ARERA, 2017; Decreto-Legge 91/2014; Decreto-Legge 244/2016). In this context also the European Commission have a role in determining the national energy tariffs with specific Directives (such as EC, 2009) or the state aid rules (EC, 2014c).

"National regulatory authorities should be able to fix or approve tariffs, or the methodologies underlying the calculation of the tariffs, on the basis of a proposal by the transmission system operator or distribution system operator(s), or on the basis of a proposal agreed between those operator(s) and the users of the network. In carrying out those tasks, national regulatory authorities should ensure that transmission and distribution tariffs are non-discriminatory and cost-reflective, and should take account of the long-term, marginal, avoided network costs from distributed generation and demand-side management measures" EC, 2014c, Recital 36, page L 211/59.

The possibility of a complete "grid defection" effect due to the decreasing prices of key technologies and the increasing electricity system costs/charges is also a matter of debate (Bertani, 2016; ENERGEIA, 2016; RMI, 2014) since: *"Even before mass defection, a growing number of early adopters could trigger a spiral of falling sales and rising electricity prices that make defection via solar-plus-battery systems even more attractive and undermine utilities' traditional business models"* RMI, 2014, page 6.

The final direction the regulation is going to take (in Italy as well as in other countries that are facing similar market conditions) will probably have a significant impact on the business plan of a microgrid, since if all the electricity consumed (self-produced and taken form the main grid) will have to pay the system charges, the economic benefits of self-consumption will shrink.

The current Italian regulatory framework is also a clear example of how complex can be trying to allow and support a configuration that is considered socially, economically and environmentally welcome while avoiding to disrupt the systems and cause problems to the other consumers. ARERA has established a number of different private possible configurations, where the electricity transport activities are not considered as transmission and/or distribution activities (regulated natural monopolies) but as energy self-suppling activities (free market). The possible allowed configurations have to meet different requirements about: the maximum installed power, installations of renewables or high efficiency cogeneration (HEC) power plants, layout (minimum share of self-consumption, number of consumers and consumers), and also by what date the authorization request should be submitted (ARERA n. d.; ARERA, 2013).

Today only two categories are allowed for new installation requests (Table 3-3).

Table 3-3. Microgrid configuration allowed in Italy for new installation according to the current legislative and regulatory framework.

Configuration type (Italian name)	Max power	RES or HEC obligation	Layout constraints
Sistemi efficienti di utenza (SEU)	20 MW	Yes	- Max 1 client (consumer) - Max 1 producer (can be different from the client) - Max 1 consumption unit (1 energy meter) - Installation in a private property of the client
Altri sistemi di autoproduzione (ASAP)	No limit	No	Total annual electricity consumption of the site must be at least equal to 70% of the total electricity generation of the site itself

Source: ARERA n. d.; ARERA, 2013

A focus on e-mobility: perceived barriers

The main aspects traditionally discussed and perceived as barriers for EVs adoption are (Bossart, 2015; Calstart, 2012; IEA, 2017a; IEA, 2018b; IEDC, 2013;IRENA, 2017; OIES, 2018):

- The high upfront costs of EVs (due to the high costs of batteries)
- The battery performance (with connected range anxiety problems)
- The charging time (usually compared to the ICEVs refuelling time), which depends on the charging station power rate
- The availability of the charging infrastructure
- The costs of the charging infrastructure
- The charging costs (electricity tariffs and charges)

Following the fast technological advancements of the last few years, supported by important R&D investments and pilot projects from different stakeholders involved in the e-mobility field, and the expected market evolutions, most of these issues are becoming less and less critical.

As reported in the latest IEA and IRENA publications dedicated to EVs or battery technologies, the battery energy density[40] (Wh/L) has been increasing over time, while the costs have been decreasing (USD/kWh). According to the Oxford Institute for Energy Studies a technological or cost break-through occurred in the EV industry:

In future, the central reasons for rapid penetration of EVs are likely to be the falling cost of EVs and batteries and the increased range of EVs. The decline in the cost of EVs is largely related to declining battery costs, which are inversely proportionate to battery density (…). IEA (…) argues that the cost of batteries in the R&D phase is below those now being sold and, hence, future costs of EV batteries will continue to fall. Bank of America Merrill Lynch (…) forecasts that battery cell and pack costs will fall by 6.1 percent annually between 2016 and 2030. There is debate about whether and at what pace battery costs will fall, with concern expressed about potential shortages of lithium or cobalt. However, the consensus appears to be quite strong that the cost of batteries will fall significantly, even if there are periods when the prices of these materials spike" OIES, 2018, page 6.

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[40] "Energy Density (Wh/L) – The nominal battery energy per unit volume, sometimes referred to as the volumetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery size required to achieve a given electric range". MIT, 2008.

Lithium-based batteries represent one of the most promising technologies, since it has high energy density (Wh/L) and high power density[41] (W/L), it is lighter that others, cheaper and suitable for fast charge (IRENA, 2018c; Yong et al., 2015). Lithium-ion should remain the main technology for the next decade, and: the battery capacity will increase to serve large all-electric driving ranges; the world manufacturing capacity will increase (a number of new factories have been announced and will become operational in the next few years), with large production and economies of scale; technology developments in the battery chemistry will allow higher energy densities and lower reliance on cobalt. (IEA, 2018b; Yong et al., 2015)

"Today typical batteries used in EVs are based on the lithium-ion technology which has reached a development level enabling the design of vehicles that begin to match the performance of ICE vehicles. Current battery packs for light-duty applications have gravimetric energy densities of 200 Watt-hours per kilogram (Wh/kg) (…) and volumetric pack energy densities of 200 – 300 Watt-hours per litre (Wh/l) (…). The lifetime of the battery is another important parameter. For EV batteries, a good proxy is the expected mileage associated with a battery's lifetime and its ability to retain a good share of its initial capacity (usually 80%). Available literature suggests that modern Li-ion chemistry for EV batteries can withstand 1 000 cycle degradation (…). Assuming a battery capacity of 35 kWh and an average consumption of 0.2 kWh/km suggests that this cycle life threshold would not be attained over the first 175 000 km of driving and indicates that the lifetime of the battery is compatible with the expected lifetime for a car". IEA, 2018b, pages 59-60.

Regarding the charging infrastructure from 2010 to 2017 the number of charging outlets deployed all over the world increased from few thousands to roughly 3.5 million, showing a quite impressive fast development. Less than 0.5 million are publicly available ones, more than 90% of all are slow ones, and, in 2017, China had approximately three-quarters of the world's publicly accessible fast chargers and a major part of the slow chargers (IEA, 2018b).

All over the world there currently are or are planned a number of public initiatives (often in partnership with energy companies, which range from multinationals – oil or power ones - to local utilities, and OEMs on the automotive and/or charging infrastructure industry), as well as completely stemming from some private stakeholders, with substantial funds, for the deployment of a public charging infrastructure[42] (IEA, 2018b; ARF, 2014).

As already pointed out in the Introduction chapter ultra-fast charging (350 kW, 450 kW) is an already existing option, and, in general, having a high speed charging infrastructure can address some of the e-mobility perceived limitations, that are the time to charge and range (Burnham et al, 2017 Yong et al., 2015; IEA, 2018b).

In 2017 several ultra-fast charging standardisation bodies released new descriptions or official protocols to charge at up to 200 kW, and some high-power charges were deployed, although there were not yet commercial vehicles suitable for charging at that level. Enabling ultra-fast charging requires a specific and more complex battery design considerations and can reduce the battery lifetime. But with an appropriate design and sized thermal management system, increasing charging speed should not impact the lifetime, although it could nearly double the cell costs (IEA, 2018b). The work of standardisation bodies in very important also to ensure the interoperability of the charging infrastructure, preventing the existing different standards from becoming a barrier for a massive deployment of e-mobility (Lo Schiavo et al., 2017; San Román et al., 2011).

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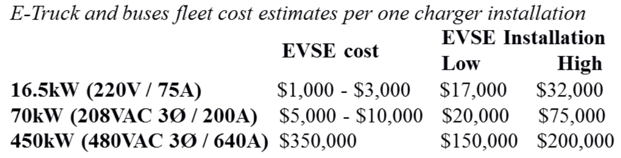
[41] Power Density (W/L) – The maximum available power per unit volume. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery size required to achieve a given performance target". MIT, 2008

[42] Most of the project are for non-residential privately owned charging points

One of the main current barriers for a fast charging infrastructure regards the higher capital costs, and also, possibly, higher grid connection costs. Table 3-4 shows some data about the costs, including the installation.

Table 3-4. Some electric vehicles supply equipment (EVSE) costs, including the installation costs

<table>
<tr><th>Source</th><th>Data</th></tr>
<tr><td>Gallo, 2016</td><td>

<i>E-Truck and buses fleet cost estimates per one charger installation</i>
<table>
<tr><th></th><th>EVSE cost</th><th colspan="2">EVSE Installation</th></tr>
<tr><th></th><th></th><th>Low</th><th>High</th></tr>
<tr><td>16.5kW (220V / 75A)</td><td>$1,000 - $3,000</td><td>$17,000</td><td>$32,000</td></tr>
<tr><td>70kW (208VAC 3Ø / 200A)</td><td>$5,000 - $10,000</td><td>$20,000</td><td>$75,000</td></tr>
<tr><td>450kW (480VAC 3Ø / 640A)</td><td>$350,000</td><td>$150,000</td><td>$200,000</td></tr>
</table>
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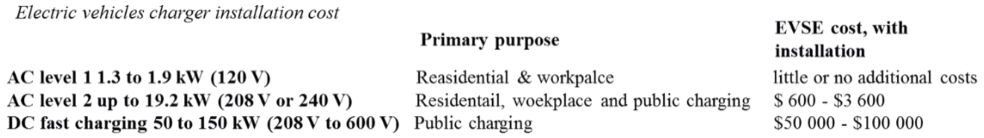
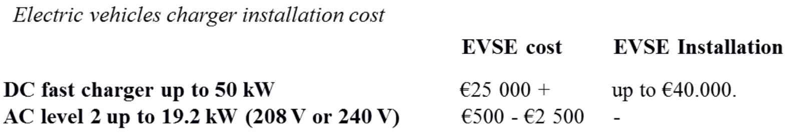
<tr><td>Bossart, 2015</td><td>

<i>Electric vehicles charger installation cost</i>
<table>
<tr><th></th><th>Primary purpose</th><th>EVSE cost, with installation</th></tr>
<tr><td>AC level 1 1.3 to 1.9 kW (120 V)</td><td>Reasidential & workpalce</td><td>little or no additional costs</td></tr>
<tr><td>AC level 2 up to 19.2 kW (208 V or 240 V)</td><td>Residentail, woekplace and public charging</td><td>$ 600 - $3 600</td></tr>
<tr><td>DC fast charging 50 to 150 kW (208 V to 600 V)</td><td>Public charging</td><td>$50 000 - $100 000</td></tr>
</table>
</td></tr>
<tr><td>Clean Technica, 2017</td><td>

<i>Electric vehicles charger installation cost</i>
<table>
<tr><th></th><th>EVSE cost</th><th>EVSE Installation</th></tr>
<tr><td>DC fast charger up to 50 kW</td><td>€25 000 +</td><td>up to €40.000.</td></tr>
<tr><td>AC level 2 up to 19.2 kW (208 V or 240 V)</td><td>€500 - €2 500</td><td>-</td></tr>
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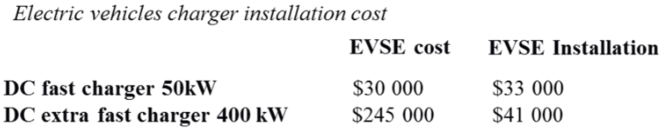
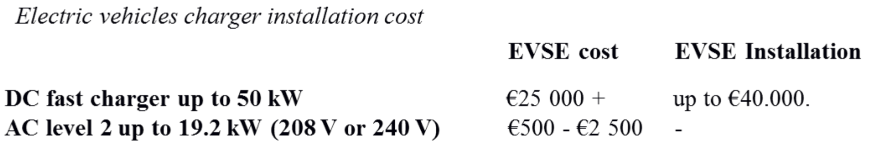
</td></tr>
<tr><td>Burnham et al., 2017</td><td>

<i>Electric vehicles charger installation cost</i>
<table>
<tr><th></th><th>EVSE cost</th><th>EVSE Installation</th></tr>
<tr><td>DC fast charger 50kW</td><td>$30 000</td><td>$33 000</td></tr>
<tr><td>DC extra fast charger 400 kW</td><td>$245 000</td><td>$41 000</td></tr>
</table>
</td></tr>
<tr><td>Schroeder & Traber, 2012</td><td>

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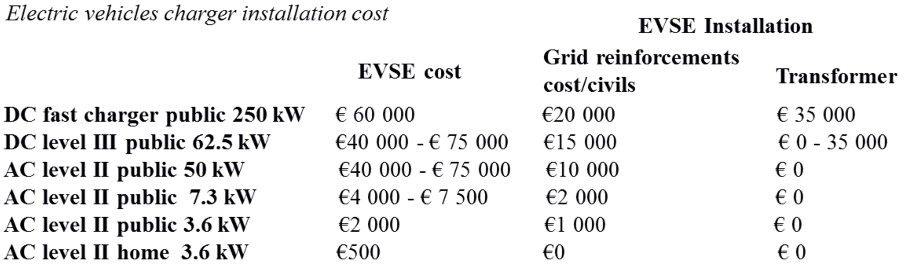
<i>Electric vehicles charger installation cost</i>
<table>
<tr><th></th><th></th><th colspan="2">EVSE Installation</th></tr>
<tr><th></th><th>EVSE cost</th><th>Grid reinforcements cost/civils</th><th>Transformer</th></tr>
<tr><td>DC fast charger public 250 kW</td><td>€ 60 000</td><td>€20 000</td><td>€ 35 000</td></tr>
<tr><td>DC level III public 62.5 kW</td><td>€40 000 - € 75 000</td><td>€15 000</td><td>€ 0 - 35 000</td></tr>
<tr><td>AC level II public 50 kW</td><td>€40 000 - € 75 000</td><td>€10 000</td><td>€ 0</td></tr>
<tr><td>AC level II public 7.3 kW</td><td>€4 000 - € 7 500</td><td>€2 000</td><td>€ 0</td></tr>
<tr><td>AC level II public 3.6 kW</td><td>€2 000</td><td>€1 000</td><td>€ 0</td></tr>
<tr><td>AC level II home 3.6 kW</td><td>€500</td><td>€0</td><td>€ 0</td></tr>
</table>
</td></tr>
</table>

Source: Author´s own elaborations on the selected literature

The connection costs can include grid upgrade costs and/or need to set up a microgrid or at least to install some stationary batteries, but also higher network charges based on the peak power availability requested to the main grid (Clastart, 2015; Burnham, 2017; Gallo, 2016).

But, as pointed out by Burnham et al. (2017), who thoroughly analysed the economics of fast charging *"While initial experience by OEMs developing these high power systems found that the equipment costs may be significantly higher, the expectation is that they will be similar in cost to current systems once they are beyond the prototype development phase"* Burnham et al., 2017, page 243.

The policy support and also an increasing use rate (hours per day), which is assumed to increase as EVs become more and more widespread, and that could also be enhanced by smart charging types, will also support the profitability of the charging infrastructure (Burnham et al., 2017; CleanTechnica; 2017; Schroeder & Traber, 2012).

As can be seen in the data reported in the table the total expenses vary greatly according to the installation costs and also the necessity for upstream grid reinforcements (included only in the last source in the table), which tend to be non-incremental, so that upgrading in two steps rather than one can entail more than double costs (FREVUE, 2016; Schroeder & Traber, 2012). Furthermore in a complete business plan also some yearly maintenance and repair costs should be considered (up to 10% of material costs rule of thumb in Schroeder & Traber, 2012). The distance from the main power infrastructure, and also the surface material of the location where the works for the wire will be made are other elements than can have a relevant impact on the economics of the installation (Burnham et al., 2017).

In the context of the FREVUE project the delivery company UPS worked with the UK power networks, the local DSO and substation owner as well as the landlords, to provide for potential charging capacity for 68 EVs, and it incurred in substantial costs: the grid upgrade process took more than one year and a cost of over £ 600 000, and without having any control over the asset it was investing in (FREVUE, 2016).

While, from the CALSTART experience in e-trucks and e-buses: *"Infrastructure costs are high and vary widely. In addition, the faster a vehicle needs to be charged, the more expensive the charging infrastructure will be (…). One fleet who deployed 20 E-Trucks at a facility in Southern California had to upgrade a transformer on the customer side of the meter to accommodate the added load to the facility. In this particular case, the $470,000 transformer price tag had a significant impact on the total project cost".* Gallo, 2016, page 6.

Finally, the way electricity tariffs are designed could represent another important barrier for e-mobility penetration: charging stations are not energy but power-intensive loads, and this issue can become very relevant especially when a number of high power chargers are clustered together in the same location (Lo Schiavo et al., 2017). A high power rate could be needed and requested to the main grid just for one hour per day, or even less; one solution could be some kind of smart charging, but it might be difficult for a fleet of trucks to adapt the charging schedule to the grid needs and costs (Gallo, 2016; Lo Schiavo et al., 2017).

