Role of regulation on distribution systems for the penetration of Local Energy Communities

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Synopsis:

In the EU's latest energy & climate package *Clean Energy for all Europeans*, the concept of *Local Energy Communities* is recognised as a facilitator for reaching a cost-efficient transition towards renewable energies. According to the proposals, adjustments of national regulation on distribution systems is required to enable the development of such local energy systems. The Thesis analyses relevant changes for the case study of Sweden by applying the overall methodology of the Choice Awareness theory. A cooperation with a Swedish DSO allows an assessment of the purpose of LECs within Swedish distribution grids and a business-economic impact calculation. Supplemented by interviews with the DSO and the regulatory body, relevant regulatory changes are identified. These include the economic incentive regulation, concession rights, connection charges, rules on roles and responsibilities including storage operation as well as shift of power for decision-making processes.

Summary

Overall, the Thesis deals with an investigation of required regulatory frameworks concerning distribution systems to allow the development of Local Energy Communities as proposed within the revised Directive 2009/72/EC on common rules for the internal market in electricity as part of the EU's *Clean Energy for all Europeans* package. The problem analysis outlines recent political discussions within the EU and issues arising with feed-in of distributed generation as part of the transition towards RES-based energy systems. In a second step, it is reflected upon the role of energy communities on a local level to facilitate the required transition. Definitions and proposals within current EU legislation result into the overall research question;

"How can national regulation of distribution systems support the establishment of Local Energy Communities that contribute to EU energy policy objectives?"

The theoretical framework forms the foundation of the Master Thesis' analysis. It includes an overall reflection on definitions of energy communities, theories on designing renewable energy systems as well as overall paradigms related to sustainable energy transitions.

For the analysis, case study research based on the example of Sweden is chosen as methodology, where parts are conducted for the concrete case of a Swedish DSO. A cooperation with E.ON Energidistribution AB and the author of this Thesis enabled to conduct this case study. To answer the overall research question, three sub-questions are established. These are structured based on the methodology developed under the Choice Awareness theory, i.e. description of LEC as technical alternative, economic feasibility and regulatory proposals. Further research on introduced theories in combination with insights gained from the problem analysis result into hypotheses. These hypotheses are tested to reflect on each sub-questions to finally conclude on the research question. Main methods include data analysis of the case DSO, scenario modelling with the micro-grid software HOMER Pro, a business-economic impact calculation based on the DSO's revenue calculation method as well as interviews with both the DSO and the regulatory authority.

Overall, the analysis reveals the need to adjust various regulatory areas affecting distribution systems to allow a development of LECs as proposed by the EU. These include the re-design of regulation on DSO business, that is currently shaped towards conventional energy systems by incentivising capital cost-intense solutions. In addition, concession rights need to include provisions allowing LECs to own or lease parts of existing networks. The introduction of a fair calculation method for charges invoiced to communities for connections to the overall distribution network is another identified need in regulation. Clear rules on roles and responsibilities for both DSOs and LECs are relevant to ensure security of supply within the community and the overall distribution grid. Empowerment of communities within local decision-making is further relevant to enable all functions of the LEC. Another point of discussion is to allow DSOs to operate storage facilities for providing backup services to LECs while decreasing grid upgrades.

Preface

Background

This Thesis is composed in the time period between February and June 2018 at the Planning Department of Aalborg University for obtaining the MSc degree in Sustainable Energy Planning and Management. The work is conducted in cooperation with the Swedish DSO E.ON Energidistribution AB of the E.ON Group, enabling a data collection for economic evaluation and modelling of grid scenarios for the Swedish case study.

Reading guide

Source references appear in the form of the Harvard method. At the end of the paper. an alphabetically listed bibliography is provided. References from books, homepages or alike appear in the from of the last name of the author and the year of publication, i.e. [Author, Year].

Figures and tables in the report are numbered according to the respective chapter. In this way, the first figure in Chapter 2 is numbered 2.1, the second 2.2 etc. Explanatory text is found in the caption below the object. In case of no references in the caption, the figure or table is composed by the author of the Thesis.

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At this point, I do not want to forget expressing my biggest thanks to my family. Despite the geographical distance between us, you have been the backbone during all stages of conducting this Master degree and beyond. I cannot stress enough how grateful I am for having you.

"Only one who devotes himself to a cause with his whole strength and soul can be a true master. For this reason mastery demands all of a person." - Albert Einstein

Daniela Wohlschlager

Nomenclature

Abbreviations

AAU	Aalborg University
CAPEX	Capital expenditure
CEP	Clean Energy Package
DG	Distributed generation
DH	District heating
DSM	Demand Side Management
DSO	Distribution System Operator
EC	European Commission
Ei	Swedish Energy Markets Inspectorate
EU	European Union
GHG	Greenhouse gas
H&C	Heating and cooling
ICES	Integrated Community Energy System
ICT	Information and Communication Technology
IKN	Non-concessionary networks
LEC	Local Energy Community
NRA	National regulation authority
OPEX	Operating expenditure
P2G	Power-to-gas
P2H	Power-to-heat
P2P	Peer-to-peer
R&D	Research and development
RES	Renewable energy sources
RQ	Research question
SCB	Statistics Sweden

SES	Smart Energy System
$WACC$	weighted average cost of capital

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Introduction 1

The importance of a global contribution to fight against climate change gained momentum through the Paris Agreement of COP21 [UNFCCC, 2015]. With its commitment to the Agreement, the EU needs to do its part towards reaching a global reduction of greenhouse gas (GHG) emissions. In this context, decarbonising the energy system is a necessity. With a contribution of 78% in 2016, latest numbers of the the European Environment Agency (EEA) show that the majority of EU's total GHG emissions are resulting from energy supply and usage. [EEA, 2017] To realise a transition, power integration from distributed generation (DG) is becoming an important part for achieving renewable energy systems. At the same time, falling technology prices partly supplemented by governmental support schemes have been stimulating a switch of the role of consumers to become "prosumers" by not only consuming but also producing energy, i.e. by installing small-scale production units. Since the structure of conventional networks is designed for transmission and distribution of power from centralised generation, Member States with already increased feed-in from DG have been facing technical problems within distribution networks, resulting in increased tariffs for overall society.

One solution to facilitate an integration of DG while reducing technical issues is increased local self-consumption within communities. Such local systems can potentially contribute to a higher and more efficient use of renewable energy sources (RES). At the same time, benefits might go beyond the community boundaries, e.g. by reducing the need for DG connections to the main distribution grid. The concept of energy initiatives on a local level further gained increased attention on the political agenda. Consequently, the EU's latest energy and climate package *Clean Energy for All Europeans* includes provisions for Member States to facilitate a penetration of so-called *Local Energy Communities*, short LECs. The concept might further reflect a solution for Member States to realise their national energy targets, such as the Swedish objective of reaching a 100% renewable electricity share by 2040.

Derived from the EU's proposals, regulation of distribution systems and their operators are identified as a key legislative area for the establishment of such local communities. Member States are expected to translate the proposals into national legislation. Accordingly, this Thesis investigates related regulatory issues of distribution systems for the case study of Sweden to provide insights on potential required adjustments.

Problem Analysis 2

2.1 Role and problems of distributed generation

Outlined in Koirala et al. [2016], distributed generation (DG) can be defined as power or heat produced on a local level. Especially electricity from distributed RES, i.e. from DG units, storage and controllable loads, has been on the rise globally. [Koirala et al., 2016] The share is expected to further increase, caused by progressing electrification of transport and heating as anticipated within the EU 2050 Roadmap [EC, 2012]. In various Member States of the EU, electricity integration from DG increased due to feed-in from residential installations. Consequently, there is a trend of a shift from consumers to become "prosumers", thus not only consuming but also producing electricity. The generated power serves for self-consumption with the possibility of surplus feed-in into the distribution network. According to Kampman et al. [2016], prosumer participation has great potential to further grow, based on the capability for integrating locally available RES. This could serve to accelerate a transition and a more efficient use of RES. Accordingly, an estimated share of 83% of all households within the EU could be actively involved in the energy system by 2050. This development is facilitated by political incentives from both the EU and national governments, including investment subsidies, support schemes such as feed-in tariffs or grants for research and development (R&D). One example of increased feed-in from DG is seen in Germany. Promoted through high feed-in tariffs, consumption from RES electricity increased fourfold between 2000 and 2013, where solar PV installations reached the highest installed capacity among all types of power generation in 2014. [Verzijlbergh et al., 2017; Koirala et al., 2016] The increase of DG has been further stimulated by falling RES technology prices, especially enabling an increase of residential RES installations. Outlined in a study on EU household prosumers in [EC, 2017a], costs for RES technologies have been falling in general, where residential solar PV system prices have been affected the most. Accordingly, prices decreased by >70% in only six years from 2008 to 2014.

By definition, power production units of DG differ from traditional large-scale plants due to the comparatively lower capacity, up to a few megawatts, and the direct connection to the distribution grid. [Ackermann et al., 2001; Ehsan and Yang, 2018] This aligns with current RES-based electricity production from DG in the EU, that is almost entirely connected to distribution grids. [EC, 2017c] Existing distribution systems, however, have been developed in the environment of traditional centralised energy systems, thus facing technical obstacles when integrating high share of power from DG. These challenges include voltage control and power quality issues, and distribution system operators (DSOs) have been in need for infrastructure upgrades. [Huda and Živanović, 2017; Günther et al., 2017] Consequently, rising integration of DG has been leading to increased network tariffs for consumers and higher taxes, levies and other fees needed to cover costs induced by national support schemes for RES electricity feed-in, but also to bear investments caused by technical issues and infrastructure development. [EC, 2017a; Verzijlbergh et al., 2017]. Germany is once again an example to reflect on the negative effects of a high integration of RES, where electricity prices reached the highest level among all EU Member States. [Verzijlbergh et al., 2017] Next to related high investments, required grid reinforcement could lead to delays in network expansions, hampering a further integration of additional installed RES.