The discussion about who should bear the microgrids and EV infrastructure costs is now open: should they be included in the regulatory asset base (RAB)[43], considering that they will allow the transition and also probably lead to lower upgrading investments for the main grid? (Cohn, 2018; Burnham et al., 2017).

Figure 3-7 shows the hypothetical electricity consumptions of a charging station with 10 charging outlets or 450 kW each, assuming that the full maximum capacity is used just one hour per day. The table annexed to the picture shows that in both the two examples (Italy and Sweden) they represent a relevant yearly cost, which could be paid to use the capacity for one hour or maybe less every day. They become even more relevant when compared to the total annual cost of electricity, in particular in Sweden, where electricity is less expensive than in Italy. To calculate the total electricity and connection costs (the final bill) also subscription

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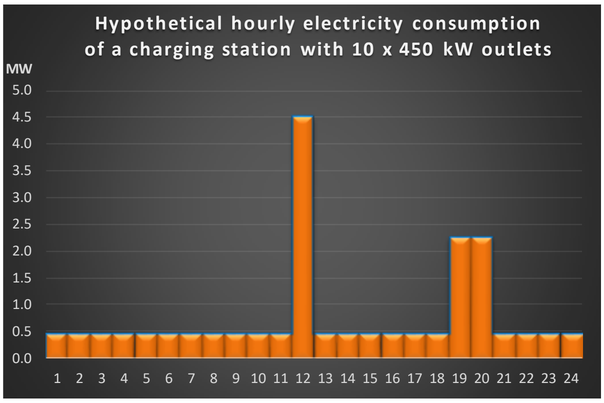
[43] Value of net invested capital for regulatory purposes, calculated on the basis of the rules defined by the national competent Authorities for determining base revenues for the regulated businesses; it is a fundamental parameter in utility regulation in order to determine the allowed profit of these businesses for remuneration of both historic and new investments. The structure of individual components included into the RAB and their valuation differ significantly among EU Member States and even among the regulated sectors.

fees (€/year or month), electricity tariffs, usage fees, and other taxes and levies (€/kWh) have to be included in the calculation.



Yearly capacity fees & energy component	Data source		tot SEK/year	tot €/year
Sweden		kr/KW		
Distribution, medium voltage	Göteborg Energi	36.2	1 954 800	195 480
		krc/kWh		
Electricity prices for industrial consumers	SCB - Swedish Energy Agency	39	2 626 358	262 636
Italy		€c/kW		
Distribution, medium voltage	ARERA	3 011		135 500
		€/MWh		
Electricity prices for non-households	ARERA	68.5		461 296

Figure 3-7. Yearly capacity fees in Italy and Sweden (Gothenburg area) for 4.5 MW (450 kW x 10 charging outlets).

** HP: 1 € = 10 SEK; 2018 capacity fees.*

Source: Author´s own elaborations on Göteborg Energi, SCB (statistics based on Swedish Energy Agency data) & ARERA data

In 2010 ARERA, the Italian Energy Authority, launched a pilot project, setting a special tariff dedicated exclusively to EV charging with low voltage connections and located in public places: a "monomial tariff", where all the components (also the capacity fee) are expressed in €/kWh (energy) (Lo Schiavo et al., 2017). This tariff makes more viable installing and using public charging stations, removing the yearly fixed capacity charges and becoming a sort or pay-per-use tariff. But due to the need to cover anyway the connections and grid costs, the €/kWh unitary values are much higher than the ones set for traditional "trinomial tariffs" (energy €/kWh + connection €/year + capacity €/kW/year), so that the monomial tariff would results economically reasonable only when the total amount of energy withdrawn from the main grid is not too high (ARERA, 2018).

The batteries and charging infrastructure considerations and developments described above hold true for all the different possible kinds of EVs (all the segments of the transport sector shown in Figure 1-4), although the following elements need to be considered, when the focus is on buses or heavy-duty trucks instead of cars:

- Large batteries tend to have lower specific costs (USD/ kWh) because of a higher cell to pack ratio (IEA, 2018b)
- Larger batteries need faster charging for reasonable and comparable with ICEVs charging times, which increases the costs per kWh, both due to chemistry and more complex thermal management systems (IEA, 2018b)
- Higher (faster) power charging is usually (or probably, if the target/need is having charging times comparable with ICEVs refuelling time) required, which means has higher capital costs, and also, possibly, higher grid connection costs, as already reported above (Burnham et al., 2017; Calstart, 2015; Gallo, 2016)

Focus on charging: regulation & new business models

If the technical and economic aspects for microgrid and e-mobility seem to be progressively addressed and less a matter of concern for researches and stakeholders compared to just few years ago, there are other aspects that will probably take more time to be finally faced. Regulatory issues and the new business models for e-mobility are two focus areas that are getting more and more attention from businesses, policy makers and researches.

The tariff design represents a possible economic barrier for e-mobility that pertains to the power system regulation sphere. There is an ongoing, and far from be solved, discussion on the electricity tariffs for EVs charging stations, with two main matters of concern for the development of e-mobility, and that should be contextualised in the general discussion about the power market reforms:

- The existence and consistency of capacity fees in the current tariff structures (see previous section). This could addressed updating the regulation and/or configuring the charging station as a microgrid, with renewable DERs and stationary batteries to level out the peak power demand (Burnham et al., 2017; Calstart, 2015; Gallo, 2016; Schroeder & Traber, 2012)
- The electricity pricing (€/kWh): as already discussed in the previous sections, a real-time-pricing could support e-mobility integration in the main grid and the adoption of smart charging types (Eid et al., 2016; Gallo, 2016).

Updating the regulation in order to accommodate new technologies and loads and then supporting the energy transition toward decarbonisation is something that usually requires years. In this context a holistic perspective is needed, since, as already briefly discussed in the previous sections for microgrid as well as for e-mobility, when the rules of the game are changed or updated to favour something (a technology) or someone (some market actors), it means that someone else is paying for that.

National electricity tariffs usually are not flat but made up of a complex net of cross-subsidies between different electricity consumers and producers categories which can vary according to the country socio-economic priorities. The impact of changing one piece of this complex puzzle to "incentivise" a market/technological development goes well beyond the single incentivised element, so that, pilot projects apart, a power system reform is usually needed (Eid et al., 2014; Erdogdu, 2011; Percebois & Pommeret, 2018; Picciariello et al., 2015).

With Directive 2014/94/EU on Alternative Fuel Infrastructure (AFI Directive), the EC opened (or reignited) the debate over the different market actors that can/should own, develop, manage or operate EV´s charging stations. One of the EC main concern is about ensuring that the EV charging activities are carried under competitive conditions: *"The establishment and operation of recharging points for electric vehicles should be developed as a competitive market with open access to all parties interested in rolling-out or operating recharging infrastructures"* EC, 2014d, Recital 30, page L 307/5.

For this reason the possible role of DSOs, as regulated companies working in local monopoly marker conditions, is going to be subject to some restrictions and to the approval of the national regulatory authority (EC, 2014d; Lo Schiavo et al., 2017). In 2012 the EDSO[44] published position paper explaining how and why the DSOs should a core role charging

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[44] The European Distribution System Operators' Association - https://www.edsoforsmartgrids.eu/

stations business, but so far, at least three EU countries - Italy, Germany and the UK - have already rejected the DSOs model (EDSO, 2012; IEA, 2018b; Lo Schiavo et al., 2017).

"Depending on the specific regulatory approach of a country, and whether legislation considers EV charging stations as retailer or as distributor of electricity, the regulatory environment can facilitate or hinder investments by actors in the electricity sectors and private companies" IEA, 2018b, page 49.

Today many energy utilities are investing and in some cases already creating had hoc companies within their groups to expand their business toward e-mobility, providing new services to their final customers; at the same time a number of initiatives are coming from the automotive sector and other OEMs (Deloitte, 2017; IEA, 2018c). Different market players[45] are trying to place themselves along the e-mobility value chain, where there are some new business opportunities that did not exist with ICEVs (Figure 3.8 shows a representation of the EV´s value chain from McKinsey). There are different possible approaches, but the general trend for automakers seems to be to try to expand the business toward the charging infrastructure, and possibly also the system/data management, thought a vertical integration (TELSA) or partnerships (BMW, Daimler, Ford and Volkswagen with Audi and Porsche) (Deloitte, 2017; IEA, 2018c, IONITY, n.d.).

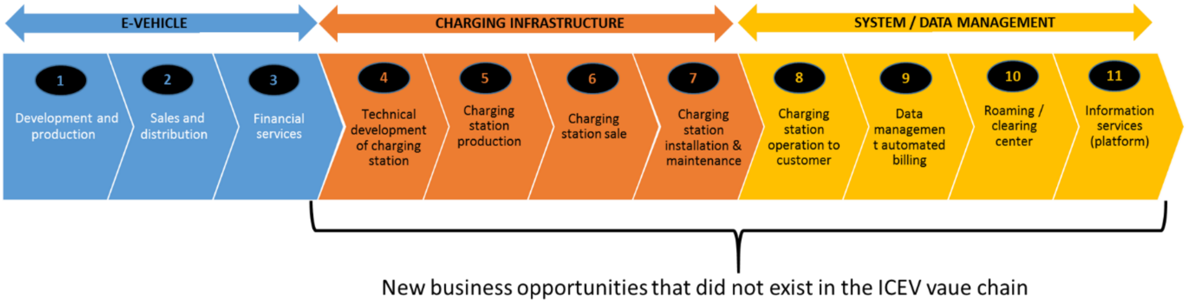

Figure 3-8. EV value chain

Source: ARF, 2014

But if it seems clear that different actors are interested in the new opportunities that e-mobility is opening up, at the same time: *"The roles of the actors on the market are not clearly defined yet. There is a lack of definition of the strategy vis-à-vis the relationship between the different actors (e.g. EV manufacturers have not yet decided if they are going to compete against utilities or if they will collaborate)"* LGI Consulting, 2015, page 12.

E-mobility is also strictly linked to the rise of "mobility as a service" (Maas), which is challenging the traditional model centred on vehicle ownership, shifting toward the objective of meeting the final consumer needs in the most efficient way thought the provision of a service (ARF, 2014; Goodall et al., 2017; Holmberg et al., 2016; Sarasini & Linder; 2018).

All in all a new value chain and new possible actors call for new business models: "*how a company creates, delivers and capture value*" - Chalmers, 2017, page 145 - across the value chain of a product or service. Different studies have started to focus their attention on the different roles and possible e-mobility business models, especially in the context of the charging infrastructure (ARF, 2014; Chalmers, 2017; ESG, 2017; Lo Schiavo et al. 2107; Rambow-Hoeschele et al., 2017; San Román et al., 2011; Serradilla et al., 2017). Figure 3-9 shows the

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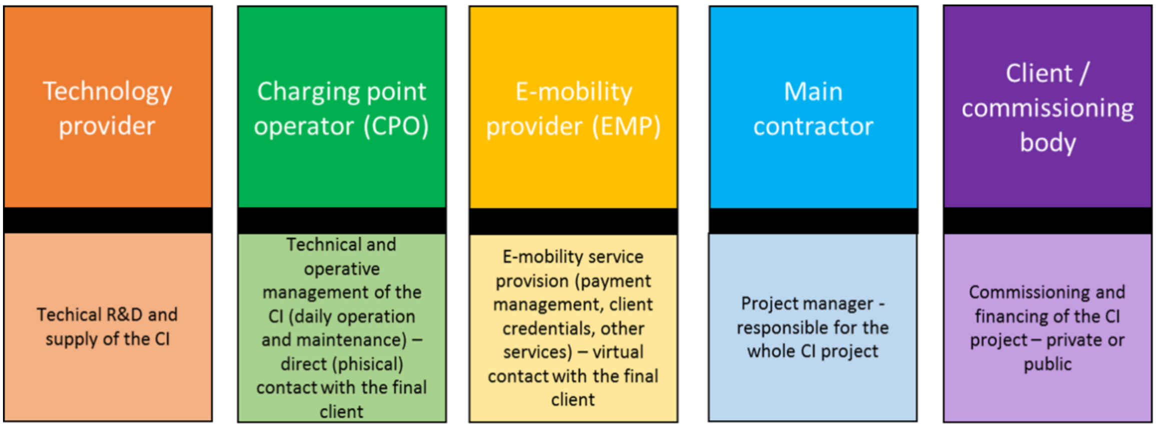
[45] From the incumbents of the traditional automotive value chain to a number of new entrants (charging station specialists, energy companies and utilities, municipalities…)

taxonomy of the charging infrastructure roles according to the Energy & Strategy Group[46] analysis. The same maker actor (energy company, OEM company and so on) can pursue a vertically integrated strategy, and get involved in more than one of the roles.



Technology provider	Charging point operator (CPO)	E-mobility provider (EMP)	Main contractor	Client / commissioning body
Techical R&D and supply of the CI	Technical and operative management of the CI (daily operation and maintenance) – direct (phisical) contact with the final client	E-mobility service provision (payment management, client credentials, other services) – virtual contact with the final client	Project manager - responsible for the whole CI project	Commissioning and financing of the CI project – private or public

Figure 3-9. The roles in a charging infrastructure (CI) project: the taxonomy

Source: ESG, 2017

3.2 Background theoretical framework and research approach

The main theoretical background that applies to the present research is the so called “energy transition”, intended as a long term structural change of the energy system toward a low carbon economy. It will not only require technological improvements, but also some combination of economic, political, institutional and socio-cultural changes (Berkhout et al., 2012).

Within the energy transition context electrification represents the focus area for this research. Electrification is seen as one of the main pillars of energy transition, as a key factor to foster economic growth, human development and environmental sustainability, and to mitigate climate change (IEA, 2017b; IEA, 2017c; IEA & IRENA, 2017; IRENA, 2018b; Sugiyama, 2012). Transport electrification in particular is seen as a key factor of the energy system transformation for decarbonisation. I will also support energy security thanks to the increased diversity of the transport fuel mix (with the variety of energy sources that can be used for electricity generation) and the resulting freeing-up of biomass and natural gas resources for other uses (McCollum et al., 2014)

The research design of this paper is based on a deductive approach, where starting from the selected literature review and analysis and with the precious inputs (data and information) coming from all the different stakeholders interviewed (from Volvo Group as well from many other organisations) the author was able to answer the research questions.

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[46] http://www.energystrategy.it/home.html

4 Results: analysis and discussion

In this chapter the main findings of the present research project on charging sites/microgrids are summed up, discussed and analysed.

In the first section the literature review results are discussed together with the insights gathered with the interviews conducted by the author (qualitative part of the study); the literature review and the interviews were indeed run by large extent in parallel over the first weeks of the thesis work, and they also influenced each other as the author progressively gained a deeper and more comprehensive view and knowledge about the topic.

In the second section the results of the quantitative analysis are discussed. Also for this part the information stemming from the interviews were relevant, but more for developing the methodology and to discuss the possible elements that could influence the final results of the calculations, rather than to comment the final quantitative results themselves.

4.1 Connecting the dots: insights from the literature and interviews

This work provides significant evidence that the impact of e-mobility on the main grid, and, more in general, on the power system, will depend on the level of penetration of EVs, and on the way the charging process is achieved, both in terms of power rate and of timeframes over the day.

Although the specific grid impacts are highly dependent on the local actual conditions and structure of the power system, with a "high" level of EVs penetration, expensive grid reinforcements and upgrades will probably be needed. As an example, in the Italian context, a significant rate of electrification, that would require to "take action", could be represented by an electrification rate of the transports of some 30%-40%; while a nation-wide 10% electrification rate, which is still very far from the actual numbers[47], should not entail substantial changes and investments for the national power system (I6).

This possibility also opens up the discussion about who should bear these costs.

- Should they be completely, or to a large extent, paid by the TSOs – DSOs, ending up in the regulatory asset base (RAB), and finally be socialised? This could be a reasonable option if considering that: all citizens would benefit from the expected widespread environmental advantages of e-mobility compared to ICEVs; the grid upgrades would enable the deployment of a public infrastructure that can be used by everyone; a well-established charging infrastructure that is spread all over the territory would support a further development of e-mobility, lowering the technology costs.
- Or should they be completely, or to a large extent, paid by the companies that are investing in e-mobility and in the charging infrastructure? This alternative can also make sense when it is considered that such companies are (or will be) making money out the services they provide to their customers.

In reality the relative investments could finally be evaluated and shared on a case by case, but some new/updated rules, that will take into account the peculiarities and advantages of e-mobility, and who is going to see most of the expected economic and socio/environmental benefits of electrification, will very likely be required.

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[47] According to the Ministry of Infrastructure and Transport in 2017 3,5% of the circulating cars were electric. (Electric) trains are excluded by the percentages mentioned in the text Source: http://www.mit.gov.it/node/8352

4.1.1 Microgrids? Yes, but...

Microgrids, distributed energy resources - DER (renewables in particular), stationary batteries and other storage systems can also constitute sound technical solutions to reduce, or at least delay, the need for grid investments; at the same time they can integrate an increasing share of EVs in the systems and effectively supply them electricity according to their needs. Many different interviewed stakeholders pointed out how those solutions could effectively support the charging needs of EVs (I2; I3; I4; I13; I15; I16). In particular: stationary batteries can be used to solve the possible rise of technical grid issues related to e-mobility development, and to avoid high grid reinforcement costs (I2); storage systems, eventually coupled with solar PV can be used for peak shaving, if and when a high peak demand is required in a charging site (I3; I4).