Innovative solutions such as demand side management (DSM) could potentially decrease such problems within power networks as outlined in Günther et al. [2017]. This requires smart grid development of power networks, established by means of technologies known as information and communication technologies (ICT). Here, next to technical problems related to historical design of infrastructure, problems related to institutional arrangements arise. In this context, regulatory aspects of distribution systems show constraints for the development. Accordingly, Günther et al. [2017] identifies very few national regulatory frameworks for DSOs among EU countries that include incentivising elements to invest in innovative solutions. This results from historical design of regulation, that has been shaped towards traditional operation of energy systems rather than innovative approaches including smart grids. Consequently, it is assumed that lacking incentives in the regulation hamper electricity DSOs from taking required actions enabling innovative solutions that could potentially facilitate an integration of RES from DG.

The EU has been continuously developing strategies to realise a transition towards decarbonised energy systems and consequently to address these problems. In early 2015, the European Commission (EC) published the EU's current main energy and climate framework - the Energy Union Package [EC, 2015]. The paper emphasises the need to adapt embedded business models and national policies that sustain conventional energy systems. The issue regarding DG is recognised as followed; *"Energy infrastructure is ageing and not adjusted to the increased production from renewables. There is a need to attract investments, but the current market design and national policies do not set the right incentives [...]"*

To accelerate a transition, the EC proposed the EU's latest energy strategy "Clean Energy For All Europeans" [EC, 2016b], short Clean Energy Package (CEP), in the end of 2016. It includes provisions for improved market conditions supporting an integration of electricity from RES, including DG. In general, the proposals are built upon achieving overall energy and climate objectives. To create a link to the provisions' origins within the CEP, the following sections introduce the EU's overall energy and climate framework and 2030 targets before reflecting upon the proposals of the CEP in more detail.

2.2 EU's energy and climate strategy

2.2.1 Energy Union and 2030 targets

The EU's energy policy is built upon three core objectives, i.e. providing its citizens with secure, sustainable and competitive energy. The Energy Union Package aims to achieve the three core objectives while further serving as a pathway for fulfilling its international climate commitments. Accordingly, the EU aims to lower its GHG emissions, provide its citizens access to energy at any time and competition among energy suppliers to ensure affordability of energy. [EC, 2018b] Overall, an important aspect of the strategy is to guarantee affordable energy for consumers. In fact, benefits and increased empowerment for citizens is highlighted as priority:

"[...] Most importantly, our vision is of an Energy Union with citizens at its core, where citizens take ownership of the energy transition, benefit from new technologies to reduce their bills, participate actively in the market, and where vulnerable consumers are protected." [EC, 2015]

For the post-2020 period, the EC established targets under the 2030 Climate & Energy Framework, serving to realise the goals of the Energy Union. The targets address the three key areas of reducing GHG emissions, increasing the share of RES and reducing energy consumption by improving efficiency. The targets for RES and energy efficiency were defined by the revision of the Renewable Energies Directive 2009/28/EC [EC, 2017b] and the Energy Efficiency Directive 2012/27/EU [EC, 2016a]. The final agreement between EU institutions and resulting revised versions of the Directives led to the following three key objectives for 2030;

1. *Cut of GHG emissions by at least 40% (from 1990 levels)*
2. *Share of 35% from renewable energy*
3. *Reduction of energy consumption by 40%* [EC, 2014; European Parliament, 2017a]

In contrary to the 2020 targets, the objectives for 2030 are not translated into national binding targets, but defined on EU-level. Accordingly, it is left to the Member States to implement measures. In this context, the proposal for a regulation on the Governance of the Energy Union [EC, 2016d] requires each Member State to establish Integrated National Energy and Climate Plans that lead to a fulfilment of the EU-wide target instead, accompanied with progress reports on the implementation of these plans. The previously introduced latest EU energy and climate strategy, the CEP, serves to implement the Energy Union objectives and to guide Member States to take the right measures for achieving the 2030 targets. It includes revisions of several related Directives that are partly still undergoing interinstitutional negotiations for the final adoption into EU legislation. The objectives and content of the current status is outlined in Section 2.2.2 below.

2.2.2 Clean Energy For All Europeans Package

As the name indicates, reaching a transition that creates benefits for *all* consumers is the core goal of the Package. Accordingly, the proposals aim for more sustainable and smart energy, fulfilment of the Paris Agreement commitments and technology development while achieving economic growth contributing to overall welfare for its citizens. The measures included in the CEP are framed upon three main dimensions;

1. *Putting energy efficiency first*
2. *Achieving global leadership in renewable energies*
3. *Providing a fair deal for consumers* [EC, 2016b]

Regarding energy efficiency, the proposals aim to achieve the 2030 efficiency target of 40% as outlined in the revised Energy Efficiency Directive. The efficiency target is expected to be achieved by the extension and adjustment of existing efficiency policies. In this context, active participation of consumers is once again seen as facilitator and supported by providing relevant information to consumers e.g. in form of energy labelling. [EC, 2016e]
Proposal within the revised Directive on renewable energies serve to achieve the global leadership in renewables, where a cost-effective realisation of the 2030 target is one of the key areas. In addition, the Package focuses on creating suitable policy frameworks for RES penetration in all energy sectors. Same as for the efficiency objectives, increased empowerment and access to information is another area. [EC, 2016c]
The latter is directly related to the third main objectives, wherein the CEP aims to reach a fair distribution of costs for energy consumers. In this context, and as outlined in the Energy Union framework, the CEP once more highlights the desire of an increased inclusion and active participation of consumers. Described in EC [2016c], consumers in the future energy system are expected to change their role into becoming prosumers. The revised Renewable Energy Directive includes proposals for supporting conditions for consumers becoming prosumers and information provided to citizens regarding energy performance and sources, i.e. information on consumption such as through clearer metering and billing and access to smart meters.

The awareness of a required transition towards RES-based energy systems is not only present among policy makers on EU-level - ambitious energy and climate strategies have also been developed on national level. One governmental energy strategy with comparatively high RES targets is established by Sweden, which is the chosen Member State for the analysis of this Thesis. Current energy and climate objectives and strategies of both the EU and on national level will be outlined in the following sections.

2.3 Swedish energy policy

Before discussing current Swedish energy and climate targets, it is important to introduce basic characteristics of Swedish total energy and electricity supply composition and reflect upon historical developments.

2.3.1 National energy supply

According to recent numbers of the Swedish Energy Agency [2017], final domestic energy use was 370 TWh in 2015, whereof the majority of approx. 40% was consumed by households and services (60% for space heating and hot water, 40% for lighting and electricity appliances). Industry consumed 38% and the rest was used for transportation. Historically, Swedish energy supply was dominated by imported fossil fuels. In 1970, oil and petroleum products amounted to three quarters of total energy supply. [Swedish Energy Agency, 2017] Illustrated in Figure 2.1, however, the composition has undergone changes over the last decades. Until 2015, the share of oil and petroleum products decreased to 23%, with the remaining energy supply primarily based on 30% nuclear power, 25% biomass and 14% hydro power.

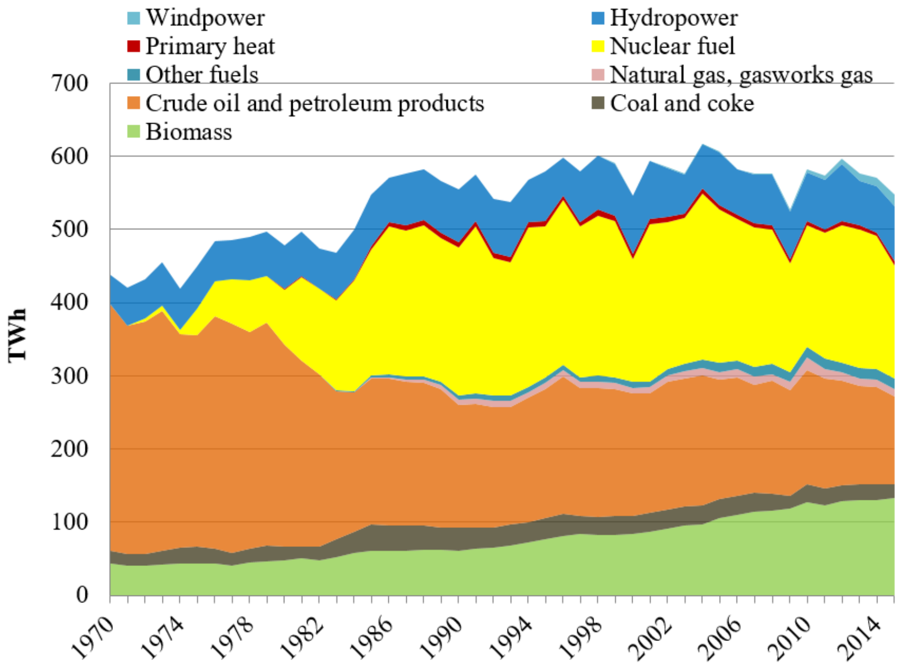

Figure 2.1. Swedish total energy supply by energy commodity 1970-2015 [Swedish Energy Agency, 2017]

National efforts towards energy independence and accordingly a desired phase-out of fossil fuels was driven by the two international oil crises in the 1970s and later by international climate change debates. In the early 1970s, Sweden established nuclear power, with several additional reactors commissioned in the 1980s. In addition, Sweden was one of the pioneers introducing a carbon tax in 1995. The policy was especially very effective within the heating sector, where fuel supply was dominated by imported oil. The taxation triggered the expansion of district heating (DH) and an increased use of biomass and residues from Sweden's large forest industry therein. [Werner, 2017] The first conversion of a Swedish

DH plant from oil to biofuels took place in the city of Växjö, which was a global pioneer of becoming fossil-fuel free as described in Alarcón Ferrari and Chartier [2016]. Nowadays, DH is the main heating source in Sweden, with the presence of DH networks in all main Swedish cities and towns. In the residential sector, the market share is above 50%. Next to biomass, fuel input is mainly supplied by local low-carbon sources such as combined heat and power and industrial excess heat. [Werner, 2017] Accordingly, Swedish heating demand is largely covered by local energy. Another initiative for decarbonisation followed in 2003, with focus on the electricity sector through the introduction of the electricity certificate system. Producers receive tradeable certificates for generation from wind, solar PV, geothermal, tidal power, biofuels or small-scale hydro power. The scheme obliges electricity suppliers to provide a certain quota of power generated from RES by purchasing certificates. [RES-legal, 2017a] The fuel development and role of local energy within the electricity sector will be outlined in more detail in the following section.