But today the main barrier for distributed stationary power solutions still remains the costs of the involved technologies. This holds true for complete microgrids as well as for single components of a microgrid, such as in particular the stationary batteries. Although the costs substantially dropped in the last few years, the expected further reductions for the next years and decades are a necessary step to have a more widespread deployment. The economics are highlighted as the main current issue for stationary power solutions by different interviewees (I2; I3; I4; I13; I15; I16), and in this sense a key element for a real business case evaluation would be to assess an alternative project/investment that could be made to pursue the same final objective. The costs of a stationary power solution for an e-mobility charging site should be compared to the grid reinforcement/upgrade costs (I10; I13), and the decision on how to configure and size should take into account the local electricity tariffs and fees structure, in particular the capacity fees (I3).

Comparing the investments in microgrids (or some simple DER) with the grid expansion costs can be particularly relevant for the local grid manager, the DSO, or also eventually the TSO, since they have all the information about the current use and saturation level of the substations and grid components (I6).

The electricity tariffs and fees are a crucial elements also when it comes to study and plan the use of the different components of a microgrid. They are essential inputs also to optimise the energy flows under the economic perspective, although while battery prices are high, as it is still the case, the optimization has relatively less impact on the business case (I6).

The technical and economic feasibility of microgrid solutions has been tested in many different context, as shown in the literature review, but also two interviewees reported the direct experience of two different kind of companies.

Göteborg Energi, the local owned by the City of Gothenburg (Sweden), who has an ongoing project to deploy a number of charging points all over the city, had some test project/plan with stationary batteries and solar PV (I10). Fortum, a Finnish electricity utility operating worldwide in 10 countries (mainly European Nordic countries, but also other relevant markets, such as India) had a small community (two residential buildings as main loads) microgrid pilot project in Finland (I15).

In both cases the economics were not favourable to the tested solutions, and, in the European Nordic countries context, where the grid is very reliable and the use of solar PV panels is limited by the irradiation conditions, the deployment of microgrids is much less reasonable (I10; I15). While, in a country like India, with limited grid reliability, a limited geographical spread of the central electricity grid, and good irradiation conditions all throughout the year, the business case is very different, and microgrids are good solutions (I15).

Based on the Nordics versus India comparison for a microgrid solution, the following questions should always be asked and answered: why a microgrid? Why do we want it? Which benefits do we expect from it? (I15). The reliability and independence and other possible befits that a microgrid can bring are services, and their value depends on local socio/economic context, or on the client needs, and the possible alternatives (I15).

Finally, if economics have a primary role, as it always is for business cases, they (can) depend on the (legislation and) regulation (I5). Regulation can affect, among other things, the way electricity tariffs are designed (I3), who is bearing which costs (I6), grid connection costs and fees (I3; I5), and who is allowed to do what (I7; I16). The regulatory frameworks for power, which has been basically the same for decades, will need to change and evolve to support the energy market of the future, and in particular to support microgrid installations (I7). For instance, in Sweden, where today there are essentially no problems with availability of energy (i.e. on balance, electricity is exported) but there are capacity issues (possible problems in coping with the peak demand, which could be exacerbated by e-mobility), a debate about moving to only capacity based electricity tariffs has been ongoing for a while. This could represent a barrier for e-mobility, but would support microgrids (I7).

Regulation is lagging behind, compared to technology (I4), and it will take time to set up the new regulatory context for the new power system (I2), but since it sets the rules of the game, it has a crucial role in real business cases.

4.1.2 Smart charging? Yes, but first let me just charge, please!

If microgrids can be deployed to support the deployment of e-mobility, also smart charging opportunities can have a role in this respect (I17).

But if demand side response (DSR) seems to represent a possible opportunity to improve the economics of charging sites already today, arriving at a situation where there is provision of vehicle-to-grid (V2G) services still is seen as something quite far in the future, at least at large scale (I4). Compared to providing demand response services, such as regulating the charging speed/power according to the need of the grid (and of the use of EVs), a bidirectional flow of energy is a much more complex operation. It can impact the duration and performances of batteries, requires the acceptance for the EVs owners to let the grid use their vehicles, entails contractual issues, and requires the aggregation of a (large) number of vehicles – possibly with different consumption profiles (I3; I4; I10). Providing services to the grid, and maybe also participating in ancillary services markets, also calls for updating the grid and market regulation in order to facilitate the participation of new actors (I3).

Also in the context of the so called “PussEl” project[48], some smart charging solutions were considered, but only focused on DSR, while V2G was not even tested (I14). The project had the objective to assess the expected energy and peak power need for city of Gothenburg (and some surrounding small towns) in case of a complete electrification of all transports. This gives some hints about how e-mobility stakeholders currently see the V2G possibilities as very complex to include in future scenarios, and not a high priority. Proving V2G services could eventually be unavoidable in the future, and create further stream of revenues for e-mobility, but today there are too many uncertainties regarding their potential and how to include them in current scenarios.

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[48] https://www.goteborgenergi.se/DxF-44408010/PussEl___Vad_behovs_for_att_elektrifiera_transportsystemet_i_Goteborg.pdf?TS=636661163438750312

All in all, the final main target of a charging station, a charging site, or a charging site configured as a microgrid, should not be forgotten; it is the charging process to allow the use of EVs according to the needs of their users, and not to provide extra services to the grid. Extra services can bring revenues, but they can also entail higher initial capital costs, and also increased operative costs, so they could be not economically justifiable (I3).

In general, DSR, as well as all smart charging types, including the V2G modes, should be contextualised in the need to change the way the power system is seen and planned in the future. With the expected increase in electrification, and the emergence of new electricity loads (EVs, heat pumps), it becomes less and less reasonable (or doable) to dimension the system to be able to satisfy the possible peak demand. Demand management is key to avoid the high investments needed to cover a peak lasting just few hours over a year (I17).

4.1.3 How to build up the business case?

Similarly to the microgrid, the feasibility assessment of an electric transport solution usually entails the comparison with an alternative, or a "baseline" such as a non-electric drivetrain based on ICE technology (I4).

In such evaluations, the total cost of ownership (TCO) is a crucial concept for EVs, and it entails a life cycle assessment, with assumptions on the use of the vehicles. These can also include the costs of the charging station/site, and/or the need to change the EV battery after a number of years (I2; I4). This in turn may require data/assumptions to be generated on the use and configuration of the charging site (e.g. Microgrid? Stationary batteries? DER? 100% grid connection? Grid reinforcement costs? Which charging points? Charging speed/power?) (I4).

For the charging stations/sites the utilization rate is one of the key elements of the business case. Today charging stations/sites do not have high revenues (or do not have revenues at all) mainly because of the low use rates and high grid connection costs (capacity fees and eventual grid related investments) (I7). Sharing the charging infrastructure between different vehicles and transport modes may be a way to reduce the costs (I4). Assessing the expected use rate of a charging site reconnects with the need to estimate its possible consumption patterns according to the use and journey of the vehicles, and the question of how to estimate them. In line with information provided by the literature review analysis, many of the interviewed stakeholders confirmed the rationality of starting from the use data of equivalent ICEVs to estimate the energy and, consequently, charging needs of EVs (I2; I3; I4; I13; I8; I16; I17; I18; I20; I21).

The first step should then be checking if electrification can be pursued keeping the same routes and habits of ICEVs. The, if the answer is positive, the second step should be verifying if keeping the same routes makes sense. Can the journey be adapted to minimize the EVs costs and maximize the revenues (such as having smaller/lighter batteries and bigger payloads)? Can they also be adapted to optimise the use and location of the charging sites? (I18). The general view is that vehicles use can be charged if can be demonstrated that it makes economic sense (I1; I18). Furthermore, municipalities and other public administrations might be interested in "setting (a) good example". Also private companies might be willing to switch to electric, even paying little extra costs, for reputational and marketing reasons (I18). Some large and reputable delivery companies such UPS, DHL - with money to invest – are already into electric projects, since they realised the potential of EVs for their business (I1).

One of the main issues and potential barriers, pointed out by different interviewees (I2; I3; I10), can be finding the proper location for a charging site in urban contexts, where there can be relevant space constraints. This is particularly so when big vehicles like trucks or buses are involved. Space issues could indeed limit the possibility of developing e-mobility in urban areas, where it could represent a major cost and physical barrier (I2), and setting up and signing contracts with the landowners (when needed) can also take time and resources (I10).

The business case evaluation can also change and be positively or negatively impacted by legislative and regulatory developments, such as the introduction of direct invectives, or the evolution of grid connection cost and electricity tariffs and fees. Thus far, no ad hoc regulation for large/high power charging sites (such as for trucks of buses), which might be connected in medium or even high voltage, have been implemented - at least in Italy, Spain or Sweden (I3; I4; I7). The Italian pilot project (Lo Schiavo et al., 2017) discussed in the literature reviews was only for public charging stations/sites with low voltage connections, and in the current regulatory context it would not be feasible to apply it also to medium and high voltage connections (I3).

All in all, this results in a situation where it is difficult to separate the vehicles from the charging in the business case, which makes the evaluation more complex. The charging infrastructure is a crucial aspect of e-mobility, and assessing its costs and benefits requires a lot of data and assumptions, which change according to the kind of vehicles involved and the way there are used-charged (I1). This is especially true for truck and buses, since for bigger and commercial/public vehicles it more difficult to rely on the already existing public charging infrastructure[49] for space and time/power reasons, and they have less flexibility in their use.

4.1.4 New business models!

Building up the business case for e-mobility solutions is then very complex, and it will also require new business models. Many interviewees agree on the fact that for e-mobility, compared to ICEVs, the hardware (the vehicles and their components), will no longer be the core part of the business model and value chain, and that e-mobility will increasingly be about providing a service rather than a product to the final customers (I2; I7; I9; I11; I10; I12; I13; I19; I20; I21).

Implementing a new, and potentially disruptive for the existing value chain, business model takes time, and together with the time needed to update the regulation this is one of the reasons why the e-mobility "revolution" will probably not happen in the short term (I2). What is already pretty clear today is that the electric power trains are much simpler that the combustion engines, and the large share of revenues that today comes from the aftermarket will shrink, while data, connectivity and digitalisation will become more relevant; but what is not clear is who will have which role, and which new agreements or partnerships will form (I9; I12; I13; I19; I21).

4.2 Quantitative analysis results: finally the LCOE

Figure 4-1 shows the LCOE calculation results for all the different cases and configurations assessed, together with the microgrid components sizing and grid power subscription values. Figure 4-2 reports the same results in a column chart format to allow a better comparison between the different cases and configurations. Figure 4-3 shows the percentage shares of the LCOE components in all the different cases and configurations, while Figure 4-4 reports the LCOE composition in absolute terms (the solar PV only are excluded for readability reasons).

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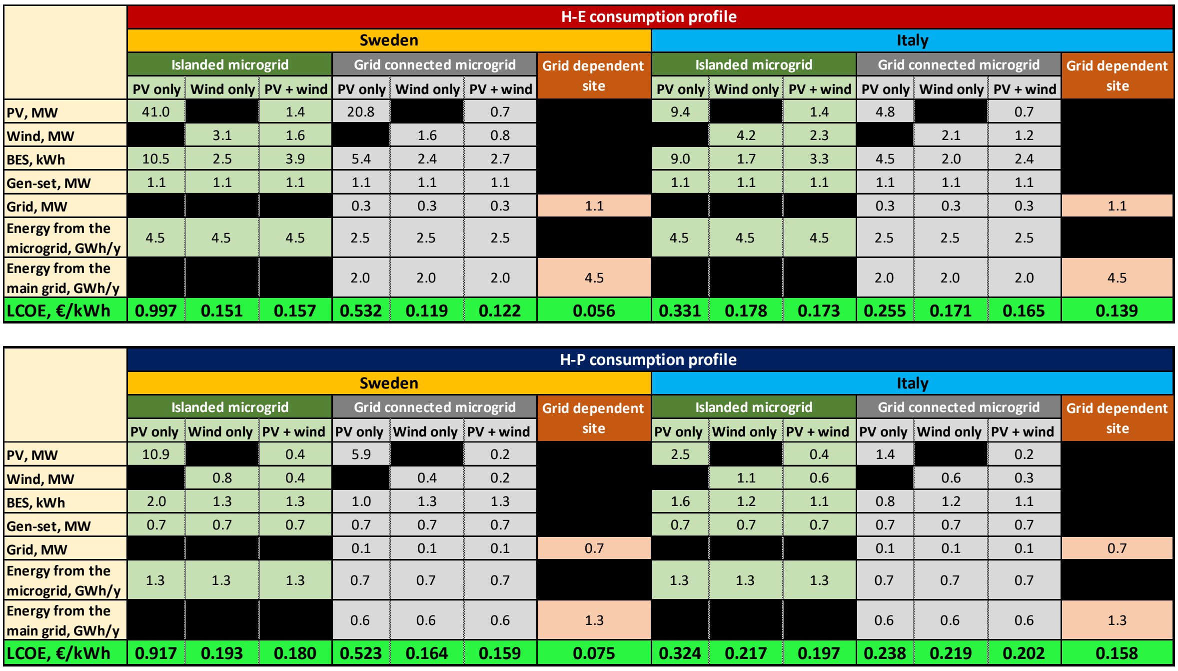
[49] Which in most existing cases has been developed only for cars or other light duty vehicles



	H-E consumption profile													
	Sweden							Italy						
	Islanded microgrid			Grid connected microgrid			Grid dependent site	Islanded microgrid			Grid connected microgrid			Grid dependent site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind		PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
PV, MW	41.0		1.4	20.8		0.7		9.4		1.4	4.8		0.7	
Wind, MW		3.1	1.6		1.6	0.8			4.2	2.3		2.1	1.2	
BES, kWh	10.5	2.5	3.9	5.4	2.4	2.7		9.0	1.7	3.3	4.5	2.0	2.4	
Gen-set, MW	1.1	1.1	1.1	1.1	1.1	1.1		1.1	1.1	1.1	1.1	1.1	1.1	
Grid, MW				0.3	0.3	0.3	1.1				0.3	0.3	0.3	1.1
Energy from the microgrid, GWh/y	4.5	4.5	4.5	2.5	2.5	2.5		4.5	4.5	4.5	2.5	2.5	2.5	
Energy from the main grid, GWh/y				2.0	2.0	2.0	4.5				2.0	2.0	2.0	4.5
LCOE, €/kWh	**0.997**	**0.151**	**0.157**	**0.532**	**0.119**	**0.122**	**0.056**	**0.331**	**0.178**	**0.173**	**0.255**	**0.171**	**0.165**	**0.139**

	H-P consumption profile													
	Sweden							Italy						
	Islanded microgrid			Grid connected microgrid			Grid dependent site	Islanded microgrid			Grid connected microgrid			Grid dependent site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind		PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
PV, MW	10.9		0.4	5.9		0.2		2.5		0.4	1.4		0.2	
Wind, MW		0.8	0.4		0.4	0.2			1.1	0.6		0.6	0.3	
BES, kWh	2.0	1.3	1.3	1.0	1.3	1.3		1.6	1.2	1.1	0.8	1.2	1.1	
Gen-set, MW	0.7	0.7	0.7	0.7	0.7	0.7		0.7	0.7	0.7	0.7	0.7	0.7	
Grid, MW				0.1	0.1	0.1	0.7				0.1	0.1	0.1	0.7
Energy from the microgrid, GWh/y	1.3	1.3	1.3	0.7	0.7	0.7		1.3	1.3	1.3	0.7	0.7	0.7	
Energy from the main grid, GWh/y				0.6	0.6	0.6	1.3				0.6	0.6	0.6	1.3
LCOE, €/kWh	**0.917**	**0.193**	**0.180**	**0.523**	**0.164**	**0.159**	**0.075**	**0.324**	**0.217**	**0.197**	**0.238**	**0.219**	**0.202**	**0.158**

Figure -1. Quantitative analysis results: the LCOE in the different cases and configurations

Source: Author´s own elaborations

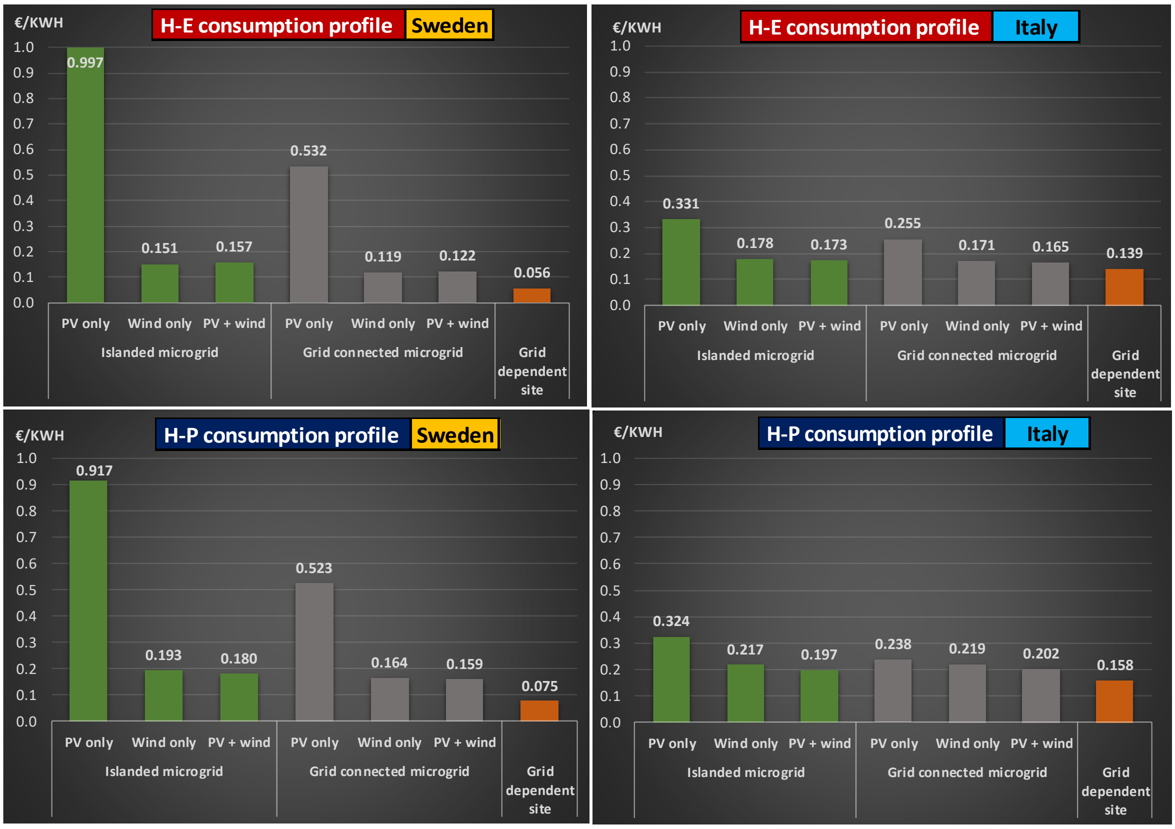


Figure 4-2. LCOE in the different cases and configurations: graphical comparison

Source: Author´s own elaborations

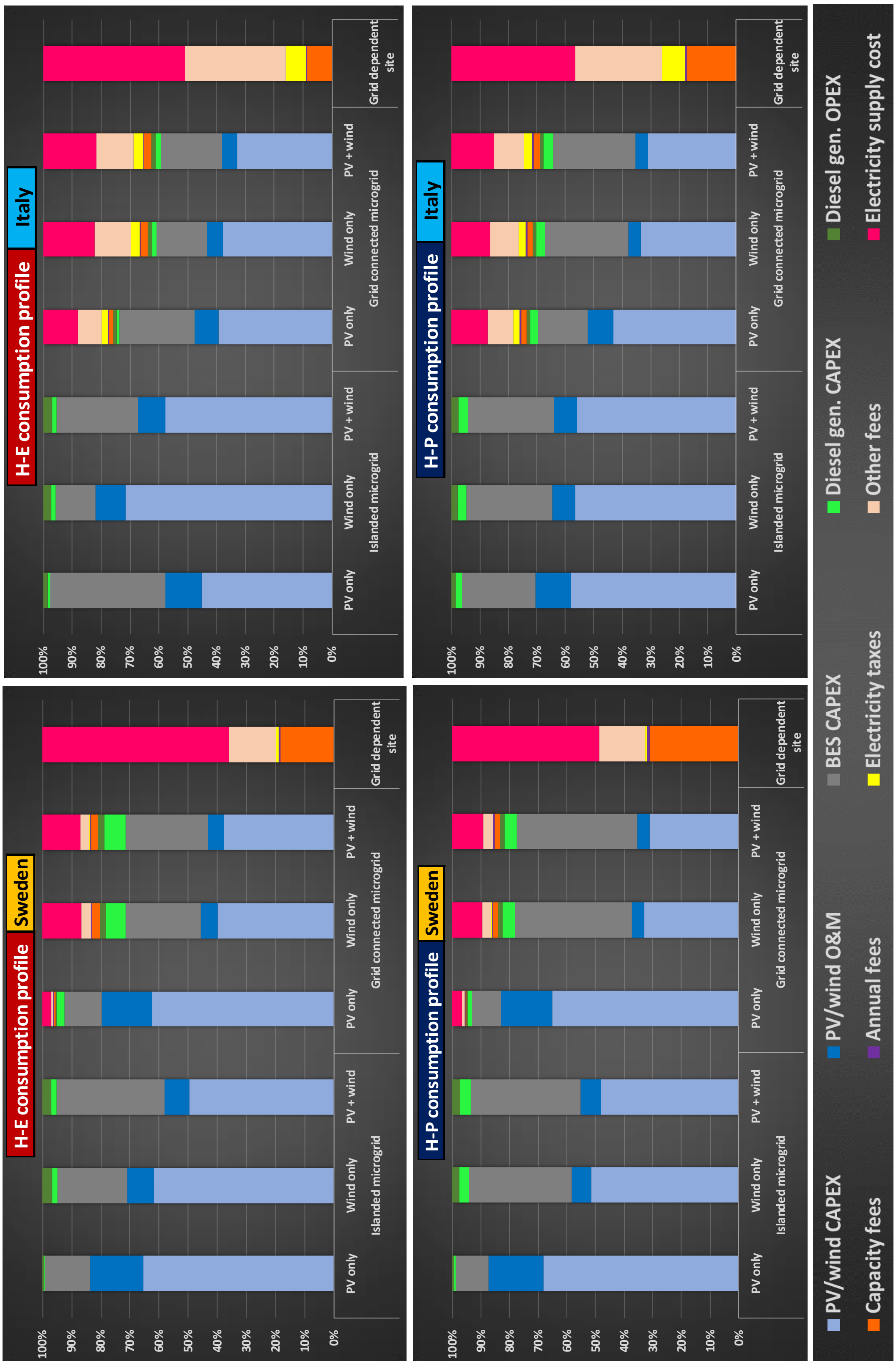


Figure 4-3. LCOE composition in the different cases, percentage shares

Source: Author´s own elaborations

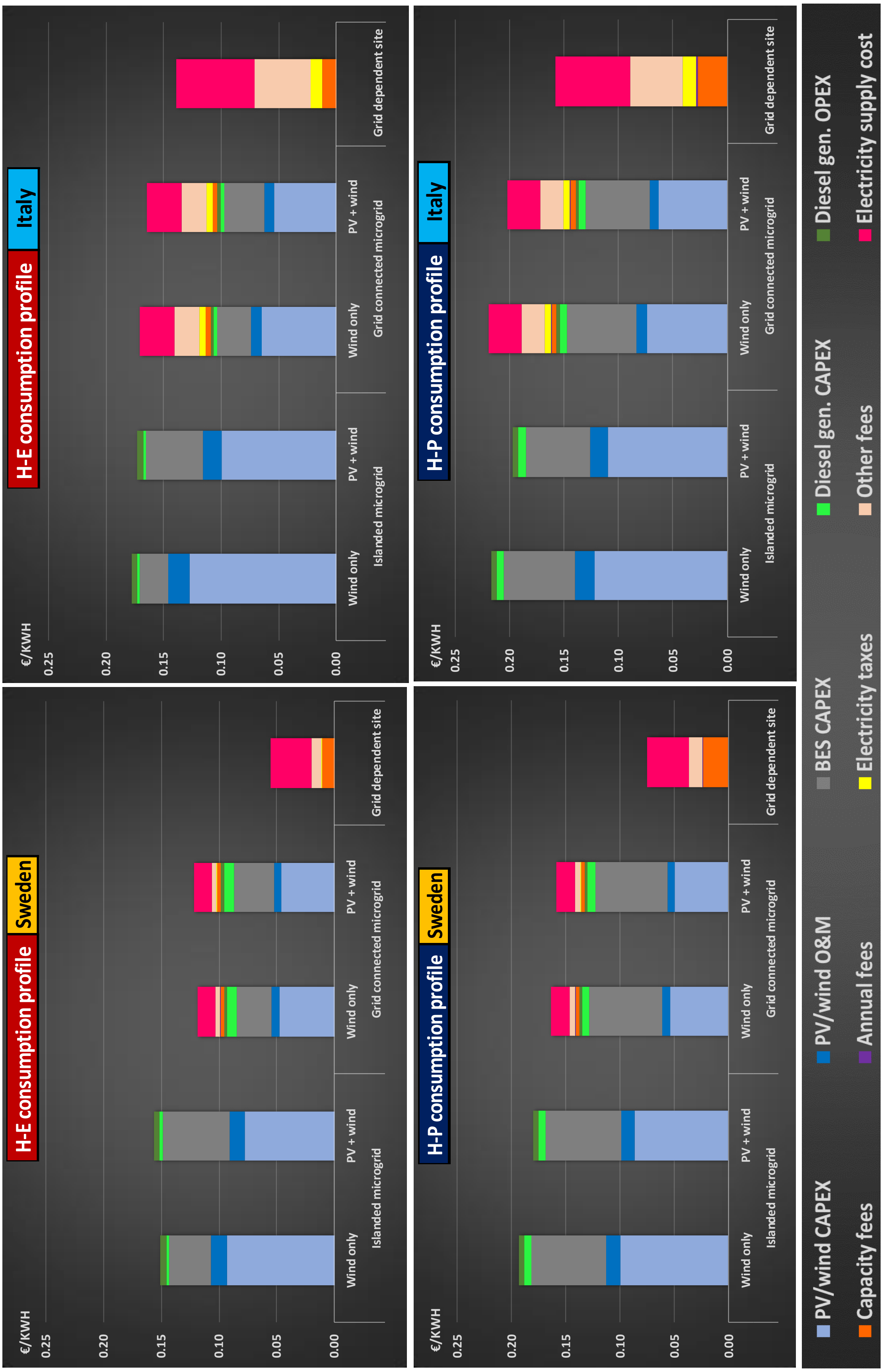


Figure 4-4. LCOE composition in the different cases, absolute terms (€/KWh) – only PV excluded

Source: Author´s own elaborations

The LOCE calculations were performed for two European countries, Sweden and Italy, which have different solar irradiation and wind speed conditions, and also different electricity tariffs. For both countries two different possible charging patterns were considered:

- A "High-Energy – H-E" profile – with high energy consumption spread on a number of hours all over the average weekday
- A "High-Power – H-P" profile – with a high peak load in the middle of the day, lasting for 3 hours, and then a pretty flat consumptions for the rest of the day.

An islanded microgrid, a grid connected microgrid and a totally grid dependent charging sites were assessed, and for each microgrid alternative three possible electricity generation configurations were assessed: solar PV only, wind only and a combination of solar PV and wind.

The LCOE results can be commented and analysed from different angles. The following commentary delivers evaluation from a number of these perspectives (deemed most relevant by the author).

4.2.1 Why a microgrid?

The first issue worthy of immediate recognition is the clear indication that all LCOE results for the assessed microgrid configurations (completely islanded as well as grid connected), are much higher than for the grid dependent cases.

The higher LCOE results for microgrid configurations are due to the high capital costs of the involved technologies. These remain dominant not only in the completely islanded solution but also in the grid connected one, and in relative share terms as well as in in absolute terms (Figure 4-3 and Figure 4-4).

This result is coherent with the literature review and interviews outcomes. Notwithstanding the marked decrease of the costs of technologies in the past years, in many cases they are still too high to be always economically feasible without incentives, especially in regions of the world with not very favourable solar irradiation conditions and a reliable/affordable power grid connection. And even where and when a solar PV solution for electricity generation is already a competitive electricity generation technology, the possible need to couple it with stationary batteries can significantly alter the business case.

Sweden versus Italy

The differences between the microgrid and the grid dependent cases are particularly evident, as probably expected, for configurations which rely only on solar PV for electricity generation. A solar PV only configuration for the Swedish case lead to LCOE results that are much more expensive than the other cases and configurations, while for Italy the result is more reasonable. On the other side, for the wind only configurations the higher average load factor of wind farms in Sweden compared to Italy leads to lower costs for the Scandinavian country.

As such, the geographical location, with potentially very different solar irradiation and wind conditions, of the charging site can have a significant impact on the business case economic feasibility assessment, and also on its technical and regulatory aspects. One MW of fixed ground mounted solar PV should need at least 1 hectare[50] of space, but it can be much more that this considering other accessories and requirements, such as 3 hectares (7.5 acres) (Ong et

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[50] http://www.suncyclopedia.com/en/area-required-for-solar-pv-power-plants/

al., 2013). This means the equivalent of a number of soccer fields[51] for all the solar PV only configurations, making hard if not impossible to have them in many areas of the world, such as in urban context, industrial clusters, zones devoted to agriculture or protected natural reserves. It also means that signing agreements just for using or buying the land may take extra time, and even if the land is already available, an opportunity cost evaluation would probably be needed. Similar issues can arise for wind, since a dedicated area is needed even for relatively small installations, and in any case, and both for solar PV and wind there can be national/local laws and regulations that restrict their deployment in certain areas.

The higher electricity tariffs in Italy result in higher LCOE for all grid connected configurations compared to Sweden. The higher tariffs in Italy are due to higher electricity supply costs, but also to other system fees (which include RES-E incentives, subsidies for specific social categories and other system costs), and much higher taxes that are imposed on the electricity consumptions. As a result in the Swedish context, the electricity supply and capacity fees have higher shares, since the rest of the components of the tariffs are much smaller in absolute terms (Figure 4-3, Figure 4-4).

For the Italian grid connected microgrid the costs related to the electricity tariffs (electricity supply costs, other fees and taxes in particular) have a much higher weight on the LCOE composition compared to the Swedish cases (both in relative and absolute terms). This entails a limited reduction of the LCOE for Italy in the intermediate case with the H-E consumption profile, while with the H-P consumption profile the final LCOE is even higher than in the islanded microgrid for the wind only and in the wind + PV configurations. This is due to the combination of the electricity tariffs burden together with a total battery energy capacity just slightly lower than the islanded microgrid ones (Figure 4-2, Figure 4-3, Figure 4-4). The microgrid components sizing is indeed based on a linear sequential methodology targeted at avoiding overgeneration, while no overarching cost optimization process has been included.

High-Energy (H-E) versus High-Power (H-P) load profiles

The H-P load profile LCOEs for the grid dependent sites are higher than the H-E ones because of the higher impact of the capacity fees on the total electricity consumptions (Figure 4-3). But dealing with an H-P profile, with a high peak demand lasting few hours and then relatively very low for the rest of the day, brings about higher costs also in the microgrid configurations (Figure 4-2).

This is due to the intrinsic difficulties involved in matching a high in power and short-lasting electricity demand with an (intermittent) energy generation sources that (on an average seasonal basis) have a very different profile. This discrepancy in the load and generation profiles occurs and constitute an issue (a cost) also for the H-E consumptions, but having a higher (and closer to the peak) average hourly consumption reduces the storage need and the associated CAPEX. As can be seen in Figure 4-3 and in Figure 4-4, the battery energy storage (BES) CAPEX tend to be higher with the H-P profiles compared to the H-E profiles in relative share terms as well as in in absolute terms.

The cost differences over 10 years of operation

Figure 4.5 summarises the cost gaps (M€) over 10 years of operation of the different cases and configurations, calculated comparing the LCOEs results. The highest differences are for the "PV only" configurations, and when comparing the islanded microgrid with the grid dependent case.

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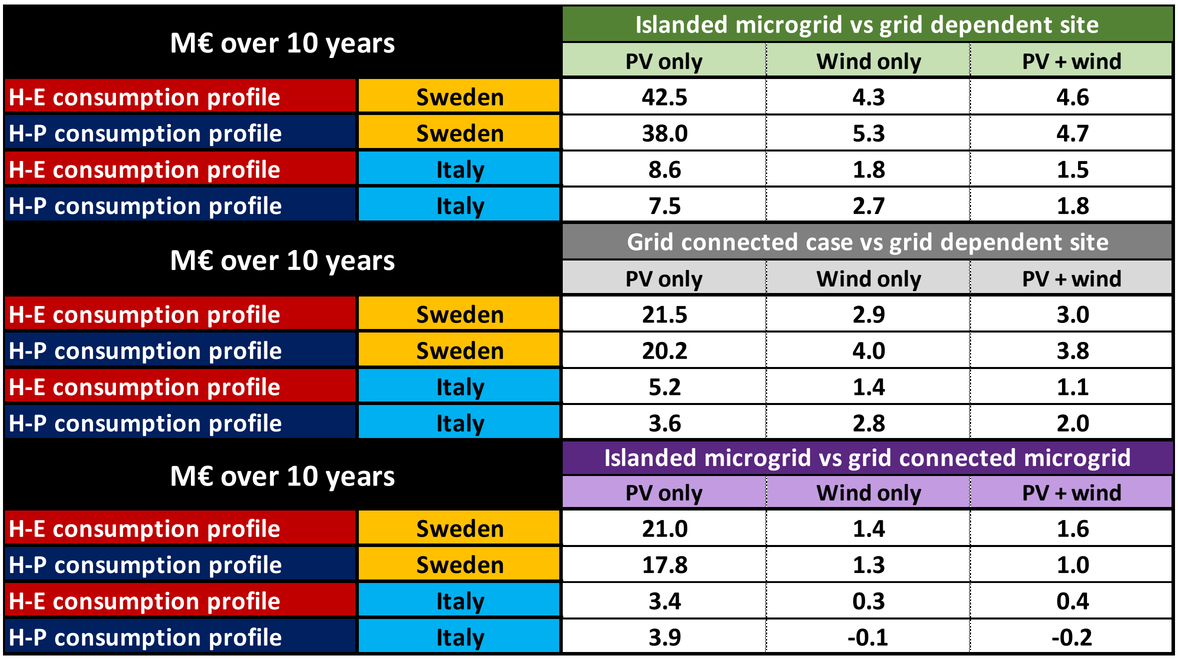
[51] A soccer field surface is roughly equal to 1 hectare.