2.3.2 National electricity supply

In 2015, the total national electricity use was 137 TWh. The residential sector and services consumed just above 50% while 36% were consumed by industry. Similar to the energy supply mix, electricity has become less CO_2 intense within historical developments as captured by Figure 2.2.

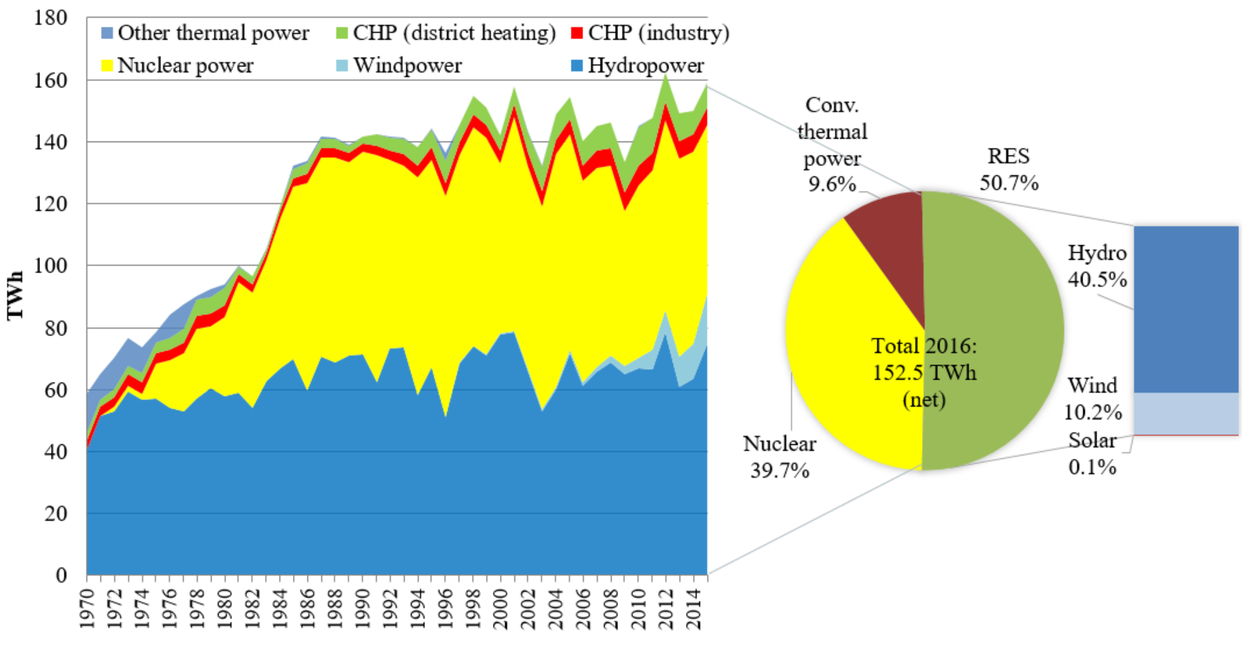

Figure 2.2. Swedish net electricity production 1970-2015 and fuel composition 2015 based on Swedish Energy Agency and SCB [2017]; Swedish Energy Agency [2017]

Whereas in the 1970s electricity was primarily based on thermal power plants, the share of RES exceeded half of electricity production in 2016, with more than 40% generated by hydro power. Wind power capacity has been growing continuously since the first installations in the 1980s, reaching 6.4 GW in 2016, covering approx. 10% of total generation. Although solar power has been increasing, it still only contributes to 0.1% in 2016. [Swedish Energy Agency, 2017] Compared to heat supply, however, a shift to local electricity has not been a priority of national policies as the current centralised production is considered as secure and sufficient [Rydén, 2015]. In fact, around 80% of electricity is generated by hydro and nuclear plants. Although the existence of small-scale hydro plants, most hydro power is generated by units with a capacity of at least 50 MW. [Swedish Energy Agency and SCB, 2017] This is confirmed by the numbers of hydro power generation falling under the electricity certificate system, reflecting that solely 1.7 TWh out of 74.8 TWh are entitled to certificates, i.e. coming from plants with a capacity below 1.5 MW. [Swedish Energy Agency, 2017] Accordingly, Swedish power is currently mainly produced domestically by large-scale, centralised power production units. As outlined by the Swedish Energy Markets Inspectorate, Energimarknadsinspektionen, (Ei), the three main players Vattenfall, Fortum and E.ON own large shares of power generation, specifically nuclear power units, and generate three quarters of total electricity. [Ei, 2016a] Thereof, state-owned Vattenfall represents the largest producer contributing to approx. half of total power generation and holding a 30% market share of total Swedish electricity sales. [Vattenfall AB, 2017] The same players further dominate power distribution as well as trading on the Nordic and Baltic exchange market Nord Pool. [Ei, 2016a] In 2016, total Swedish power generation exceeded domestic consumption and consequently, a total net surplus of 11.7 TWh was traded across borders. [Swedish Energy Agency and SCB, 2017]

2.3.3 Energy objectives

Sweden's energy strategy follows the EU's energy policy objectives of security of supply, sustainability and competitiveness. Driven by EU policy objectives, the *Integrated Climate and Energy Policy* established by Ministry of Enterprise Energy and Communications and Ministry of the Environment [2009] set national goals for 2020. These were partly more ambitious compared to the EU's targets, such as a 40% decrease of GHG in non-ETS sectors compared to 1990 levels (vs. national EU obligation of 17% reduction from 2005 levels) as well as a total RES share of 50% (vs. EU obligation of 49%). The latter was already reached in 2012, with a total share of 51% RES based on the calculation method outlined in the revised Renewable Energy Directive 2009/28/EC. [Ministry of Enterprise Energy and Communications and Ministry of the Environment, 2009; EC, 2018a]

The climate policies under the national 2009 framework, however, were lacking long-term strategies for the post-2020 period. Therefore, Swedish energy policy was reviewed. Published on the website of the Swedish government Regeringskansliet [2016], a first framework agreement on future goals for GHG emissions and RES share in electricity was made in June 2016. Built upon that, the final new energy policy strategy outlines three key objectives;

1. *Zero net GHG emissions by 2045, negative emissions thereafter*
2. *100% renewable electricity generation by 2040*
3. *50% higher efficiency in energy consumption by 2030* [Energikommissionen, 2017]

According to the Swedish government [Regeringskansliet, 2016], the electricity certificate system is expanded by additional 18 TWh until 2030 to realise a growing RES-share in power generation. Regarding the role of active consumers, the importance of demand flexibility is further recognised, realised through measures enabling consumers a full participation in the power market. For supporting small-scale generation, the framework foresees an investigation of current regulations and taxation affecting small-scale producers, including technologies and services of energy efficiency, storage and sales. [Regeringskansliet, 2016] This inquiry, however, has not been in place yet and accordingly, regulatory barriers have not been identified and adjusted yet. Although the Government further outlines the need for future energy system to be based on *"a variety of large- and small-scale renewable production that is tailored to local and industrial needs"*, there are no concrete proposals or measures supporting that development. [Regeringskansliet, 2016]

One topic that has historically been on the political agenda is the future of nuclear power, as outlined in Hong et al. [2018]; Litmanen et al. [2017]. Despite the decided decommissioning of four reactors by 2020, proposals highlight that a complete forced nuclear phase-out is not foreseen. In fact, taxation on installed nuclear capacity, that has been limiting profitability, is abolished and the framework allows new commissioning for replacing retiring reactors. [Energikommissionen, 2017] A possible solution for the future of nuclear power in relation to reaching the RES target can be linked to the stated aim of finding joint solutions with neighbouring countries participating in the Nord Pool exchange, i.e. by exporting non-RES based power production in the future. With the decreasing capacity of nuclear reactors and the needed increase of power from fluctuating RES, the current energy strategy is especially set on re-designing the Swedish power system to meet capacity needs. Discussed challenges include investment decisions in production units and power grids, and the need for flexibility. In line with the EU's energy policy, an increased involvement of active consumers through smart technologies and services is recognised as option for flexibility. Storage technologies and synergies between energy sectors are further addressed as solution to meet future capacity needs, with sector-coupling between heat and power mentioned as example. [Energikommissionen, 2017]

Since RES for power generation are typically disseminated geographically, the national target of a 100% RES share implies an increased role of distributed generation (DG) in the future Swedish electricity system. Next to sustainability reasons, the new national energy strategy in Energikommissionen [2017] further addresses the importance of increasing small-scale power generation in the perspective of energy security, i.e. to reduce reliance on the outside world while increasing security of national power supply. Derived from Member States that already experienced an increasing share of DG in power production, however, Sweden might face problems related to DG as introduced in Section 2.1. One potential solution that could serve as facilitator for the integration of DG for Sweden to reach a secure development towards small-scale RES generation are local energy initiatives, where energy is generated based on locally available resources and consumed to a large extend within the community. The concept of such energy projects on community-scale have been spreading among Member States and has been addressed among EU policy makers lately. Existing initiatives and the understanding within the EU's proposals are outlined in the following sections.

2.4 Energy communities as facilitator

Overall, initiatives branded under the terminology of energy communities are not a novelty. In fact, various local projects have already been developing across Europe, as outlined in the following section.