As already discussed above when assessing the economic feasibility of a microgrid configuration the additional costs reported in the table should be compared to the estimated costs of upgrading the local electricity grid. These costs can substantially vary according to the specific local conditions, such as, in particular, level of use and saturation of the existing infrastructure, and they might pertain to the systems operator or the investor based on the specific cases and to the legislative and regulatory context.



M€ over 10 years		Islanded microgrid vs grid dependent site		
		PV only	Wind only	PV + wind
H-E consumption profile	Sweden	42.5	4.3	4.6
H-P consumption profile	Sweden	38.0	5.3	4.7
H-E consumption profile	Italy	8.6	1.8	1.5
H-P consumption profile	Italy	7.5	2.7	1.8
M€ over 10 years		Grid connected case vs grid dependent site		
		PV only	Wind only	PV + wind
H-E consumption profile	Sweden	21.5	2.9	3.0
H-P consumption profile	Sweden	20.2	4.0	3.8
H-E consumption profile	Italy	5.2	1.4	1.1
H-P consumption profile	Italy	3.6	2.8	2.0
M€ over 10 years		Islanded microgrid vs grid connected microgrid		
		PV only	Wind only	PV + wind
H-E consumption profile	Sweden	21.0	1.4	1.6
H-P consumption profile	Sweden	17.8	1.3	1.0
H-E consumption profile	Italy	3.4	0.3	0.4
H-P consumption profile	Italy	3.9	-0.1	-0.2

Figure 4-5. Additional costs of microgrid cases over the grid depended cases and of the islanded microgrid case over the grid connected one.

Source: Author´s own elaborations

According to Balducci et al (2006)[52], who analysed the costs of a number of projects[53] in the United States, new substations and new transformers can be the most costly items within projects[54]; the average cost per project was equal to 0.7 M$. According to the IEA, the investments costs for a distribution system as a percentage of total electricity delivery costs ranges between 27%-34% of the total cost (IEA-ETSAP, 2014). As already commented in the Literature Review and Analysis chapter, these costs can then substantially alter the business case assessment, and can then be a crucial reason for having a microgrid solution.

4.2.2 Discussion & reflection (methods applied)

As detailed in the Methodology chapter the "solar PV + wind" microgrid configurations were based on a linear sequential methodology targeted at avoiding overgeneration, and did not seek to minimize the costs of the systems. A cost minimization would require an overarching

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[52] The paper "classifies and analyses the capital and total costs for 172 electricity distribution system capacity enhancement projects undertaken during 1995-2002 or planned in the 2003-2011 time period by three electric power utilities in the Western United States" (Balducci et al., 2006, page 1). Although this source is quite dated, compared to other more recent sources it provides a very detailed and comprehensive assessment of possible grid update costs that still results worthwhile to mention.

[53] The type of projects where about eh following components/works: capacitors, load transfers, new feeders, new lines, new substations, new transformers, reconstructing, and substation capacity increase.

[54] $112/kVA and $87/kVA respectively in the paper, with a cost per project of 3.5 M$ and 1.4 M$ respectively, and in average increase in capacity per project of 36.8 MVA and 16.8 MVA respectively.

optimization process (model) targeted at having the lowest possible LCOE considering all the system constraints (the load and intermittent RES-E generation profiles).

Notwithstanding the possible limits of the adopted approach, especially for a real business case evaluation, the approach applied in the present research project has the benefit of providing a comparative analysis of a number of alternative cases and configurations and to show which can be the major and most impacting costs involved in each alternative. In particular, relative to other studies, the present research has the merit to compare the same kind of configurations in two load cases and two different countries for two different load profiles; as a result it shows how the local weather irradiation and wind speed conditions and different regulations (electricity tariffs structure) and alternative consumption patterns can impact the economic results.

Depending on the needs of the audience and on the available data the methodology applied here can be altered to improve the informative quality of the results. This analysis and its results can then be seen as a first useful result to explore this new business opportunity and also a first step of a wider research and assessment, headed to deal with the main costs centres and directly focused on minimizing the LCOE.

A further step in the analysis could be to assess, starting from the journey/consumption of the vehicles, if and how the load profiles could be modified with the final target to reduce costs – the LCOE – without modifying the vehicles' use (implementing smart charging). Following that, it could also be analysed if, when and how it could make economic sense to modify the vehicles' use to reduce the costs.

In Kharrich et al. (2017) a modelling approach has been adopted to optimise the sizing-cost of a small microgrid with solar PV, wind turbines and BES, getting to a final LCOE of 0.021 $/kWh (best case). This value is much lower than any result obtained in the present research, which on one side is due to optimization method used by the authors, which allowed them to pursue the best solution, but also to the very different conditions and constraints. First: the microgrid geographical location, the Mohammadia School of Engineers in Rabat (Morocco), where the irradiation condition are much more favourable to solar PV installations than in Sweden and even Italy. Second: the power load profile is stable all over the year (and equal to the lighting needs of the school) – laying between 40 and 50 kW.

In a recent study by Siemens for the Puerto Rico electricity system *"to achieve the vision of a more renewable, resilient and reliable Puerto Rico"* (Siemens, 2018, page 1) following the hurricanes Irma and Maria, economic evaluation of ten "mini-grids" covering most of the island has been conducted. The proposed mini-grids have a peak demand that ranges from 200 MW to more than 500 MW, and the supply-mix has been selected to minimize the electricity supply costs; the energy resources include: solar PV, wind turbines, storage, small CCGTs[55], other existing power plants assumed to remain in service. The final LCOE for the mini-grid in islanded operation mode (only during "catastrophic events") ranges from 0.152 $/kWh to almost 0.170 $/kWh, which are levels comparable to the results of the present research. The Siemens study also reports the results of two alternative integrated systems at island level: a base case, where the LCOE is equal to 0.089 $/kWh, and an "enhanced case", with higher renewables penetration, where the LCOE is equal to 0.095 $/kWh (Siemens, 2018).

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[55] Combined cycle gas turbines

The two cases compared in the present study show the possible cost differences of the same charging site configurations. On one side a country (Sweden) with challenging solar irradiation conditions, a very reliable and with very low CO2 emission electricity supply and low electricity prices. On the other side a country (Italy) with better irradiation conditions, a reliable but with higher CO2 emissions[56] electricity supply and higher electricity costs.

The presented comparison can then be generalised have a value global level. Microgrid solutions can be particularly reasonable in contexts where the local average weather conditions are favourable to RES-E, and where the electricity supply from the grid is less reliable and more expensive, or, by extension, where the electricity grid is not very much developed, and the grid upgrades/extension would be very expensive (such as in India or Africa).

The benefits of diversification & reliability

As can be clearly seen in Figure 4-2, and has partially already commented in the previous paragraphs, in some cases the "PV + wind" configurations resulted in LCOE values higher than the "wind only" configurations. Indeed, in one case also the intermediate case (grid connected microgrid) has higher LCOEs than the islanded microgrid. This is mainly due to the fact that the component sizing is not based on overarching cost optimization process – however, it also opens up the discussion about including other elements in the assessment, and in particular the value of sources diversification and of system/energy reliability.

Even in case of (slightly) higher LCOE values, a configuration that entails a more diversified energy supply mix (more energy generation sources and, eventually also the possibility to take energy from the main grid), might be more valuable because of the lower supply disruption risks. Assessing the value of supply diversification as well as of an enhanced reliability that a microgrid can provide compared to relying only on the main grid is very case specific, and there are significant differences according to the geographical location, the socio-economic differences and the purpose of the energy need.

The benefit of sources diversification can in the first instance seen just comparing and overlaying the solar PV and wind generation profiles, which have quite different average seasonal variabilities, but then the level of correlation should be analysed more in the detail according to the local solar irradiance and wind speed level (Bett & Thornton, 2016).

Electricity system reliability is not a major issue in in Europe today; as a result, industries and essential services usually have some relatively modest back-up emergency generators, and they can mainly depend on the grid. A much lower reliability characterises the electricity system in other countries, such as India or the South East Asian region, which means that, ceteris paribus, microgrid configurations can be more valuable in such regions (IEA, 2017b; IEA, 2017c; I15).

A forward looking perspective

A final remark should be devoted to comment the LCOE results of the present research with a forward looking, and possibly long term, perspective.

As described in the Methodology and Literature review and analysis chapters the costs of the technologies (solar PV panels, wind turbines, battery energy storage systems) have decreased markedly in the last few years, and they are also expected to further decrease in the next years,

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[56] See the European Environment Agency data. https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment

so that, ceteris paribus, microgrid configurations should become more and more economically feasible.

But… What about electricity prices?

"European wholesale electricity prices peaked in the third quarter of 2008 and, apart from a slight recovery in 2011, have been falling ever since. Prices have fallen by almost 70 % since 2008 and by 55 % since 2011 and in 2016 reached levels not experienced for 12 years (…). The pass-through of reduced coal and gas prices, together with other factors, have been key drivers of electricity prices (…) In several markets, the rise of low marginal cost solar and wind-powered electricity decreases wholesale prices. Econometric analysis suggests that every percentage point increase in renewable share reduces the wholesale electricity price by €0.4/MWh in the EU on average; lower demand linked to subdued economic growth, combined with capacity expansion, has led to overcapacity in several countries; and reduced demand for CO2 allowances and strong supply of international credits (CDM) has led to a large surplus in the ETS market, resulting in lower CO2 prices, which are passed through in wholesale prices" EC, 2016a, pages 4 and 5.

But in contrast to that the average EU electricity prices for industry reported yearly increases between 0.8% and 3.1% from 2008 to 2015, due to the network taxes and levies components. This trend leaded to an increased economic viabiliy for microgrids, although: *"large energy consumers, including more electricity-intensive industries, may produce their own power, have long-term contracts for energy supply or often pay lower network tariffs, taxes and levies which can result in prices 50 % lower than for other industrial consumers in the same country"* EC, 2016a, page 7.

The CO2 prices under the EU ETS system has rapidly increased in the last few months[57], and the projections are for substantial increases for the future (EC, 2016b; "EU carbon prices" 2018), and according to EC long term Reference scenario also the other components of the average electricity price could increase (EC, 2016b).

Do these expected trends will lead to an improved economic feasibility for microgrids? The final result will depend on the combination of many case specific and macro factors. But these final considerations highlight the potential relevance of including some forecasts/assumptions about the future evolution of some key external cost variables when exploring and then planning an investment in any kind of stationary power solution that can have a lifetime of decades.

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[57] https://sandbag.org.uk/carbon-price-viewer/

5 Conclusions

In the long term the European power sector is expected to face a radical transformation toward a (almost) complete decarbonisation. Electrification of energy demand is seen as one of the key elements for substantially decreasing the GHG emissions and other socio-environmental impacts of human activities.

E-mobility is one main side of the electrification process, where the other main side is the switch to the electricity vector for the heating & cooling energy needs. The electrification of transport is indeed considered by many researchers and stakeholders as a crucial way to reduce the emissions of the sector. And its success is highly dependent upon the battery technology and recharging infrastructure developments.

E-mobility differs in many ways from the traditional transports based on ICEVs technology, starting from a core aspect: the "fuel", and, with that, the way the "refuelling" happens and the fuel distribution infrastructure. The fuel that propels EVs, electricity, comes from a system that needs to be constantly monitored in order to be able to supply the required energy to all the loads. If the transport sector has/wants to be part of the power system, it has to learn how to play its rules (power regulation) and how to deal with its actors.

Currently many studies and scenarios clearly illustrate that if e-mobility is really going to catch on, it could not help to be an integral part and an enabler of the energy transition, allowing more RES-E integration in the systems and providing services to the power grid.

The present research project has been performed in order to support the exploration of the new business opportunities that electrification of the transport sector could open up for Volvo Penta, a Swedish private manufacturing company which is part of the Volvo Group. The specific focus of the present research project is on e-mobility charging sites configured as microgrids for commercial freight vehicles. Based on the results of the literature review and of the interviews a microgrid configuration can indeed be a good solution to provide electricity for a power intense charging site, and could also support the integration of e-mobility in the power system.

Exploring this new business opportunities for a company like Volvo Penta requires gathering and analysing a lot of data and information that are beyond the perimeter of its current activities. Beside that it also entails delving into the power system, with its regulations and market players. E-mobility clearly opens up the possibility to make business with the power sector and actors, and this possibilities will happen via the charging sites interaction with the power system.

Three different but interrelated aspects of e-mobility charging sites were analysed and assessed: impacts and implications for the power system; potential consumption patterns; technical, economic, regulatory feasibility.

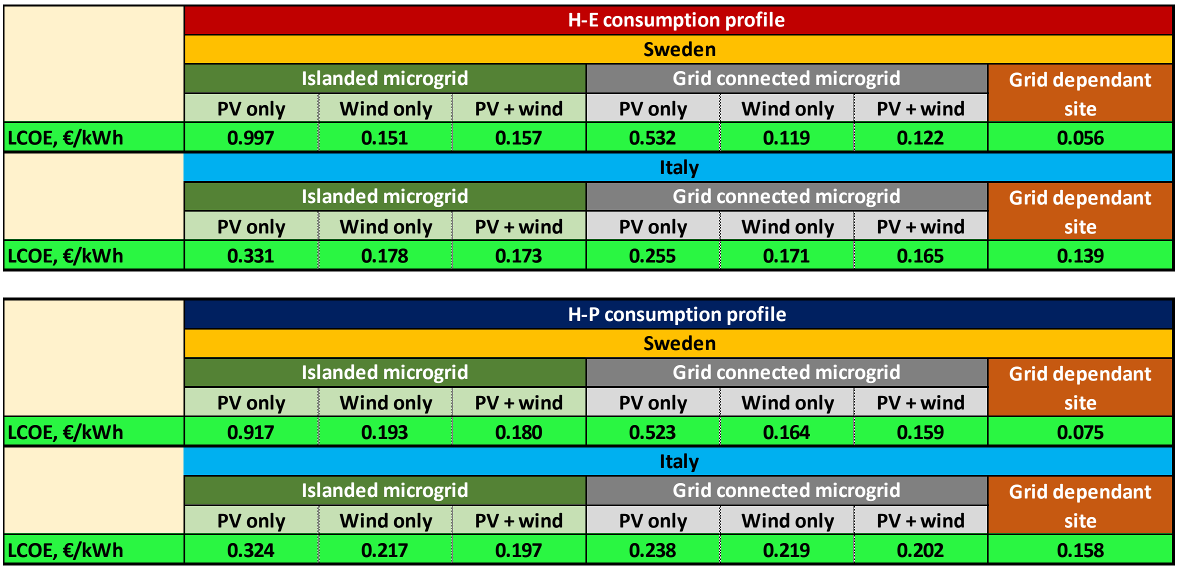
The impacts and implications of the charging sites for the power system will probably become visible and will need to be directly addressed only when e-mobility will reach a high level of penetration (in terms of share on EVs on the total vehicles). But the fact that EVs have to interact with the power system can't be denied even today, and, in any case, since industrial decision take years before eventually happening and become operative, a long term view is needed.

Evidence gathered strongly suggests that regulation can be one of the main possible elements that in the mid-long term can hinder, or at least slow down, the development of e-mobility charging sties and microgrids. Regulation can affect, among other things, the way electricity tariffs are designed, who has to bear the eventual grid upgrade costs, grid connection costs and fees, and who is allowed to do what. But if regulation could have an impact in the mid-long term, today the main feasibility problems are still related to the economics, and in particular the costs of the involved technological solutions.

From the discussions with relevant actors the author found evidence that e-mobility also calls for new business models, where traditional market players from the transport and energy/power sectors together with new entrants will have new roles in the value chain. With the rising of "mobility as a service" concept, (Maas), which is challenging the traditional model centred on vehicle ownership, automakers will probably need to expand/change their business and find their collocation over the new EV value chain, where the competition with new entrants can be very intense.

Assessing potential consumption patterns represent a crucial aspect to configure and optimise a microgrid solution, so that is also one of the key elements needed to assess its technical, economic and regulatory feasibility. Following that, a quantitative comparative analysis of some alternative possible cases and configurations for heavy-duty truck charging sites allowed to show the cost composition and differences based on LCOE calculations.

Two different possible charging patterns were considered, a "High-Energy" (H-E)[58] and a "High-Power" (H-P)[59], for two European countries, Sweden and Italy, which have different solar irradiation and wind speed conditions, and also electricity tariffs. An islanded microgrid, a grid connected microgrid and a totally grid dependent charging site were considered, and for each microgrid alternative three possible electricity generation configurations were assessed: solar PV only, wind only and a combination of solar PV and wind (Figure 5-1).