2.4.1 Existing initiatives

The first appearance of local energy initiatives reaches back as early as to the 1970s and 1980s, such as community-owned district heating in Denmark or wind cooperatives in the Netherlands, with German projects even dating back over a century. [Oteman et al., 2014] According to Walker [2008], the connected idea of consumer participation and increased utilisation of locally available resources to increase energy autarchy through energy communities has also been advocated by researchers since the 1980s. Outlined in Walker and Devine-Wright [2008], the fundamental idea of collective initiatives is to increase sustainability. Accordingly, and although there are a few countries with major fossil-based resources, local supply in community projects can be set in equivalent to renewable energies. [Rydén, 2015] Existing literature on energy communities outline hundreds of low-carbon initiatives in the energy sector that have been spreading on community level. While Koirala et al. [2016]; Van Der Schoor and Scholtens [2015]; Van Der Schoor et al. [2016]; Walker [2008]; Berka and Creamer [2018] primarily address the Netherlands, Denmark, Germany and the UK as examples in the European context, Ruggiero et al. [2018] deals with local energy project in Finland while also mentioning existence of community energy projects in other European countries including Spain and Italy. In the case of Sweden, Rydén [2015] outlines a strong approach of municipalities participating in energy projects, including initiatives such as "Climate Municipalities" (*Klimatkommunerna*), and "Transition towns Sweden" (*Omställning Sverige*).

The development in various Member States is accelerated by emerging regional and local goals and strategies towards renewable energy systems or increased energy autarchy. Also, since governments need to fulfil the EU's climate goals, local projects have partially enjoyed from national financial support or incentives such as feed-in tariffs. [Van Der Schoor et al., 2016; Koirala et al., 2016] A review of existing policies regarding local energy identified increased energy safety as the primary target of communities by becoming self-sufficient and subsequently reaching independence from fossil fuels. [Rydén, 2015] This is in accordance with historical reasons for the development summarised in Oteman et al. [2014], including the aim for independence, driven by the oil-crisis, anti-nuclear movements as well as climate change debates. Additional benefits are of social and environmental character such as local job creation and the reduction of local GHG emissions. [Rydén, 2015; Koirala et al., 2016] Whereas members of local community initiatives are typically characterised by attitudes towards sustainability, motivations of financial nature have been becoming more important over recent years. [Oteman et al., 2014] Related to economic growth, another motivation of communities is to sustain financial resources in the region rather than contributing to the profit of large multinational energy utilities. [Van Der Schoor et al., 2016]

Part of the CEP, a revision of Directive 2009/72/EC on common rules for the internal market in electricity is proposed. The provisions therein target a change of market conditions to facilitate an integration of RES-based electricity, including DG. In this context, the Directive recognises community energy projects as one potential facilitator. The following section outline the EU's understanding of such community energy projects, i.e. the concept of "Local Energy Communities" (LEC) as part of the CEP.

2.4.2 Local Energy Communities in EU policy

According to EU's proposals addressing LECs, an effective integration has the ability to partly contribute to achieving key energy policy goals such as increased energy efficiency, further integration of RES and consumer engagement. The latter is reached by the possibility for consumers to become stakeholders within the energy system while having the possibility to control the energy system by producing, consuming or sharing energy with members of the community network. Every member can take an active part, including customer groups without access on an individual basis, e.g. lacking possibility to install RES technologies on their own property. [EC, 2017c] Since the concept of LECs is included in the proposed revision of Directive 2009/72/EC on common rules for the internal market in electricity, the focus is set on electricity generation and supply. Next to the roles of prosumers, LECs are entitled to participate in supply (sale and resale of electricity), storage (either electricity or converted form of energy), aggregation (pooling customer loads or electricity for sale, purchase or auction to other markets) or act as DSOs and energy efficiency service providers. In contrast to traditional energy companies, LECs are described as legal entities that are value-driven rather than profit-oriented. Latest amendments of the Parliament further add the desired purpose to create *"local environmental, economic or social community benefits for its members or the local area or areas where it operates"*. [European Parliament, 2017b]

The boundaries of the community network are further geographically limited, i.e. the members are physically located within the community, wherein local shareholders are in control of the energy system. Overall, the Directive describes LECs as *"an efficient way of managing energy at community level by consuming the electricity they generate either directly for power or for (district) heating and cooling with or without a connection to distribution systems."* [EC, 2017c] The Directive further foresees an operation of LEC within a smart grid environment, implying access to smart meters for participants that allows services such as demand response (DR) and DSM that can potentially contribute to a more efficient integration and use of locally available RES.

2.5 Regulatory aspects on distribution systems

The revised Directive 2009/72/EC outlines various provisions for adjustments of electricity markets across the EU to realise energy policy targets, including the development of LECs. A translation of these provisions into national legislation, however, is left to the Member States. Based on the proposals, the design of national regulation on power distribution systems arises as a key factor realising LEC development. Since distribution grids are natural monopolies, DSOs are subject to regulation by the national regulation authority (NRA), represented by Ei in Sweden. [Wallnerström et al., 2016] Important identified regulatory areas of distribution networks that are within the scope of the Thesis are introduced in the following sections. Here, the focus is set on the economic perspective rather than technical issues.

2.5.1 Grid concession rights

One regulatory issue arises with the first provision in EC [2017c], demanding Member States to guarantee that LECs *"are entitled to own, establish, or lease community networks and to autonomously manage them."* Amendments of the European Parliament[1] further added that this applies *"as long as the concession system of the Member State is respected."* [European Parliament, 2017b] In many Member States, including Sweden, ownership of distribution networks is based on concessions. [AF-Mercados EMI et al., 2015] Accordingly, the distribution grid is typically divided into geographical areas that are owned and operated by a certain DSO.

Also within literature on energy communities such as Koirala et al. [2016], access to distribution networks is recognised as a key requirement. Further outlined, existing examples of energy communities in Germany took control over the distribution grid. In fact, the trend towards re-munipalisation of distribution grids is seen within the country. In one mentioned case of a community initiative in Feldheim, Germany, an agreement with the DSO to buy or lease the community network failed. Accordingly, the LEC decided to establish both their own power and heat networks. For realisation, however, private funds and EU subsidies were required. [Koirala et al., 2016]

Consequently, for fulfilment of the provision allowing LEC establishment within an existing network area, the design of concession rights is a relevant regulatory area to investigate.

2.5.2 Connection charges

The second regulatory area concerns network charges including connection fees. This arises from the definition described in Section 2.4, i.e. LECs can choose to operate with or without a connection to the distribution system network, but shall have the right to be connected. The revised Directive 2009/72/EC includes the provision that LECs *"may conclude an agreement with a distribution system operator to which their network is connected on the operation of the local energy community's network."* EC [2017c] In accordance with latest amendments from the Parliament, LECs area required to *"adequately contribute to the costs of the electricity system to which they remain connected"* Therefore, the Directive

[1] Amendments from the first reading of the trialogue, representing the current status of the proposals during the time-frame of the Thesis

further defines that charges at a certain connection point apply for a connection between the LEC network and to the overall distribution grid. NRAs are requested to transparently outline the methodology determining network charges. These need to be cost reflective and non-discriminatory. The calculation method of these network charges is another chosen regulatory area for investigation.

2.5.3 DSO revenue regulation

Characterised as natural monopolies, regulation of DSO business is a key aspect of national legislation affecting power network operators. Although regulation schemes are differing among Member States, regulation in form of revenue caps are wide-spread across the EU, including Sweden. As the name indicates, revenue caps define the maximum allowed yearly DSO revenue. [Wigenborg et al., 2016; AF-Mercados EMI et al., 2015] The regulation on DSO business is related to previously introduced legislative area of concession rights. The business-economic impact of selling or leasing a network area to LECs depends on the current design of the revenue cap. Accordingly, incentivising elements within regulation of revenues define the related economic loss or benefit occurring with LEC penetration.

The extent of the economic impact resulting from revenue cap design further affects network tariffs for DSO customers outside LEC boundaries, as the revenue cap determines allowed charges posed by DSOs to their customers base. Since the EU's key objective is to provide a fair deal for *all* consumers, LEC development shall not lead to higher tariffs for remaining customers from a socio-economic perspective. This is another key factor for the relevance to analyse the appropriateness of revenue cap regulation and resulting economic impact.

2.6 Research question

Capturing the potential of geographically distributed RES implies a shift from currently centralised to more decentralised energy systems. Historically, neither the technical design of energy infrastructures nor existing business models are shaped to meet the needs of transforming energy systems. One potential solution that has been developing across Member States are energy communities on a local level. The concept of "Local Energy Communities" has been included in proposals of EU's CEP within the revised Directive 2009/72/EC on common rules for the internal market in electricity [EC, 2017c]. It defines the production and consumption from locally available RES within a geographically defined energy system that is controlled by local shareholders that act in diverse roles across the supply chain to optimise local energy use. Energy communities are not only serving customer empowerment, but are supposed to enable a cost-effective and efficient integration of DG from RES, that has so far been causing technical problems and increased electricity prices as experienced in countries with already high shares. Accordingly, an integration of LECs can potentially contribute to an achievement of all three key goals defined under the CEP while further facilitating the fulfilment of energy and climate targets on national level, such as the Swedish objective of 100% RES power supply by 2040.

To allow an establishment of LECs, however, Member States need to fulfil certain provisions. Interactions and alignment with distribution network operators are identified as prerequisite, and accordingly feasible regulatory frameworks for distribution systems are required. Among other aspects, the economic impact of LEC penetration on DSO business is a relevant factor defining the willingness to support LEC development by selling or leasing the grid area to local communities. Allowed DSO revenues further influence consumer tariffs, which is an important aspect for determining the value of LECs to overall society under current legislative circumstances. At this point, the overall research question (RQ) of the Master Thesis arises, that is;

"Which regulatory changes within national regulation of distribution systems are required for the establishment of Local Energy Communities as proposed by the EU to contribute reaching an energy transition?" - case study Sweden

2.7 Overall research strategy

For investigation, three sub-questions serve as steps for the analysis;

1. Which technological set-ups and grid areas are feasible for LEC establishment to facilitate an energy transition in Sweden?
2. How should national regulation on allowed DSO revenues be designed to create business-economic feasibility of LEC penetration?
3. How can other regulatory areas on distribution networks be adjusted to support LEC development?

Since the main RQ targets a reflection upon regulation on national level, case study research based on the example of Sweden represents the overall method of the analysis. The concrete framing of regulation areas on distribution systems such as the allowed revenue cap is determined by regulation for each network company. Therefore, parts of the analysis are further conducted for the concrete case of a chosen Swedish DSO. Accordingly, a cooperation with one of Sweden's largest network operators E.ON Energidistribution AB is conducted for the case study.

To investigate on the sub-questions, hypothesis testing is the chosen strategy of the underlying research design within this Thesis. These hypotheses are derived from a further research on the conclusions gained from reflecting on both the problem analysis as well as the introduced theoretical framework. A more precise description on the strategy and developed research design is outlined in Section 4.1.

2.8 Limitations

Case study - Sweden

Limitations of the investigated research areas are set to narrow down the scope of the Thesis. The first limitation arises with the chosen methodology of case study research, since the analysis is conducted for the specific case of Sweden and more specifically for the grid area of one selected DSO. Although results are framed upon regulation and financial calculation methods resulting from the context of the case study, the developed methodology can potentially be applied for analysing the feasibility of national regulation and economic impacts on distribution systems in other Member States. Despite the relevance of other dimensions arising with LEC establishment, i.e. environmental, technical or social, the focus is set on regulatory and economic issues.

Regulation area - focus on electricity distribution

Although other legislation domains are relevant for LEC penetration, e.g. technical requirements or roles and responsibilities within LECs, regulation on distribution systems is chosen as scope of the analysis. This results from the EU's provisions outlining an integration within the current distribution grid as fundamental requirement for LEC development. Since the EU's proposals are part of the revised Directive 2009/72/EC on common rules for the internal market in electricity, provisions regarding LEC establishment are addressing issues concerning the electricity grid. Therefore, the regulatory analysis is further limited to power distribution systems. Despite the inclusion of sector-coupling variations of LECs as a relevant factor for scenario modelling, a reflection on the appropriateness of regulatory issues involving other energy carriers and related infrastructures, e.g. thermal grids, exceeds the scope of this Thesis. The same applies for the economic evaluation, as outlined below.

Business-economic assessment - network operator

The Thesis compromises a business-economic evaluation rather than from the socio-economic point of view. Based on the focus of the Thesis, i.e. national regulation of distribution systems, the assessment is conducted from the perspective of the distribution network operator. Consequently, investigations of optimal processes within LEC boundaries are not further analysed, thus excluding assessments on related costs or tariff design for the community.

Although the economic evaluation is based on the perspective of DSOs' business, the overall aim of answering the research question is to realise the EU's overarching energy and climate policy objectives. Accordingly, resulting regulatory proposals are targeted on achieving suitable framework conditions that might require regulatory changes to facilitate RES integration via local communities to improve societal welfare rather than DSO business.

Theoretical framework 3

To supplement the definitions of LECs derived from the EU's proposals, an outline of theoretical approaches on community classifications and definition within literature on community energy projects constitutes the first part of the theoretical framework. Since LECs shall contribute to reaching an energy transition, paradigms and theoretical approaches dealing with sustainable transitions of the energy system are further outlined.

3.1 Concept of energy communities

In Section 2.4 outlined proposals on the EU's idea of LECs are rather unspecified and leave room for interpretation. To create a better understanding of potential characteristics, literature dealing with the terminology of *energy communities* is reviewed to outline existing definitions and how these match with EU proposals.

3.1.1 Classifications in literature

Project expectations

One methodology to categorise types of energy communities is developed by Ruggiero et al. [2018], resulting from an analysis on existing community energy projects in Finland. The classification is based on the initial motivation and expectations of involved actors. As a result of the study, community energy projects can be classified into three main types;

- *Cost reduction projects*: small-scale projects (one property or village) with no intention to expand, main expectation to lower energy costs
- *Technical expertise projects*: also small-scale with no intention to expand, main expectation to achieve environmental benefits, self-autarchy and local energy cost reductions by using technical know-how of actors
- *System change projects*: larger projects that are not limited to a small geographical area, main expectations to establishment new technologies or other ways of RES production and societal change; R&D for new solutions with the aim to expand by replicating outcomes/ spreading information [Ruggiero et al., 2018]

When analysing the form of LECs as proposed by the Commission compared to the categories above, there is no definite matching since only limited information about the community project is provided. Overall, desired purposes of LECs depend on the perspective. Derived from motivations of existing community initiatives described in Section 2.4.1, motivations from the viewpoint of community members are concerning local benefits and are consequently most likely resulting into desired cost reduction or technical expertise projects. From the perspective of the EU, however, LECs are further foreseen as potential contributor to achieving an energy transition. Accordingly, system change projects might be the desired from a political and socio-economic perspective. Based on the different motivations depending on the viewpoint, the LEC set-up should optimally be designed to fulfil both the expectations of community members but also contribute to the EU objectives.

Another parameter used in literature to classify community energy projects is the form of ownership, described in the next section.

Ownership forms

Aware of different levels of participation of the civil society within community initiatives, Ruggiero et al. [2018] describe members' involvement in both energy production and saving as characteristics defining an energy community. For the example of developments in the UK as outlined in Walker [2008], however, initiatives branded as community energy include projects where energy production units are owned and run by local entities, such as authorities, entrepreneurs and organisations, rather than various community members. Accordingly, the following main categories for energy community initiatives are defined;

- *Cooperatives*: citizens take ownership by investing in the project, e.g. owning shares of a wind farm
- *Community charities*: charity organisation provides citizens with community facilities (churches, schools etc.) that are powered and/or heated by RES
- *Development trust*: mostly to represent community interests in profit-oriented companies with partial inclusion of community ownership forms
- *Shares owned by local community organisation*: shares or parts of commercial projects (e.g. wind turbines) provided to a community organisation; community benefits directly related to the production performance
  [Walker, 2008]

Other than some of the definitions of energy communities described above, the Thesis aims to analyse energy communities where members are in control of their local energy system, as proposed by the EU. This involves active participation in production and consumption and resulting benefits from integrating locally available resources, rather than solely taking stake of RES technologies. Consequently, forms of energy communities entirely owned and managed by other parties than the community are out of scope. Within projects of community-based ownership forms, the share of community ownership can vary between being entirely community-owned and co-ownership forms. The energy produced in initiatives under the above listed ownership forms can further be utilised either locally for the consumption within the community or fed into the main grid, as distinguished between self-consumption projects and electricity export projects in Berka and Creamer [2018]. Outlined in Section 2.4.2, the concept of LECs as proposed by the EU clearly targets increased local consumption. Consequently, the latter type of community initiatives is not desired.

Community definition

Whether the community-produced energy is utilised locally or exported further depends on the definition of "community" and its actors, which is another important definition when describing different assumptions of local energy communities. In relation to their involvement in energy projects, Walker [2008] outlines two different categories of communities. Accordingly, members forming a community can either be defined as *communities of location*, i.e. members physically located within a defined geographical area, or *communities of interest*, where members investing in a common RES project such as a cooperative but without being necessarily located close to other members and/or the production facility. The CEP tackles communities of location, since the proposals clearly address the attitude of locality as outlined in Section 2.4. In contrast to communities of interest that only follow economic and environmental purposes, communities of location further involve possible changes in technical and institutional aspects. [Koirala et al., 2016] Since the focus of this Thesis is on analysing regulatory framework conditions that are further related to institutional aspects, communities of interest are out of scope for this Thesis. Same applies for projects that are defined as community energy because of the non-commercial status of the leading organisation, e.g. charity, social-enterprise, rather than due to active participation of civil society, as described before.

3.1.2 Dimensions of energy community projects

By analysing various initiatives in the UK, Walker and Devine-Wright [2008] clustered interpretations of communities in relation to RES projects into two key dimensions, as illustrated in Figure 3.1.

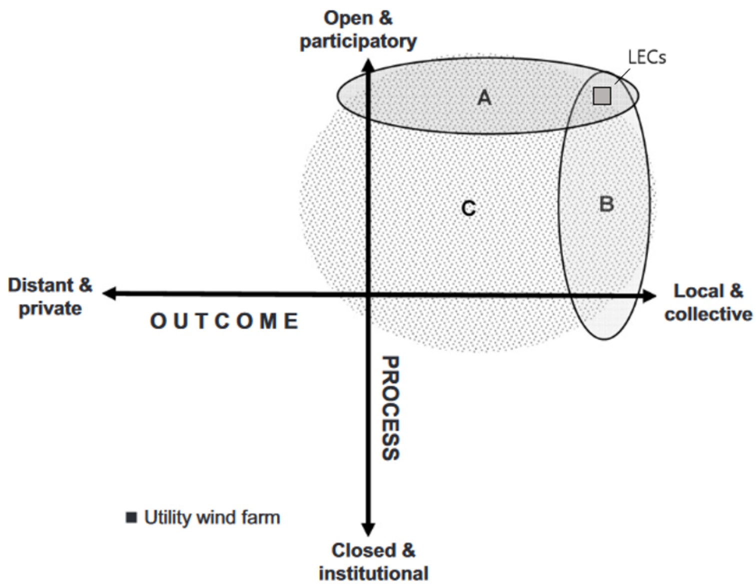

Figure 3.1. Interpretations of community energy based on the dimensions of outcome and processes
derived from Walker and Devine-Wright [2008]

Accordingly, the following two parameters can serve to identify the role and benefits of local citizens being involved in the energy community;

- *Process*: defines actors involved and having influence; actors that *develop* and *operate* the project; ranging from "closed & institutional" to "open & participatory"

- *Outcome*: defines actors that *benefit* from the project (economic and/or socially); ranging from "distant & private" to "local & collective"
[Walker and Devine-Wright, 2008]

Shareholders of projects characterised as "closed & institutional" are represented by institutions that do not offer participation for actors outside. This is mainly the case for projects of the conventional energy system, typically further combined with "distant & private" outcomes, i.e. benefits stay within the institution. Accordingly, traditional centralised energy projects are located in the negative ranges of the X- and Y-axis, as the illustrated utility-owned wind farm in Figure 3.1. In general, such projects do not focus on locality since generated energy is typically fed into the main grid. This is in contrast to "open & participatory" initiatives, allowing active involvement of other players such as households and creation of local benefits. [Walker and Devine-Wright, 2008] Community renewable energy projects can be divided into three different viewpoints of, illustrated by areas (A), (B), and (C) in the figure. Definitions of community energy in shape (A) focus on local participation, i.e. the empowerment of citizens is defined as necessity for community energy projects. Here, less focus is set on maximising local benefits created by the outcome, which is captured by area (B). This category covers initiatives run by local institutions such as authorities that generate value for citizens, e.g. providing RES-powered public facilities, as described in the section on ownership forms above. The third possible perception of community energy of area (C) is broader. It can be interpreted as covering any kind of initiative having more focus on both local participation and value creation compared to traditional approaches.