	H-E consumption profile						
	Sweden						
	Islanded microgrid			Grid connected microgrid			Grid dependant site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
LCOE, €/kWh	0.997	0.151	0.157	0.532	0.119	0.122	0.056
	Italy						
	Islanded microgrid			Grid connected microgrid			Grid dependant site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
LCOE, €/kWh	0.331	0.178	0.173	0.255	0.171	0.165	0.139

	H-P consumption profile						
	Sweden						
	Islanded microgrid			Grid connected microgrid			Grid dependant site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
LCOE, €/kWh	0.917	0.193	0.180	0.523	0.164	0.159	0.075
	Italy						
	Islanded microgrid			Grid connected microgrid			Grid dependant site
	PV only	Wind only	PV + wind	PV only	Wind only	PV + wind	
LCOE, €/kWh	0.324	0.217	0.197	0.238	0.219	0.202	0.158

Figure 5-1. Quantitative comparative analysis, the LCOEs in the different cases and configurations

Source: Author´s own elaborations

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[58] With high energy consumption spread on a number of hours all over the average weekday

[59] With a high peak load in the middle of the day, lasting for 3 hours, and then a pretty flat consumptions for the rest of the day

Coherently with the literature review and interviews outcomes, the LCOE results show that generation of electricity in a microgrid configuration in Sweden and Italy is more expensive than taking it from the main grid. Completely islanded solutions can be particularly tricky to manage due to the difficulty to match the load profiles with solar PV and wind (average) generation profiles. Stationary batteries then have a crucial role and are a relevant cost component, and having some degree of grid connection can help to lower costs. Only solar PV configurations are probably not realistically achievable, especially in Sweden, and, finally, H-P load profiles usually entail higher both microgrid and grid connection costs.

The worst results are indeed for the solar PV only configurations in Sweden, where the LCOE is on average more than 10 times higher than the grid dependant cases. But the PV only configurations are the ones with higher LCOEs also in the Italian context: 2 times the LCOE of the grid dependant case on average.

Without considering the PV only configurations the average differences decrease considerably:

- For Sweden on average the microgrid configurations LCOE are 2.4 times higher than grid dependent cases.
- For Italy on average the microgrid configurations LCOE are 1.3 times higher than the grid depended cases.

This differences between the two countries are mainly due to the higher electricity tariffs in Italy compared to Sweden, which results in higher LCOEs for all grid connected configurations, and in particular for the completely grid dependent cases.

Comparing the results for the two selected consumption profiles, the LCOEs for the "H-P" profile for the grid dependent sites are higher than the "H-E" ones because of the higher impact of the capacity fees on the total electricity consumptions (+35% in Sweden and +13% in Italy on the LCOE). But dealing with an H-P profile, with a high peak demand lasting few hours and then relatively very low for the rest of the day, brings about higher costs also in the microgrid configurations compared to an H-E profile (+17% in Sweden and +13% in Italy on the LCOE on average).

The LCOE results imply that microgrids are relatively more economically feasible solutions where the solar irradiation and/or the wind speed local conditions are more favourable, and also where the final costs of electricity from the main grid is higher and the structure of the electricity tariffs design less favourable to high power load. And as other studies show, microgrids are already cost-effective in places where the main grid is less reliable and less widespread than in Europe, and where the climate is favourable to renewables generation, such as in India or the South East Asian region.

Different elements can radically change this results. A major disruptive cost element could come from possible needed grid upgrades that could make microgrids more viable. Thinking about possible future scenarios, the costs of the main microgrid components is expected to keep on decreasing in the next years, while the electricity tariff could increase, with the final result that microgrid configuration could become more viable.

And if the economics are probably not (yet) favourable to microgrids, but they could be in the near future, and also if technology is not seen as a major hurdle, power regulation can represent a more delicate issue for e-mobility stakeholders. Upgrading the regulation to support the energy transitions and effectively integrate e-mobility in the power system will take time and require a completely rewriting of rules which have been basically the same for decades.

The present research project adds a comprehensive view to the academic body of knowledge in the e-mobility charging site/microgrid field, contextualizing transport electrification in the broader energy transition topic and highlighting how complex the relation between e-mobility and the power sector can be. The comparative analysis also provided useful insights, showing which are the main costs are and how things can significantly change according to aspects like the geographical location and the load profile.

Possible investors and researches should bear in mind those aspects when delving into e-mobility, since, differently from transport based on ICE technologies, the refuelling/charging is going to be a crucial element of e-mobility business models and value chains.

Further research should be conducted in particular regarding the feasibility aspects. Studies can be focused on how the regulation could develop to support the energy transition and e-mobility. Then scenarios about the e-mobility penetration level that would cause issues and costs for the power system can be elaborated.

Assumptions and analyses about the possible business models and roles of different actors can be conducted. The LCOE comparison can be refined including more data (costs and eventually revenues, like incentives) and more detailed data (more specific solar and wind profiles) in the calculations, and also cost optimization techniques/model can be used to size the different components. A possible follow-up to the quantitative analysis could be to assess, starting from the journey/consumptions of the vehicles, if and how the load profiles could be modified with the final target to reduce costs – the LCOE – without modifying the vehicles' use (implementing smart charging). Following that, it could also be analysed if, when and how it could make economic sense to modify the vehicle's' use to reduce the costs.

In the future specific business cases, with all their relative specifications and data, will need to be assessed by Volvo Penta in order to get more exact results and insights.

Bibliography

ABB powers e-mobility with launch of first 350 kW high power car charger (2018, April 24): Retrieved from: https://new.abb.com/news/detail/4439/abb-powers-e-mobility-with-launch-of-first-350-kw-high-power-car-charger

Abdalrahman, A., & Zhuang, W. (2017). A Survey on PEV Charging Infrastructure: Impact Assessment and Planning. Energies, 10(10), 1650. https://doi.org/10.3390/en10101650

Ali, A., Li, W., Hussain, R., He, X., Williams, B., & Memon, A. (2017). Overview of Current Microgrid Policies, Incentives and Barriers in the European Union, United States and China. Sustainability, 9(7), 1146. https://doi.org/10.3390/su9071146

ARERA (2013). Testo Integrato dei Sistemi Semplici di Produzione e Consumo – TISSPC. Retrieved from: https://www.arera.it/allegati/docs/13/578-13all_ti.pdf

ARERA (2017). Segnalazione al Governo e al Parlamento in merito all'articolo 6, comma 9, del disegno di legge di conversione in legge del decreto legge 30 dicembre 2016, n. 244, recante "Proroga e definizione di termini" (AS 2630), sugli oneri generali di sistema elettrico per i clienti finali non domestici. Segnalazione 24 gennaio 2017 20/2017/I/eel. Retrieved from: https://www.arera.it/it/docs/17/020-17.htm

ARERA (2018). SCHEDA TECNICA Prezzi dei servizi di ricarica per veicoli elettrici e sistema tariffario dell'energia elettrica. Luglio 2018: Retrieved from: https://www.arera.it/allegati/elettricita/schede/TariffePrezziRicariche_st.pdf

ARERA (n.d.). Definizioni rilevanti in relazione alle configurazioni private ammissibili, con particolare riferimento ai Sistemi Semplici di Produzione e Consumo. Retreived from: https://www.arera.it/allegati/elettricita/definizioni_SSPC.pdf

ARF (2014). Evolution. Electric vehicles in Europe: gearing up for a new phase? Amsterdam Roundtable Foundation and McKinsey & Company The Netherlands. April 2014. Retrieved from: https://www.mckinsey.com/featured-insights/europe/electric-vehicles-in-europe-gearing-up-for-a-new-phase

Attaianese, C., Tomasso, G., Monaco, M. D., D'Arpino, M., & Abronzini, U. (2014). Validazione di un convertitore modulare per infrastrutture di ricarica multi-sorgente per l'ottimizzazione dei flussi di potenza nelle micro-grid. Ricerca di Sistema Elettrico, Report RdS/PAR2014/104. Retrieved from: http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/elettromobilita/2014/rds-par2014-104.pdf

Balducci, P. J., Schienbein, L. A., Nguyen, T. B., Brown, D. R., & Fathelrahman, E. M. (2006). An Examination of the Costs and Critical Characteristics of Electric Utility Distribution System Capacity Enhancement Projects. 2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES. :78-86 2006. DOI: 10.1109/TDC.2006.1668461.

Berkhout, F., Marcotullio, P., & Hanaoka, T. (2012). Understanding energy transitions. Sustainability Science, 7(2), 109–111. https://doi.org/10.1007/s11625-012-0173-5

Bertani D. (2016). Grid defection Utopia o scenario plausibile?. Ricerca di Sistema, il contributo di RSE alla Strategia Energetica Europea. Milano, 29 Febbraio 2016 Retrieved from: http://www.sistemaelettrico.it/documenti/pubblicazione/317443

Bett, P. E., & Thornton, H. E. (2016). The climatological relationships between wind and solar energy supply in Britain. Renewable Energy, 87, 96–110. https://doi.org/10.1016/j.renene.2015.10.006

BMW Group, Daimler AG, Ford Motor Company and Volkswagen Group with Audi & Porsche Plan a Joint Venture for Ultra-Fast, High-Power Charging Along Major Highways in Europe (2016, November 29). Retrieved from: https://www.press.bmwgroup.com/global/article/detail/T0266311EN/bmw-group-daimler-ag-ford-motor-company-and-volkswagen-group-with-audi-porsche-plan-a-joint-venture-for-ultra-fast-high-power-charging-along-major-highways-in-europe?language=en

Bossart, S. (2015). Plug-In Electric Vehicle - Grid Integration. National Energy technology Laboratory. Southeast Distribution Apparatus School, September 21-24, 2015, Auburn, AL. Retrieved from: https://www.netl.doe.gov/File%20Library/Research/Energy%20Efficiency/smart%20grid/presentations/Electric-Vehicle-Grid-Integration-092115-short.pdf

Brenna, M., Foiadelli, F., Longo, M., & Zaninelli, D. (2017). Ancillary services provided by BESS in a scenario characterized by an increasing penetration of unpredictable renewables (pp. 1–6). IEEE. https://doi.org/10.1109/ISGTEurope.2017.8260215

Bunda, Ş. (2016). SPECIFIC ISSUES OF DISTRIBUTED GENERATION IN POWER SYSTEMS. Journal of Sustainable Energy, 7(2), 58–61.

Burges, K., & Döring, M. (2017). The Vision of E-Mobility in the Perspective of the Existing Power Infrastructure, successfully managing conflicting expectations. 1st E-Mobility Power System Integration Symposium, Berlin, Germany, 23 October 2017. Retrieved from: http://mobilityintegrationsymposium.org/wp-content/uploads/sites/7/2017/11/3A_5_EMob17_284_paper_Burges_Karsten.pdf

Burnham, A., Dufek, E. J., Stephens, T., Francfort, J., Michelbacher, C., Carlson, R. B., Tanim, T. R. (2017). Enabling fast charging – Infrastructure and economic considerations. Journal of Power Sources, 367, 237–249. https://doi.org/10.1016/j.jpowsour.2017.06.079

Calstart (2012). Best Fleet uses, key challenges and the early business case for e-rucks: finding and recommendations of the e-trucks task force. Calstart, 2012. Retrieved from http://www.calstart.org/Libraries/E-Truck_Task_Force_Documents/Best_Fleet_Uses_Key_Challenges_and_the_Early_Business_Case_for_E-Trucks_Findings_and_Recommendations_of_the_E-Truck_Task_Force.sflb.ashx

Calstart (2015). Electric Truck & Bus Grid Integration, Opportunities, Challenges & Recommendations. Calstart, Inc. September 2015. Retrieved from: http://www.calstart.org/Libraries/Publications/Electric_Truck_Bus_Grid_Integration_Opportunities_Challenges_Recommendations.sflb.ashx

Cebulla, F., Haas, J., Eichman, J., Nowak, W., & Mancarella, P. (2018). How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany. Journal of Cleaner Production, 181, 449–459. https://doi.org/10.1016/j.jclepro.2018.01.144

Chalmers (2017). Systems Perspectives on Electromobility. Chalmers University of Technology. ISBN 978-91-88041-07-4. Retreived from: https://www.chalmers.se/en/areas-of-advance/energy/publications-media/systems-perspectives/Documents/Download%20Systems%20Perspectives%20on%20Electromobility.pdf

CIGRÉ (2015). Microgrids 1 Engineering, Economics, & Experience. Microgrid Evolution Roadmap. CIGRÉ Working Group C6.22. October 2015.

CleanTechnica (2017). Electric Vehicle Charging Infrastructure: Guidelines for Cities. December 2017, Warsaw. Retrieved from: https://cleantechnica.com/files/2018/04/EV-Charging-Infrastructure-Guidelines-for-Cities.pdf

Cohn L. (2018). Should All Utility Customers Pay for EV Infrastructure and Microgrids? June 22, 2018. Retrieved from: https://microgridknowledge.com/ev-infrastructure-rate-based-microgrids/

Coignard, J., Saxena, S., Greenblatt, J., & Wang, D. (2018). Clean vehicles as an enabler for a clean electricity grid. Environmental Research Letters, 13(5), 054031. https://doi.org/10.1088/1748-9326/aabe97

Corchero, C., Gonzalez-Villafranca, S., & Sanmarti, M. (2014). European electric vehicle fleet: driving and charging data analysis. In 2014 IEEE International Electric Vehicle Conference (IEVC) (pp. 1–6). Florence, Italy: IEEE. https://doi.org/10.1109/IEVC.2014.7056144

Daimler Trucks launches E-FUSO and all-electric heavy-duty truck Vision One (2017, October 25). Retrieved from: http://media.daimler.com/marsMediaSite/en/instance/ko/Daimler-Trucks-launches-E-FUSO-and-all-electric-heavy-duty-truck-Vision-One.xhtml?oid=30010405

Decreto Legge 244/2016. Testo Coordinato del Decreto-Legge 30 dicembre 2016, n. 244 Testo del decreto-legge 30 dicembre 2016, n. 244 (in Gazzetta Ufficiale - Serie generale - n. 304 del 30 dicembre 2016), coordinato con la legge di conversione 27 febbraio 2017, n. 19 (in questo stesso S.O. alla pag. 1), recante: «Proroga e definizione di termini.». GU Serie Generale n.49 del 28-02-2017 - Suppl. Ordinario n. 14. Retrieved from: http://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2017-02-28&atto.codiceRedazionale=17A01678&elenco30giorni=false

Decreto-Legge 91/2014. Decreto-Legge 24 giugno 2014, n. 91 Disposizioni urgenti per il settore agricolo, la tutela ambientale e l'efficientamento energetico dell'edilizia scolastica e universitaria, il rilancio e lo sviluppo delle imprese, il contenimento dei costi gravanti sulle tariffe elettriche, nonche' per la definizione immediata di adempimenti derivanti dalla normativa europea. GU Serie Generale n.144 del 24-06-2014. Retrieved from: http://www.gazzettaufficiale.it/eli/id/2014/06/24/14G00105/sg

Deloitte (2017). Powering the future of mobility. How the electric power sector can prepare for its critical role in the new transportation ecosystem. A report by the Deloitte Center for Energy Solutions. Deloitte Insights. 2017. Retrieved from: https://www2.deloitte.com/insights/us/en/focus/future-of-mobility/power-utilities-future-of-electric-vehicles.html

Divya, K. C., & Østergaard, J. (2009). Battery energy storage technology for power systems—An overview. Electric Power Systems Research, 79(4), 511–520. https://doi.org/10.1016/j.epsr.2008.09.017

E3MLab (2016). Primes Model Version 6, 2016-2017, Detailed model description. E3MLab, Retrieved from: http://www.e3mlab.eu/e3mlab/index.php?option=com_content&view=category&id=35%3Aprimes&Itemid=80&layout=default&lang=en

EC (2008). Commission of the European Communities, 20 20 by 2020 Europe's climate change opportunity. Brussels, 23.1.2008 COM(2008) 30 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008DC0030&from=EN

EC (2009). DIRECTIVE 2009/72/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0072&from=it

EC (2011a). European Commission, A Roadmap for moving to a competitive low carbon economy in 2050. Brussels, 8.3.2011 COM(2011) 112 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0112&from=EN

EC (2011b). European Commission, Energy Roadmap 2050, Brussels, 15.12.2011, COM(2011) 885 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0885&from=EN

EC (2011c). European Commission, Impact Assessment, Energy Roadmap 2050. Brussels, 15.12.2011 SEC(2011) 1565 final. https://ec.europa.eu/energy/sites/ener/files/documents/roadmap2050_ia_20120430_en_0.pdf

EC (2014a). A policy framework for climate and energy in the period from 2020 to 2030. European Commission, Brussels, 22.1.2014 COM(2014) 15 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN

EC (2014b). Commission Staff Working Document, Impact Assessment accompanying the document 'A policy framework for climate and energy in the period from 2020 up to 2030. European Commission. Brussels, 22.1.2014, SWD(2014) 15 final. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014SC0015&from=EN

EC (2014c). Guidelines on State aid for environmental protection and energy 2014-2020. European Commission. 2014/C 200/01. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014XC0628(01)

EC (2014d). DIRECTIVE 2014/94/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the deployment of alternative fuels infrastructure. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=EN