The terminology of energy community in this Thesis refers to the concept of LECs as defined in the CEP, thus aiming to contribute reaching the objectives of EU's energy policy as outlined in Chapter 2. When projecting the desired characteristics of LECs into Figure 3.1, the concept fits best into the overlapping area covered by shape (A) and (B), as added to the illustration. Accordingly, both the EU's objective of active involvement in the process resulting into citizens empowerment (*citizens at the core*) as well as creating economic and social benefits for involved members as desired outcome (*fair deal for consumers*) are represented by that area.

Derived from the EU's proposals, benefits of LEC development are further foreseen to go beyond the borders of the community. Accordingly, the concept shall contribute to the overarching policy objectives, including a required transition towards RES-based energy systems. The following section introduce theories developed on realising renewable energy systems.

3.2 Approaches towards future renewable energy systems

Definitions and descriptions of future energy systems typically advocate the paradigm of a required *smart* environment. According to reviews of existing literature conducted by Lund et al. [2014, 2017], the frequently used terminology of *smart grid* is typically related to the electricity sector. As further outlined, this includes both definitions by international institutions and organisations level, e.g. U.S. Department of Energy, International Energy Agency or the European Commission, as well as within scientific literature. One example of such a definition occurs in Rodríguez-Molina et al. [2014], where the two main achievements using ICT within smart grids are defined to integrate a higher amount of available RES into power networks and to contribute to a more efficient use of electricity.

To realise a cost-effective integration of volatile RES, however, Lund [2014] emphasises the need for a substantial transformation of the entire energy system. A concept for reaching such a comprehensive transition is captured by the *Smart Energy Systems* (SES) approach. To apply the SES concept for communities on a local level, the Integrated Community Energy Systems (ICESs) approach describes required functions and characteristics of local energy systems. Both approaches are outlined in the following sections.

3.2.1 Smart Energy System approach

In general, the concept of SES builds upon sector-coupling and consequently synergies between infrastructures of different energy carriers. Lund [2014] identifies three main grid types. Next to electricity grids, these include gas grids as well as thermal grids, i.e. (district-) heating and cooling (H&C) networks. Applied for LEC set-ups, four potential energy system configurations are illustrated in Figure 3.2.1 below.

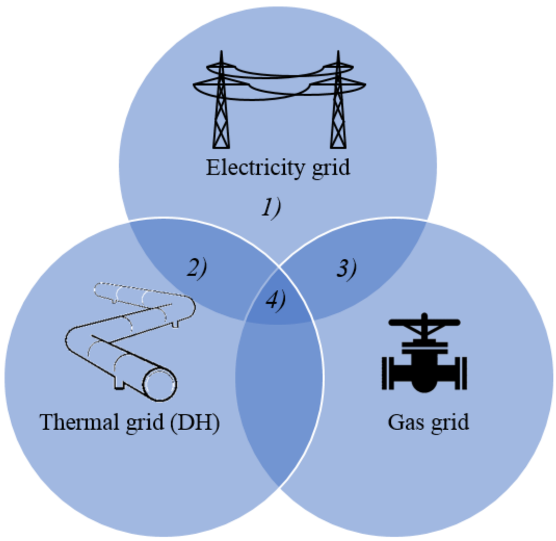

Figure 3.2. Possible LEC system configurations derived from the SES approach

The first version focuses on the electricity grid only, i.e. the community generates and consumes electricity without transformation into different energy carriers. For the remaining versions, a conversion unit serves to transform power into heat or gas (P2H or

P2G). Consequently, these versions involve an existing H&C, i.e. district heating (DH), or (natural-) gas grids respectively. The fourth potential LEC set-up combines all grids.

As the name of the theory indicates, the approach further requests a smart grid environment for energy infrastructures. Based on the smart character, the grids are further defined as intelligent infrastructures that allow a bidirectional energy flow, i.e. the participation of prosumers as discussed in the problem analysis in Section 2.1. According to the SES theory, synergies between these smart grids in combination with storage solutions creates possibilities to compensate the lacking flexibility of fluctuating RES, such as solar PV and wind energy. Illustrated in Figure 3.2.1, examples for synergies are conversions of electricity into heat or gas (hydrogen), enabling a more economic and efficient storage of electricity. Case studies on the SES approach exist for both national system level for Denmark in Mathiesen et al. [2015] and EU-wide in Connolly et al. [2016]. Results show that both the individual energy sectors but also the entire energy system can be adjusted to cope with the transition to renewable energies, if storage and infrastructure solutions are developed under the SES concept. [Lund et al., 2017]

3.2.2 Integrated Community Energy Systems concept

Koirala et al. [2016] outline the broad existence of research on implementing distributed RES locally. These studies, however, primarily focus on technology integration and lack comprehensive approaches, especially on the role of households and communities. ICES are an integrated approach by combining various options of integrating RES from DG on a local level, i.e. in energy communities. When reflecting on the possible categories by Walker [2008] outlined in Section 3.1.2, ICESs represent communities of location. Regarding the scale, there is no definite specification since ICESs can vary from single household blocks up to larger areas covering entire districts. [Koirala et al., 2016] Overall, the following key criteria characterise ICESs;

Parameter	**Description**
Locality	Local participation in investments and ownership Local system operation Local generation for self-consumption and local energy exchange
Modularity	Option for members to leave or join the community Ability to add or remove connected households and technologies
Flexibility	Local ability of demand response, balancing, flexibility of load and supply, energy and system services
Intelligence	Smart grid technologies to optimise local demand and supply
Synergy	Coupling between sectors and technologies
Customer engagement	Customer involved through investments, ownership, energy exchange and economic incentives
Efficiency	Technical and economic system efficiency

Table 3.1. Criteria defining ICESs
based on Koirala et al. [2016]

According to the ICES concept, the community has the capability of local heat and electricity production, demand flexibility services and storage options. Regarding the attitude of locality, exchange of produced energy within the community is outlined as one key characteristic and shall be based on locally determined energy prices. [Koirala et al., 2016] Next to optimising self-consumption, the mechanism serves to keep financial resources within the community that can potentially lead to increased local welfare. In addition to creating benefits within the borders of the community network, ICES can contribute to overall system stability by providing three main service types. For the electricity grid, these are energy-related services through power exchange to the superior grid, providing ancillary services, as well as network-related services, e.g. voltage control. Services can also be provided for heat and gas grids, i.e. by synergies via power conversion units. In line with core EU objectives, ICES clearly contribute to customer engagement since every citizen within the community network is entitled to become a stakeholder and an active part in energy production and consumption. Defined as non-profit entities, ICES follow the objective of creating benefits for the community such as by providing a both technically and economically efficient energy system. Further outlined in Koirala et al. [2016], citizen empowerment has the additional benefit to potentially overcome problems of public acceptance related to energy transitions. Accordingly, this includes both less social resistance against RES generation unit installations as well as changing consumption patterns.

ICESs aim to establish innovative options for existing infrastructure and available RES. Accordingly, ICESs are a concept to re-design and re-organise traditional energy systems to facilitate a local integration of DG. In accordance with EU proposals, this implies a foreseen establishment of energy communities either in existing networks or new residential areas within a concession area. Newly established energy systems outside a concession area, i.e. green field, are regarded as exception that might only occur in rural areas within developing countries without existing networks. [Koirala et al., 2016] Since the Thesis focuses on the European perspective and in particular on the case study of Sweden, analysing an integration of LECs from a green-field perspective is out of scope.

Compared to the descriptions and provisions for LECs set within EU's energy policy, all of the aspects above are relevant factors to reach the desired form of energy communities on a local level while further complying with the SES theory of sector-coupling in a smart grid environment. Consequently, applying the ICESs concept for defining characteristics of LECs is an important aspect within this Thesis. Next to technological characteristics influencing the design of LECs, paradigms dealing with energy transitions address institutional issues that are relevant to consider for the upcoming analysis. These are introduced in the next section.

3.3 Paradigms of energy transitions

Derived from previous sections, adjusting the current energy system involves a transition process. Next to a technological change, the EU's provisions for Member States to adapt national legislation further imply required adjustments of embedded institutional conditions, including regulatory frameworks. Koirala et al. [2016]

The problematic of prevailing conditions of the energy system are addressed in theories on sustainable transitions such as within the Multi-Level Perspective theory outlined in Geels [2002]. Accordingly, institutional settings have been developed over time and are consequently tailored towards the suitability for the existing conventional energy system, i.e. the current *regime*. Geels [2002]. Characterised as stable system, the regime is strengthened by well-developed technologies that are embedded in corresponding infrastructures and institutions. To enable a sustainable energy transition that allows alternatives to enter the market, the regime has to undergo changes. Studies on energy system transitions such as Mendonça et al. [2009]; Hvelplund [2013]; Hvelplund and Djørup [2017] conclude on the need to alter both technologies but also market conditions shaped by policies and regulation.

As a prerequisite, it is essential to understand why an alteration of prevailing organisational and institutional conditions is needed for an energy transition. Elaborated by Hvelplund [2013], the necessity of adapting such fundamental dimensions occurs in the case of *radical technological changes*. In addition, it requires an assimilation with different economic paradigms and the appropriateness for evaluating technical alternatives. These issues are introduced in the following sections.

3.3.1 Radical technological change

Hvelplund [2013] and Lund [2014] describe technologies by five dimensions i.e. technique, product, organisation, knowledge and profit. Further outlined, technological change is characterised as radical if at least two of these parameters are transformed. Tested on the concept of LEC as defined by the EU and within the theoretical approaches of SES and ICES, the dimensions are affected as followed;

1. *Technique*: characterised by local production using locally available RES, there is a clear change of technique, i.e. from large-scale, centralised nuclear and fossil-fuel based generation units into more distributed RES facilities. To enable high self-sufficiency, it further requires an implementation of technologies such as power conversion units (P2H or P2G) and storage facilities.
2. *Product*: in traditional energy systems, the product is the supply of electricity, heat or gas. As elaborated in Section 3.2.2, products within a LEC further occur in form of energy services such as flexibility offerings realised by smart grid technologies.
3. *Organisation*: Lund [2014] distinguishes between single-purpose and multi-purpose organisations. Accordingly, actors responsible for activities within conventional energy systems are represented by single-purpose companies. As the name indicates, these companies are specialised on one main activity, e.g. power generation or distribution, since it represents their core business. Within LECs, however, actors include prosumers such as households that are defined as multi-purpose organisations

since a participation in the energy system is only a side activity and not the main purpose.

4. *Knowledge*: linked to the different organisational characters, Lund [2014] refers to a change of knowledge-base, since single-purpose organisations typically obtain a higher level of expertise. In this context, Lund [2014] mention the problem of technology maintenance that might suffer if controlled by multi-purpose organisations.
5. *Profit*: flows of generated profit depend on involved actors. In conventional energy systems, energy is produced and supplied by single-purpose actors to passive consumers, i.e. without active involvement in ownership or production. Outlined in Section 2.3 for the Swedish case, electricity production and consequently generated profit lies majorly in the hand of a few large entities including both private and, e.g. the case of Vattenfall, state-owned producers. Within LECs, however, generated profit is foreseen to primarily stay within the community to create benefits locally, as both described in the ICES approach and further emphasises within the EU's provisions outlined in Section 2.4.2.

3.3.2 Economic doctrines

To reflect on the economic perspective of a technological alternative, researchers such as Lund [2014]; Atkinson [2010] stress the importance of the applied economic paradigm. Accordingly, the underlying doctrines among policy makers on achieving an optimal economy are shaping the design of regulation. Regarding the energy sector, actors of the current regime tend to evaluate alternatives under *neoclassical economics*. This approach assumes stable institutions, operating under conditions of a free market that further determines the best choice of technologies. [Lund, 2014] Neoclassical doctrines assume the highest economic welfare as a result from competitive prices that are market-based rather than set by regulation, while policies are seen as distortion of the market. [Atkinson, 2010] Further elaborated in Lund [2014], however, basic characteristics of a free market such as fully informed independent market participants do not apply for the energy sector. In contrary, the energy market is shaped by natural monopolies or oligopolies, e.g. network operators or energy suppliers such as in the Swedish case. Consequently, the market is subject to public regulation and operates under specific institutions. In contrary to the neoclassical paradigm, the approach of *institutional economics* recognises the influence of institutional settings. Accordingly, analyses of current institutional conditions, such as regulatory frameworks determining DSO business as relevant for the scope of this Thesis, are a prerequisite for the feasibility study.

Schneider et al. [2010] outlines another underlying paradigm that has been dominating politics of the prevailing energy market, reflected by the concept of economic growth. Here, economic development within the sector is assumed to depend on growing production and consumption. This approach, however, contrasts with sustainability ideas such as higher efficiency e.g. via technology improvements. To support sustainable development, Schneider et al. [2010] introduces the economic paradigm of *degrowth* that is further discussed in the light of energy communities in Alarcón Ferrari and Chartier [2016]. The concept targets a switch from "more to better", which can be applied for introducing alternative technological solutions.

However, such alternative solutions following the idea degrowth can only be realised if economic paradigms are altered accordingly within political processes. Resistance from powerful actors of the conventional regime against political re-design towards the paradigm of degrowth can be expected, since their economic activities are built upon economics of growth. [Alarcón Ferrari and Chartier, 2016] In this context Lund [2014], stresses the importance of appropriate democracy between different interest groups within political processes. Here, the problem arises with the comparatively higher political power of actors within the current regime. This results into stronger influences on policy making, including the design of institutional conditions. To include the aspect of energy democracy into the economic paradigm, the concept of *innovative democracy* has been developed for energy planning purposes in Denmark since the 1970s as further outlined in Hvelplund and Djørup [2017]. To realise such innovative democracy, Lund [2014] defines the requirement of a so-called *new-corporative regulation*. The terminology of corporative implies a cooperation between political decision-makers and interest groups, i.e. lobby, of different technologies. Whereas in old-corporative regulation mainly actors of the current regime have a voice, innovative democracy foresees to equally involve alternative interest groups. The design of democracy further affects the realisation of shifting economic paradigms, such as towards institutional economics and the concept of degrowth.

After all, the concluding section of the theoretical frameworks that follows next outlines the definition of LECs as understood within the Thesis.

3.4 Resulting LEC definition

First of all, four potential versions of LEC set-ups are defined based on sector-coupling possibilities derived from the SES approach, . Among these versions, the configuration of combining power and thermal networks is chosen for the analysis. This aligns with the desired concept as proposed within the EU's Directive. Therein, LECs are described as *"efficient way of managing energy at community level by consuming the electricity they generate either directly for power or for (district) heating and cooling"*. [EC, 2017c] Furthermore, a potential for such a LEC set-up can be expected for the case of Sweden due to its well-established DH market as outlined in Section 2.3.1. Figure 3.3 illustrates resulting processes for the chosen LEC version between involved actors and technologies.

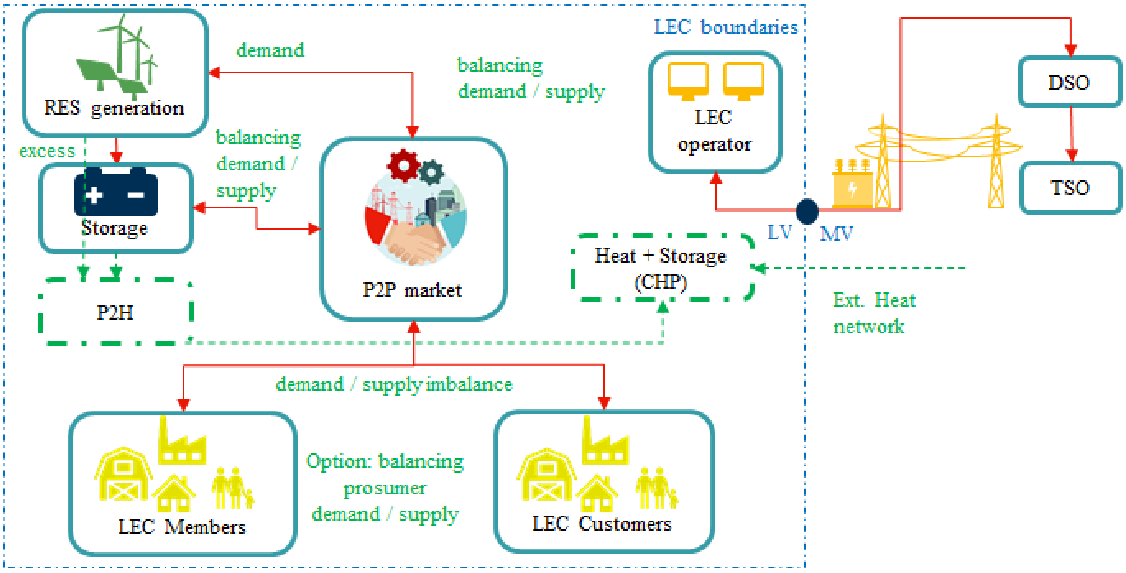

Figure 3.3. Actors and energy flows of LECs as defined within this Thesis

Based on the definition within the CEP, LEC networks can technically be described as micro-grids. According to definitions in Jiayi et al. [2008]; Koirala et al. [2016], micro-grids are controllable subsystems supplying electricity and heat locally. Micro-grids can further operate in both interconnected or island mode. As illustrated in Figure 3.3, the Thesis assumes the establishment of LECs within the low voltage (LV) networks with a connection point to the medium voltage (MV) level. This aligns with the definition of micro-grids in Jiayi et al. [2008], that are accordingly typically established in LV networks. In case of an existing interconnection, the connection point is assumed at the MV/LV transformer, owned by the DSO of the concession area and therefore excluded from the LEC boundaries. Based on analysed grid data from the chosen DSO network, however, within community networks primarily established in LV grids the occurrence of MV power lines as well as MV/LV transformers is still possible and need to be included in the asset base for the calculation the economic impact. Further illustrated in Figure 3.3, the converted electricity used for heating purposes is injected into existing, external DH grids. The same is assumed for the case of gas grids in the remaining LEC versions. As outlined in Section 2.8 on the delimitation of the Thesis, issues on regulation and tariffs regarding H&C and gas are not within the scope of the analysis.

3.4.1 Involved actors

Actors within the LEC boundaries include LEC members, LEC customers and a legal entity responsible for operating the LEC.

LEC members

The proposals outline that LEC members are stakeholders and therefore included in the ownership of LECs. Members are further entitled to actively participate in DG and other activities across the local supply chain. Accordingly, the parameter of *customer engagement* in the ICES approach applies to LECs. Prosumers are characterised as multi-purpose organisations as described in Section 3.3.1, thus involving related problems defined in the theory such as limited financial resources and knowledge resulting from this radical technological change.

Operating organisation

To contribute to these barriers of LEC members, the operating company represents the central control system of the community energy system. According to the latest proposals, the EU foresees the organisation as *"an association, a cooperative, a partnership, a non-profit organisation, SME or other legal entity"*. The operating company shall represents the required new organisation substituting the lack of knowledge for both operation and maintenance. Since this organisation is still considered to be newly established, the problem of lacking political power might still apply. Unlike traditional energy utilities, EU's proposals authorise the LEC operating entity to be involved in *"distributed generation, storage, supply, provision of energy efficiency services, aggregation, electro-mobility and distribution system operation, including across borders"*. [European Parliament, 2017b] Consequently, the operating organisation is given a certain level of power since it can be involved in both production and storage, takes the role of the DSO within the community and is responsible for balancing demand and supply, which differs from the principle of unbundling that is applied for traditional utility companies or DSOs. At the same time, however, the fulfilment of such diverse duties still implies a multi-purpose character of the operating company.