EC (2016a). Energy prices and costs in Europe. European Commission, Brussels, 30.11.2016 COM(2016) 769 final. Retrieved from: https://ec.europa.eu/energy/sites/ener/files/documents/com_2016_769.en_.pdf

EC (2016b). EU Reference Scenario 2016, Energy, transport and GHG emissions Trends to 2050. European Commission. Retrieved from: https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

EC (n.d.). Weekly Oil Bulletin. https://ec.europa.eu/energy/en/data-analysis/weekly-oil-bulletin

ECB (n.d.). ECB euro reference exchange rate: US dollar (USD). Retrieved from: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

EDSO (2012). Position paper on Electric Vehicles Charging Infrastructure. European Distribution System Operators for Smart Grids. Apr 10, 2012. Retrieved from: https://www.edsoforsmartgrids.eu/10-04-2012-edsos-position-on-electric-vehicles-charging-infrastructure/

EEA (2018). Small cut in EU's total greenhouse gas emissions in 2016 but transport emissions keep increasing. News, Published 31 May 2018. Retrieved from: https://www.eea.europa.eu/highlights/small-cut-in-eus-total

Eid, C., Koliou, E., Valles, M., Reneses, J., & Hakvoort, R. (2016). Time-based pricing and electricity demand response: Existing barriers and next steps. Utilities Policy, 40, 15–25. https://doi.org/10.1016/j.jup.2016.04.001

Eid, C., Reneses Guillén, J., Frías Marín, P., & Hakvoort, R. (2014). The economic effect of electricity net-metering with solar PV: Consequences for network cost recovery, cross subsidies and policy objectives. Energy Policy, 75, 244–254. https://doi.org/10.1016/j.enpol.2014.09.011

ENERGEIA (2016). Roles and Incentives for Microgrids and Stand Alone Power Systems. Prepared by ENERGEIA for the Energy Networks Association. October 2016. Retrieved from: https://www.energynetworks.com.au/sites/default/files/roles_and_incentives_for_microgrids_and_stand_alone_power_systems_in_australia_to_2050.pdf

Erdogdu, E. (2011). The impact of power market reforms on electricity price-cost margins and cross-subsidy levels: A cross country panel data analysis. Energy Policy, 39(3), 1080–1092. https://doi.org/10.1016/j.enpol.2010.11.023

ESG (2017). E-Mobility Report. Energy & Strategy Group, Politecnico di Milano. Gennaio 2017. Retrieved from: http://www.energystrategy.it/report/e-mobility-report.html

ESG (2018). Renewable Energy Report 2018, il futuro delle rinnovabili in Italia. Energy & Strategy Group, Politecnico di Milano. Maggio 2018. Retrieved from: http://www.energystrategy.it/report/renewable-energy-report.html

EU carbon prices could double by 2021 and quadruple by 2030 (2018, April 26). Retrieved from: https://www.carbontracker.org/eu-carbon-prices-could-double-by-2021-and-quadruple-by-2030/

European Council (2007). Brussels European Council, 8/9 March 2007, Presidency Conclusions. Brussels, 2 May 2007. 7224/1/07, REV 1, CONCL 1. Retrieved from: http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf

European Council (2014). European Council (23 and 24 October 2014) – Conclusions. Brussels, 24 October 2014. EUCO 169/14, CO EUR 13, CONCL 5. Retrieved from: http://data.consilium.europa.eu/doc/document/ST-169-2014-INIT/en/pdf

Factbox: Electric delivery vehicles in production or planned (2018, February 22). Retrieved from: https://www.reuters.com/article/us-electric-vehicles-delivery-factbox/factbox-electric-delivery-vehicles-in-production-or-planned-idUSKCN1G6231

Fang, X., Misra, S., Xue, G., & Yang, D. (2012). Smart Grid — The New and Improved Power Grid: A Survey. IEEE Communications Surveys & Tutorials, 14(4), 944–980. https://doi.org/10.1109/SURV.2011.101911.00087

FREVUE (2016). FREVUE Factsheet – UPS – Electricity grid infrastructure upgrade. May 2016. Retrieved from: https://frevue.eu/wp-content/uploads/2016/05/Electricity-grid-infrastructure-upgrade.pdf

FREVUE (2017a). FREVUE Results and Guidance for Electricity Network Operators. September 2017. Retrieved from: https://frevue.eu/wp-content/uploads/2017/09/FREVUE-Results-and-Guidance-for-Electricity-Network-Operators-v_08.pdf

FREVUE (2017b). FREVUE Factsheet – Total Cost Ownership for Rigid Electric Freight Trucks. September 2017. Retrieved from: https://frevue.eu/wp-content/uploads/2017/09/FREVUE-Total-Cost-of-Ownership-for-Rigid-Electric-Trucks-Factsheet.pdf

FREVUE (2017c). FREVUE Factsheet – Total Cost Ownership for Medium Electric Freight Vehicles. September 2017. Retrieved from: https://frevue.eu/wp-content/uploads/2017/09/FREVUE-TCO-for-Medium-Electric-Freight-Factsheet.pdf

FREVUE (2017d). FREVUE Factsheet – Total Cost of Ownership for Small Electric Freight Vehicles. September 2017. Retrieved from: https://frevue.eu/wp-content/uploads/2017/09/FREVUE-Total-Cost-of-Ownership-for-Small-Electric-Freight-Factsheet.pdf

FREVUE (n.d.). https://frevue.eu/

Gago, R. G., Pinto, S. F., & Silva, J. F. (2016). G2V and V2G electric vehicle charger for smart grids (pp. 1–6). IEEE. https://doi.org/10.1109/ISC2.2016.7580786

Gallo, J.-B. (2016). Electric Truck & Bus Grid Integration, Opportunities, Challenges & Recommendations. World Electric Vehicle Journal, 8(1), 45–56. https://doi.org/10.3390/wevj8010045

García-Villalobos, J., Zamora, I., San Martín, J. I., Asensio, F. J., & Aperribay, V. (2014). Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches. Renewable and Sustainable Energy Reviews, 38, 717–731. https://doi.org/10.1016/j.rser.2014.07.040

Georgilakis, P. S., & Hatziargyriou, N. D. (2013). Optimal Distributed Generation Placement in Power Distribution Networks: Models, Methods, and Future Research. IEEE Transactions on Power Systems, 28(3), 3420–3428. https://doi.org/10.1109/TPWRS.2012.2237043

Gómez, T. (2011). Integration of electric vehicles in smart distribution grids: Regulatory issues. 9th EU-US Energy Regulators Roundtable. Chicago, Illinois, USA. October 3-4, 2011. Retrieved from: https://www.ceer.eu/eer_international/eu-us_roundtable/9_eu-us_roundtable

Goodall, W., Dovey, T., Bornstein, J., Bonthron, B., & Daberko, I. T. (2017). The rise of mobility as a service. Reshaping how urbanites get around. Deloitte Review, Issue 20, 2017. Retrieved from: https://www2.deloitte.com/content/dam/Deloitte/nl/Documents/consumer-business/deloitte-nl-cb-ths-rise-of-mobility-as-a-service.pdf

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2013). A Survey on Smart Grid Potential Applications and Communication Requirements. IEEE Transactions on Industrial Informatics, 9(1), 28–42. https://doi.org/10.1109/TII.2012.2218253

Haas, J., Cebulla, F., Cao, K., Nowak, W., Palma-Behnke, R., Rahmann, C., & Mancarella, P. (2017). Challenges and trends of energy storage expansion planning for flexibility provision in low-carbon power systems – a review. Renewable and Sustainable Energy Reviews, 80, 603–619. https://doi.org/10.1016/j.rser.2017.05.201

Henning, E., Rauwald, C., & Weiss, R. (2018, April 6). Deutsche Post Weighs Options for Electric-Van Business. Retrieved from: https://www.bloomberg.com/news/articles/2018-04-06/deutsche-post-is-said-to-mull-options-for-electric-van-business

Hirsch, A., Parag, Y., & Guerrero, J. (2018). Microgrids: A review of technologies, key drivers, and outstanding issues. Renewable And Sustainable Energy Reviews, 90402-411. doi:10.1016/j.rser.2018.03.040

Hockenos, P. (2018). Europe Takes First Steps in Electrifying World's Shipping Fleets. Retrieved from: https://e360.yale.edu/features/europe-takes-first-steps-in-electrifying-worlds-shipping-fleets

Holmberg, P.-E., Collado, M., Sarasini, S., & Williander, M. (2016). Mobility as a Service - MaaS, Describing the framework. Victoria Swedish ICT AB, a pat of RISE. 2016-01-15. Retrieved from: https://www.viktoria.se/sites/default/files/pub/www.viktoria.se/upload/publications/final_report_maas_framework_v_1_0.pdf

IEA (2005). Energy Statistics MANUAL. Retrieved from: https://www.iea.org/publications/freepublications/publication/statistics_manual.pdf

IEA (2017a) Global EV Outlook 2017 - Two million and counting. International Energy Agency. Retrieved from https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

IEA (2017b). World Energy Outlook 2017. International Energy Agency. Retrieved from: https://www.iea.org/weo2017/.

IEA (2017c). Energy Access Outlook 2017, from Poverty to Prosperity. International Energy Agency. Retrieved from:

https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf

IEA (2018a). Nordic EV Outlook 2018. Insights from leaders in electric mobility. 2018. Retrieved from: https://webstore.iea.org/nordic-ev-outlook-2018

IEA (2018b). Global EV Outlook 2018. Towards cross-modal electrification. 2018. Retrieved from: https://webstore.iea.org/global-ev-outlook-2018

IEA (2018c). World Energy Investment 2018. Retrieved from: https://webstore.iea.org/world-energy-investment-2018

IEA-ETSAP (2014). Electricity Transmission and Distribution. IEA ETSAP - Technology Brief E12 – April 2014 - www.etsap.org

IEDC (2013). Creating the Clean Energy Economy, Analysis of the Electric Vehicle Industry. International Economic Development Council. 2013. Retrieved from: https://www.iedconline.org/clientuploads/Downloads/edrp/IEDC_Electric_Vehicle_Industry.pdf

IEEE (2018). IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003). Retrieved from: https://standards.ieee.org/findstds/standard/1547-2018.html

IIIEE (2018). Recipes for Sustainability Success: Serving Seven Strategic Solutions. International Institute for Industrial Environmental Economics, Lund, IIIEE. ISBN 978-91-87357-34-3. Retrieved from: https://www.iiiee.lu.se/sites/iiiee.lu.se/files/final_sed_public_report_27-june-2018_reduced.pdf

IONOTY (n.d.). Retrieved from: http://www.ionity.eu/ionity-en.html

IRENA (2017). Electric vehicles technology brief. February 2017. Retrieved from: http://www.irena.org/publications/2017/Feb/Electric-vehicles-Technology-brief

IRENA (2018a). Renewable Power Generation Costs in 2017. International Renewable Energy Agency, January 2018. Retrieved from: http://www.irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017

IRENA (2018b). Global Energy Transformation: A Roadmap to 2050. International Renewable Energy Agency, April 2018. Retrieved from: http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf

IRENA (2018c). Electricity storage and renewables: costs and markets to 2030. International Renewable Energy Agency, October 2017. Retrieved from: http://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

Kamankesh, H., Agelidis, V. G., & Kavousi-Fard, A. (2016). Optimal scheduling of renewable micro-grids considering plug-in hybrid electric vehicle charging demand. Energy, 100, 285–297. https://doi.org/10.1016/j.energy.2016.01.063

Karlsson, S. (2013). The Swedish car movement data project, Final report. Division of Physical resource Theory,Department of Energy and Environment, Chalmers University of Technology. SE-41296 Gothenburg, Sweden. PRT Report 2013:1, Rev 2, Nov 2013. Retrieved from: http://publications.lib.chalmers.se/records/fulltext/187380/local_187380.pdf

Karlsson, S., & Kullingsjö, L.-H. (2013). GPS measurement of Swedish car movements for assessment of possible electrification. World Electric Vehicle Journal Vol. 6 - ISSN 2032-6653 - © 2013 WEVA Page. EVS27 Barcelona, Spain, November 17-20, 2013. Retrieved from: http://publications.lib.chalmers.se/records/fulltext/184575/local_184575.pdf

Kelly, K. (2015). Medium- and Heavy-Duty Vehicle Duty Cycles for Electric Powertrains. National Renewable Energy Laboratory. Applied Power Electronics Conference, Long Beach, CA, March 20-24, 2016. Retreived from: https://www.nrel.gov/docs/fy16osti/66228.pdf

Kharrich, M., Akherraz, M., & Sayouti, Y. (2017). Optimal sizing and cost of a Microgrid based in PV, WIND and BESS for a School of Engineering. In 2017 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS) (pp. 1–5). Fez, Morocco: IEEE. https://doi.org/10.1109/WITS.2017.7934648

LGI Consulting (2015). INNOVATION OUTLOOK – TRANSPORT SERIES. EV-smart grid integration. January 2015. Retrieved from: http://www.lgi-consulting.com/wp-content/uploads/2016/01/Innovation-outlook-EV-grid.pdf

Li, J., Sun, X., Liu, Q., Zheng, W., Liu, H., & Stankovic, J. A. (2018). Planning Electric Vehicle Charging Stations Based on User Charging Behavior. In 2018 IEEE/ACM Third International Conference on Internet-of-Things Design and Implementation (IoTDI) (pp. 225–236). Orlando, FL: IEEE. https://doi.org/10.1109/IoTDI.2018.00030

Liu, Z., & Wu, Q. (2014). EV charging analysis based on the National Travel Surveys of the Nordic Area. In 2014 IEEE PES General Meeting | Conference & Exposition (pp. 1–6). National Harbor, MD, USA: IEEE. https://doi.org/10.1109/PESGM.2014.6939315

Lo Schiavo, L., Bonafede, D., Celaschi, S., & Colzi, F. (2017). Regulatory Issues in the Development of Electro-Mobility Services: Lessons Learned from the Italian Experience. 1st E-Mobility Power System Integration Symposium, Berlin, Germany, 23 October 2017. Retrieved from: http://mobilityintegrationsymposium.org/wp-content/uploads/sites/7/2017/11/2B_1_EMob17_054_paper_loSchiavo_Luca.pdf

Lopes, J. A. P., Soares, F. J., & Almeida, P. M. R. (2011). Integration of Electric Vehicles in the Electric Power System. Proceedings of the IEEE, 99(1), 168–183. https://doi.org/10.1109/JPROC.2010.2066250

Lotfi, H., & Khodaei, A. (2016). Levelized cost of energy calculations for microgrids. In 2016 IEEE Power and Energy Society General Meeting (PESGM) (pp. 1–5). Boston, MA, USA: IEEE. https://doi.org/10.1109/PESGM.2016.7741379

Mahmud, K., Town, G. E., Morsalin, S., & Hossain, M. J. (2018). Integration of electric vehicles and management in the internet of energy. Renewable and Sustainable Energy Reviews, 82, 4179–4203. https://doi.org/10.1016/j.rser.2017.11.004

Marra, D., Rizzo, G., Shafie-khah, M., Siano, P., & Tiano, F. A. (2017). Vehicle electrification: A further variable toward integrated intelligent energy systems. In Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), 2017 IEEE International Conference on (pp. 1–6). IEEE.

McCollum, D., Krey, V., Kolp, P., Nagai, Y., & Riahi, K. (2014). Transport electrification: A key element for energy system transformation and climate stabilization. Climatic Change, 123(3–4), 651–664. https://doi.org/10.1007/s10584-013-0969-z

McKinsey&Company (2010). Transformation of Europe's power system until 2050, including specific considerations for Germany. McKinsey & Company, Inc. October 2010. Retrieved from: https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/epng/pdfs/transformation_of_europes_power_system.ashx

Mies, J., Helmus, J., & van den Hoed, R. (2018). Estimating the Charging Profile of Individual Charge Sessions of Electric Vehicles in The Netherlands. World Electric Vehicle Journal, 9(2), 17. https://doi.org/10.3390/wevj9020017

MIT (2008). A Guide to Understanding Battery Specifications. MIT Electric Vehicle Team, December 2008. Retrieved from: http://web.mit.edu/evt/summary_battery_specifications.pdf

MSE (2017). SEN 2017 – Strategia Energetica Nazionale. Italy, Ministero dello Sviluppo Economico. Retreived from: http://www.sviluppoeconomico.gov.it/images/stories/documenti/Testo-integrale-SEN-2017.pdf

Mullen, T. (2018). Volvo Reveals Hybrid Boating Technology As Path To The Future. Retrieved from: https://www.forbes.com/sites/tmullen/2018/07/03/volvo-reveals-hybrid-boating-technology-as-path-to-the-future/#156696f96a67

Nguyen, H. N. T., Zhang, C., & Mahmud, M. A. (2015). Optimal Coordination of G2V and V2G to Support Power Grids With High Penetration of Renewable Energy. IEEE Transactions on Transportation Electrification, 1(2), 188–195. https://doi.org/10.1109/TTE.2015.2430288

Norway's efforts to decarbonise marine transport (2017, April 28). Retrieved from: http://bellona.org/news/arctic/arctic-transport-and-shipping/2017-04-norways-efforts-to-decarbonise-marine-transport

NREL (2014a). Smith Newton Vehicle Performance Evaluation – Cumulative. Retrieved from: https://www.nrel.gov/docs/fy14osti/62066.pdf

NREL (n.d.). Electric and Plug-In Hybrid Electric Fleet Vehicle Evaluations. https://www.nrel.gov/transportation/fleettest-electric.html

OIES (2018). Electric vehicles and electricity. Oxford Energy insight 36. Retrieved from: https://www.oxfordenergy.org/publications/electric-vehicles-electricity/

Ong, S., Campbell, C., Denholm, P., Margolis, R., & Heath, G. (2013). Land-Use Requirements for Solar Power Plants in the United States (No. NREL/TP-6A20-56290, 1086349). https://doi.org/10.2172/1086349

Peças Lopes, J. A., Polenz, S. A., Moreira, C. L., & Cherkaoui, R. (2010). Identification of control and management strategies for LV unbalanced microgrids with plugged-in electric vehicles. Electric Power Systems Research, 80(8), 898–906. https://doi.org/10.1016/j.epsr.2009.12.013

Percebois, J., & Pommeret, S. (2018). Cross-subsidies Tied to the Introduction of Intermittent Renewable Electricity. An Analysis Based on a Model of the French Day-Ahead Market. The Energy Journal, 39(3). https://doi.org/10.5547/01956574.39.3.jper

Picciariello, A., Vergara, C., Reneses, J., Frías, P., & Söder, L. (2015). Electricity distribution tariffs and distributed generation: Quantifying cross-subsidies from consumers to prosumers. Utilities Policy, 37, 23–33. https://doi.org/10.1016/j.jup.2015.09.007

Pinter, L., & Farkas, C. (2015). Impacts of electric vehicle chargers on the power grid. In 2015 5th International Youth Conference on Energy (IYCE) (pp. 1–6). Pisa, Italy: IEEE. https://doi.org/10.1109/IYCE.2015.7180811

Premiere for Volvo Trucks' first all-electric truck (2018, April 12). Retrieved from: https://www.volvogroup.com/en-en/news/2018/apr/news-2879838.html

Prohaska, R., Ragatz, A., Simpson, M., Kelly, K. (2015). Medium-Duty Plug-in Electric Delivery Truck Fleet Evaluation. National Renewable Energy Laboratory. Retrieved from: https://www.nrel.gov/docs/fy16osti/66055.pdf

Putrus, G. A., Suwanapingkarl, P., Johnston, D., Bentley, E. C., & Narayana, M. (2009). Impact of electric vehicles on power distribution networks. In 2009 IEEE Vehicle Power and Propulsion Conference (pp. 827–831). Dearborn, MI: IEEE. https://doi.org/10.1109/VPPC.2009.5289760

Rambow-Hoeschele, K., & Walter, I. (2017). The Improvement of Grid Integration for Electromobility through Innovative Business Models. 1st E-Mobility Power System Integration Symposium, Berlin, Germany, 23 October 2017. Retrieved from: http://mobilityintegrationsymposium.org/berlin2017/wp-content/uploads/sites/7/2018/06/EMob17_085_posterpaper_Rambow-Hoeschele.pdf

REN21 (2018). Renewables 2018, Global Status Report. Retrieved from: http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf

Richardson, D. B. (2013). Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. Renewable and Sustainable Energy Reviews, 19, 247–254. https://doi.org/10.1016/j.rser.2012.11.042

RMI (2014). The Economics of Grid Defection. Rocky Mountain Institute. February 2014.Retrieved from: https://rmi.org/insight/economics-grid-defection/

Robinson, A. P., Blythe, P. T., Bell, M. C., Hübner, Y., & Hill, G. A. (2013). Analysis of electric vehicle driver recharging demand profiles and subsequent impacts on the carbon content of electric vehicle trips. Energy Policy, 61, 337–348. https://doi.org/10.1016/j.enpol.2013.05.074

RSE (2013). E... muoviti! Mobilità elettrica a Sistema. Ricerca sul Sistema Energetico – RSE SpA. 2013 Editrice Alkes. ISBN 978-88-907527-3-5. Retreived from: http://www.selidori.com/tech/00000-04999/724-MtMJB.pdf

RTE (2017a). Bilan prévisionnel de l'équilibre offre-demande d'électricité en France, Édition 2017, Synthèse. France, RTE. Retrieved from: https://www.rte-france.com/sites/default/files/bp2017_synthese_17.pdf

Sandroni, C., Verga, M., Lazzari, R., Fantini, M., Sacchi, M., & Prandoni, V. (2016). RSE's microgrid: A facility for research, development and testing of future distributed generation and microgrid technologies. In 2016

AEIT International Annual Conference (AEIT) (pp. 1–6). Capri, Italy: IEEE. https://doi.org/10.23919/AEIT.2016.7892773

San Román, T. G., Momber, I., Abbad, M. R., & Sánchez Miralles, Á. (2011). Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships. Energy Policy, 39(10), 6360–6375. https://doi.org/10.1016/j.enpol.2011.07.037

Sarasini, S., & Linder, M. (2018). Integrating a business model perspective into transition theory: The example of new mobility services. Environmental Innovation and Societal Transitions, 27, 16–31. https://doi.org/10.1016/j.eist.2017.09.004

Sbordone, D., Bertini, I., Di Pietra, B., Falvo, M. C., Genovese, A., & Martirano, L. (2015). EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm. Electric Power Systems Research, 120, 96–108. https://doi.org/10.1016/j.epsr.2014.07.033

Schey, S., Scoffield, D., & Smart, J. (2012). A First Look at the Impact of Electric Vehicle Charging on the Electric Grid in The EV Project. World Electric Vehicle Journal, 5(3), 667–678. https://doi.org/10.3390/wevj5030667

Schroeder, A., & Traber, T. (2012). The economics of fast charging infrastructure for electric vehicles. Energy Policy, 43, 136–144. https://doi.org/10.1016/j.enpol.2011.12.041

Serradilla, J., Wardle, J., Blythe, P., & Gibbon, J. (2017). An evidence-based approach for investment in rapid-charging infrastructure. Energy Policy, 106, 514–524. https://doi.org/10.1016/j.enpol.2017.04.007

Shemami, M. S., Alam, M. S., & Asghar, M. J. (2017). Load shedding mitigation through plug-in electric Vehicle-to-Home (V2H) system. In Transportation Electrification Conference and Expo (ITEC), 2017 IEEE (pp. 799–804). IEEE.

Shen, M., Li, M., He, F. Jia, Y. (2016). Strategic Charging Infrastructure Deployment for Electric Vehicles. University of California at Berkeley, Institute of Transportation Studies, Berkeley, CA 94720. Publication Date 2016-05-01. Retrieved from: https://escholarship.org/uc/item/6rp6n4sf

Siemens (2018). Resilient by Design: Enhanced Reliability and Resiliency for Puerto Rico's Electric Grid. Siemens Industry, Inc. 2018. Retrieved from: https://www.siemens.com/content/dam/webassetpool/mam/tag-siemens-com/smdb/regions/usa/company/topic-areas/onsite-power-generation/documents/puertoricoresiliency-wp-fprint.pdf

Speidel, S., & Bräunl, T. (2014). Driving and charging patterns of electric vehicles for energy usage. Renewable and Sustainable Energy Reviews, 40, 97–110. https://doi.org/10.1016/j.rser.2014.07.177

Sugiyama, M. (2012). Climate change mitigation and electrification. Energy Policy, 44, 464–468. https://doi.org/10.1016/j.enpol.2012.01.028

Su, W., Eichi, H., Zeng, W., & Chow, M.-Y. (2012). A Survey on the Electrification of Transportation in a Smart Grid Environment. IEEE Transactions on Industrial Informatics, 8(1), 1–10. https://doi.org/10.1109/TII.2011.2172454

Tan, K. M., Ramachandaramurthy, V. K., & Yong, J. Y. (2016). Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. Renewable and Sustainable Energy Reviews, 53, 720–732. https://doi.org/10.1016/j.rser.2015.09.012

Tesla Semi (n. d.) Retrieved from: https://www.tesla.com/semi

Torquato, R., da Silva, L. C. P., Freitas, W., Kurth, B., & Arioli, V. (2014). Impact assessment of the two-way operation of plugin electric vehicles on distribution networks. In 2014 IEEE PES General Meeting | Conference & Exposition (pp. 1–5). National Harbor, MD, USA: IEEE. https://doi.org/10.1109/PESGM.2014.6939119

Tryggestad, C., Sharma N., van de Staaij J. and Keizer A. (2017). New reality: electric trucks and their implications on energy demand. McKinsey Energy Insights. September 2017. Retrieved from: https://www.mckinsey.com/industries/oil-and-gas/our-insights/a-new-reality-electric-trucks

van der Kam, M., & van Sark, W. (2015). Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study. Applied Energy, 152, 20–30. https://doi.org/10.1016/j.apenergy.2015.04.092

van der Veen, R. A. C., & Hakvoort, R. A. (2016). The electricity balancing market: Exploring the design challenge. Utilities Policy, 43, 186–194. https://doi.org/10.1016/j.jup.2016.10.008

Vattenfall (2017). Power Climate Smarter Living. Vattenfall Annual and Sustainability Report 2016. Vattenfall. Retrieved from: https://corporate.vattenfall.com/globalassets/corporate/investors/annual_reports/2017/vattenfall_annual_and_sustainability_report_2016_eng.pdf

Veldhuis, A. J., Leach, M., & Yang, A. (2018). The impact of increased decentralised generation on the reliability of an existing electricity network. Applied Energy, 215, 479–502. https://doi.org/10.1016/j.apenergy.2018.02.009

Volvo Penta (n. d.). Volvo Penta website. https://www.volvopenta.com/brand/en-en/home.html

Volvo Trucks presents second electric truck model in three weeks (2018, May 8). Retrieved from: https://www.volvogroup.com/en-en/news/2018/may/news-2912374.html

Wu, T., Yang, Q., Bao, Z., & Yan, W. (2013). Coordinated Energy Dispatching in Microgrid With Wind Power Generation and Plug-in Electric Vehicles. IEEE Transactions on Smart Grid, 4(3), 1453–1463. https://doi.org/10.1109/TSG.2013.2268870

Yong, J. Y., Ramachandaramurthy, V. K., Tan, K. M., & Mithulananthan, N. (2015). A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. Renewable and Sustainable Energy Reviews, 49, 365–385. https://doi.org/10.1016/j.rser.2015.04.130

Yu, X. E., Xue, Y., Sirouspour, S., & Emadi, A. (2012). Microgrid and transportation electrification: A review. In Transportation Electrification Conference and Expo (ITEC), 2012 IEEE (pp. 1–6). IEEE.

Zhao, Y., Noori, M., & Tatari, O. (2016). Vehicle to Grid regulation services of electric delivery trucks: Economic and environmental benefit analysis. Applied Energy, 170, 161–175. https://doi.org/10.1016/j.apenergy.2016.02.097

Interviews list

I1. Hallung, H., Vosough, T. (2018, July 11). Hans Hallung, VP Heavy Duty Business Strategy at Volvo Group Finance; Taraneh Vosough, Business Project Manager at Volvo Group Finance. Volvo Group Finance. Personal interview. July 11th 2018.

I2. Karlström, M., (2018, July 12). Magnus Karlström, Project Leader at Lindholmen Science Park. Personal Interview. July 12th 2018.

I3. Cleaschi, S. F., Colzi, F., Mauri, G. (2018, July 18). Silvia Franca Celaschi, Filippo Colzi, Giuseppe Mauri,Ricerca sul Sistema Energetico – RSE, Transmission and Distribution Technologies Department (TTD) WebEx platform web meeting. July 18th 2018.

I4. Vidal, N., (2018, July 20). Narcís Vidal , e-mobility innovation at Enel X. Skype web meeting. July 20th 2018.

I5. Bürer, M. J. (2018, July 24). Mary Jean Bürer, Docteur en économie de l'Université de St-Gall (HSG), Cheffe de projet Ra&D HES, Institut Interdisciplinaire du Développement de l'Entreprise (IIDE). Phone interview. July 24th 2018.

I6. Genovese, A. (2018, August 1). Antonino Genovese, Energy Department, Production, Conversion and Use of Energy Division, Head of Laboratory for Transport Technologies and electric storage system at Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA). Phone Interview. August 1st 2018. Follow up call on August 8th 2018.

I7. Andersson, P. (2018, August 3). Peter Andersson, Product Manager e-Mobility at E.ON Eldistribution. Phone Interview. August 3rd 2018.

I8. Soultani, E., Stahl, A. (2018, August 9). Evangelia Soultani Data Scientist at Volvo Group Connected Solutions, Advanced Analytics & visualization; Adam Stahl, Lead Research Engineer at Volvo Group Connected Solutions, Advanced Analytics & visualization. Skype Interview. August 9th 2018. Follow-up meetings with Evangelia Soultani on August 14th 2018 and August 24th 2018 to gather further data and information.

I9. Ohlin, P. (2018, August 13). Pär Ohlin, Director S&OP Business Development at Volvo Trucks, S&OP Business Development. Personal Interview. August 13th 2018.

I10 Bramsved, M. (2018, August 13). Martin Bramsved, Göteborg Energi. Phone Interview. August 13th 2018.

I11. Mörck, J., (2018, August 14). Johan Mörck, Business Development Manager at Volvo Penta, Strategy & Business Development, PMI. Personal Interview. August 14th 2018.

I12. Bedford, L, Mello, L., B. (2018, August 14). Louise Bedford CRM Global Manager at Volvo Trucks, CRM & Operational Excellence; Leandro Bacellar Mello, VP CRM & Operational Excellence at Volvo Trucks, CRM & Operational Excellence. Personal Interview. August 14th 2018.

I13. Stewart, C. (2018, August 15). Colin Stewart, R&D E-Mobility Programme Manager, Transport Systems, Applications & Solutions at Vattenfall AB, Data Analytics & ICT Solutions, Research & Development, Strategic Development. Skype Interview. August 15th 2018.

I14. Berger, A. (2018, August 17). Anders Berger, Public Affairs Director at Volvo Group Finance, Public Affairs Management. Personal Interview. August 17th 2018.

I15. Mutatkar, N. (2018, August 17). Ninad Mutatkar, Project Manager at Fortum. Skype Interview. August 17th 2018.

I16 Engdahl, H. (2018, August 17). Henrik Engdahl, Product Owner Charging Systems at Volvo Group Trucks Technology, Electromobility. Personal Interview. August 17th 2018.

I17. Steen, D. (2018, August 17). David Steen, Post Doc, Electrical engineering at Chalmers University, Electrical engineering department. Personal Interview. August 17th 2018.

I18. Ohlin, G. (2018, August 21). Gunnar Ohlin, Project Leader at Lindholmen Science Park AB. Personal Interview. August 21st 2018.

I19. Harakamani, S. (2018, August 21). Santosh Harakamani, Strategic Planning Manager at Volvo Trucks, Services and Customer Quality, Business Office and Governance. Personal Interview. August 21st 2018.

I20. Brankell, P. (2018, August 22). Peter Brankell, Industrial Application Engineer at Volvo Penta, sales Enginering, Industrial. Personal Interview. August 22nd 2018.

I21. Basso, R. (2018, August 22). Rafael Basso, Industrial PhD student in the Automatic Control research group, in cooperation with Volvo Group Trucks Technology, Chalmers University - Volvo Group Trucks Technology. Personal Interview. August 22nd 2018.

Appendix I – Primary documents analysed to find the main elements expected to change the power system

Source geographical scope	Specific source / kind of source	Specific organisation or kind of document	Specific document
European	European Commission	2030 climate and energy framework	European Commission: “Commission Staff Working Document, Impact Assessment accompanying the document ‘A policy framework for climate and energy in the period from 2020 up to 2030”
European	European Commission – energy modelling	PRIMES model	E3MLab: “Primes Model Version 6, 2016-2017, Detailed model description”
European	European Commission – energy scenario	EU Reference Scenario	European Commission: “EU Reference Scenario 2016, Energy, transport and GHG emissions Trends to 2050”
Multinational	European energy company / utility	Sustainability report – annual report – development plan	Vattenfall: “Power Climate Smarter Living. Vattenfall Annual and Sustainability Report 2016”
National	European national or regional TSO	Grid development plan – electricity demand forecasts – long term power scenarios	France, RTE: “Bilan prévisionnel de l’équilibre offre-demande d’électricité en France, Édition 2017, Synthèse”
National	European country / government	National energy strategy /plan	Italy, Ministero dello Sviluppo Economico: “SEN 2017 – Strategia Energetica Nazionale”

Source: Author’s own elaborations

Appendix II – List of organisations contacted for interviews

(Not all the contacted organisations finally lead to actual interviews – see the Interviews list)

A2A S.p.A.

Autorità di Regolazione per Energia Reti e Ambiente – ARERA (Italian energy authority)

Chalmers University

Clever

ENEA

Enel X

EON

Florence School of Regulation

Fortum

Göteborg Energi

GÖTEBORGS STAD (THE CITY OF GOTHENBURG)

Institut Interdisciplinaire du Développement de l'Entreprise (IIDE)

Lindholmen Science Park AB

Öresundskraft

RISE Viktoria

RSE - Ricerca sul Sistema Energetico

Swedish Energy Agency

U.S. Department of Energy

Vattenfall AB