LEC customers

LEC customers are those physically connected and supplied by the LEC but without any participation. According to proposal in EC [2017b], consumers can freely choose to be involved or leave the community. This reflects the ICES' parameter of *modularity*. The concept of voluntary participation further aligns with the theoretical approach developed by Walker and Devine-Wright [2008] of interpreting dimensions of community energy projects. As outlined in Section 3.1.2, processes are described as open and participatory, i.e. allowing the community members the choice of local participation. To allow such freedom, the Directive includes the provision to guarantee access to the grid operated by the energy community on a cost-reflective basis for all customers, regardless a participation. [EC, 2017b] Since all of these actors and their actions are physically assumed within the LEC network, most of the functions covered under the parameter of *locality* are fulfilled.

The realisation of the remaining function, i.e. local energy exchange, is described in the next section on energy flows.

3.4.2 Energy flows

For surplus power from active prosumers, i.e. remaining power after self-consumption, a peer-to-peer (P2P) market is foreseen to serve for local energy exchange, enabling local balancing of demand and supply. The local market further serves to distribute generated power from local production units, that are intended to be RES-based. If local production exceeds LEC demand, the surplus is stored and used for balancing local demand and supply when needed or exported to the main distribution grid. Solutions such as DSM are possible services that the LEC operator can provide to optimise local self-consumption. In case of the other LEC versions involving synergies with additional energy grids, surplus power can be further utilised to increase local self-consumption in other sectors. Therefore, the parameter of *flexibility* is covered. To enable *intelligence*, the LEC members are supposed to be equipped by smart meters. This is also outlined in the provisions within the revised Directive 2009/72/EC, requesting Member States to ensure smart meter implementation for enabling customer participation. [EC, 2017b]. The last aspect of *efficiency* is supposed to result from the overall LEC design and functions.

Overall, this set of technological solutions potentially contributes to the paradigm of *degrowth*. Instead of investing in additional production units or grid reinforcement, establishment of storage and/or sector coupling units supplemented with smart approaches leads to local self-consumption and more efficient resource utilisation by decreasing demand. In this context, an outline of potential contribution to both political and economic objects can be made. Consequently, LECs are expected fulfil key EU policy targets outlined in Section 2.2 such as increased energy efficiency and RES utilisation as well as consumer empowerment. From the perspective of LEC actors, however, the motivation is more likely based on expected economic benefits. In this context, Lund [2014] mentions increased level of innovation, environmental benefits, improved balance of payment, e.g. resulting from reduced import dependency through local RES-based self-consumption. Another desired benefit, as also expected within the EU's proposals for LECs, is local development related to economic growth including job creation, e.g. new legal entity representing LEC operator. This potential benefit, however, has to be considered carefully as it might contrast with the concept of degrowth as reflected by findings in Alarcón Ferrari and Chartier [2016]. Consequently, local economic growth is targeted to occur in a sustainable way, i.e. establishment of new entities that contribute to environmental benefits such as contribution to improved energy efficiency and resulting decreased use of resources.

4 Methodology and research design

4.1 Overall strategy

The overall chosen concept to reflect on the RQ of this Thesis is based on hypotheses testing. Accordingly, the Thesis aims to prove established hypotheses, arising from results of the problem analysis as well as the underlying theoretical approaches. A further research on these insights are translated into several hypotheses that are tested for the Swedish case within this Thesis. Since the research question deals with regulation on a national level, the main idea of the chosen research strategy is to prove the validity of the results of literature research and theories for the specific national framework conditions. In addition, the developed hypothesis further serve as a guide on relevant questions to address within the complex topic of LECs and related regulatory frameworks.

To further structure the research, the design is based on the developed methodology in Lund [2014] under the Choice Awareness theory. The concept serves to realise such paradigmatic transformations of the energy systems as explained within the theoretical framework. Accordingly, the developed sub-questions align with the first three steps of Choice Awareness. The resulting hypotheses are structured based on the Choice Awareness' methodology and allocated to sub-question outlined in Section 2.6. Therefore, the Choice Awareness' methodology and the hypotheses derived from the theory and problem analysis are outlined before introducing the resulting research design of the Thesis.

4.2 Methodology of Choice Awareness theory

Elaborated in Lund [2014], the methodology of Choice Awareness is built upon two theses. The first thesis assumes that existing institutions constrain radical technological changes by attempting to eliminate alternative choices for society. Overall, the theory reflects that required changes of embedded institutions pose challenges to existing organisations since their activities, including resulting revenue streams, are shaped towards current rules of the game. The consciousness of these actors on the adverse effects of transitions on their organisation leads to resistance and the attempt to eliminate awareness on alternative choices to society. The approach deals with processes on political decision-making and the factual situation that interests of such embedded organisations typically obtain a higher level of power. To counteract, the theory aims to raise awareness among society about the choice for alternatives.

The second thesis concludes that raising awareness on alternative technologies creates added value for society. Resulting from the radical character of technological changes related to sustainable energy transitions, the methodology of Choice Awareness targets the promotion of both technical but also institutional alternatives. According to the theory, applying Choice Awareness is based on four main steps;

1. Description and promotion of technical alternatives
2. Economic feasibility studies
3. Proposals for public regulation measures
4. Proposals for institutional changes and improved democracy

Firstly, a thoughtful design of alternative technologies is required to counteract resistance of prevailing powerful organisations of the current regime. Lund [2014] describes three important areas to be respected. First, equal comparability to key parameters such as capacity and generation needs to be provided. Applied to the case of LECs, this implies capability of sufficient generation from alternative technologies to ensure equivalent access to energy and reliability of supply for its citizens. Secondly, benefits related to renewable energy systems should be included, i.e. more efficient energy usage by using locally available RES within the community. Further outlined in the Choice Awareness theory, technical alternatives should contribute to political objectives. In case of LECs, a contribution to key policy goals is expected within EU proposals as outlined in Section 2.4.2 of the problem analysis. In addition, contribution to economic objectives should be addressed, e.g. level of innovation, environmental consequences, local and national impacts. Lastly, the design of the alternative should lead to equal direct costs than those of the conventional technological solution. Therefore, the next step is to define the economic feasibility.

For the economic assessment, it can be distinguished between socio-economic and business-economic feasibility studies. Results of both approaches are relevant for the third step of proposing public regulation measures. Following the theory, underlying institutional conditions are shaped towards traditional technologies, including regulatory frameworks. Accordingly, business-economic assessments typically result into comparatively lower feasibility of alternatives. However, socio-economic evaluation might reveal overall societal benefits when choosing the alternative. This case would imply the need for regulatory re-design to achieve business-economic attractiveness. Accordingly, an evaluation from DSO perspective as conducted within this Thesis serves as first indicator on the feasibility of current regulation.

The fourth and last step foresees an identification of additional institutional barriers affecting the development of the alternative. Since the Thesis' limitations are set on regulatory areas of distribution systems, the last step is excluded from the analysis. Furthermore, investigating all aspects of the Choice Awareness' methodology is a complex and time-intensive process that goes beyond the boundaries of this Thesis. Nevertheless, the first three steps of methodology applied in a less detailed level serve as guideline for the analysis. The resulting research design is outlined in the following Section 4.4.

4.3 Hypotheses

4.3.1 Sub-question 1: Definition LEC as technical alternative

The first hypothesis is based on the purpose of LECs applied to the case of Sweden. One first ideas to make use of LECs arises from technical problems related to DG as outlined in the problem analysis. Accordingly, LECs could potentially be established in network areas with existing problems to solve reliability problems. Since the case is applied for Sweden, however, a reflection on the Swedish electricity supply analysed in Section 2.3.2 of the problem analysis indicates a relatively low share of DG in the current power system. When considering the national target of reaching a 100% RES share in electricity generation by 2040 as outlined in Section 2.3.3, however, a further penetration of DG from RES units is expected. This is also addressed within the current Swedish energy strategy as described in Section 2.3.3. The expansion of small-scale renewable generation in the future might lead to problems that could potentially be reduced by LECs. Consequently, testing the following hypothesis is essential for choosing a feasible network area for subsequent analyses;

Hypothesis 1: For the case of Sweden, the establishment of LECs can potentially facilitate future integration of distributed RES rather than solving existing technical network problems.

The second hypothesis results from the defined purpose of LECs outlined in Section 3.4. As stated in Section 2.4.2 of the problem analysis, the EU foresees the formation of LECs to create environmental, economic or social benefits. The latter can be reached by the provisions allowing every citizen to actively participate within the community energy system. Further outlined, the foreseen ability to integrate RES from DG locally while optimising self-consumption via various flexibility options can potentially contribute to create the remaining benefits. Accordingly, an integration of RES from DG via LECs is further expected to be realised in a cost-efficient manner, i.e. leading to lower system costs compared to an integration without LEC functions. Accordingly, the hypothesis arises;

Hypothesis 2: Next to customer empowerment, the functions of LECs including self-consumption and flexibility via storage, DSM and sector-coupling can facilitate a cost-efficient integration of RES from DG.

Testing the two hypothesis serve to reflect on the first sub-question of the Thesis, that is;

Which technological set-ups and grid areas are feasible for LEC establishment to facilitate an energy transition in Sweden?

4.3.2 Sub-question 2: Economic impact on DSO business

The hypothesis related to investigated business-economic feasibility is derived from findings in Günther et al. [2017], outlining that lacking incentives are hampering the development of innovative solutions. The same is expected to apply for LEC development and accordingly the economic impact on the DSO business is assumed to influence the readiness to cooperate. Accordingly, right incentives within regulation of revenues are a prerequisite. A potential problem arises from economic paradigms and current regulation of DSO business, i.e. the design of the revenue cap. Outlined by Ei in Wigenborg et al. [2016], regulation on network operators including DSO revenue cap regulation aims to create technology-neutrality. Accordingly, regulation focuses on technology requirements instead of concrete measures on achieving the desired functionality. Further described, the choice of technology should be determined by the DSO and the market rather than by regulation. This assumption, however, goes in the direction of neoclassical paradigms where a functioning free market is assumed to decide on the technology. As outlined as part of the theoretical framework, the neoclassical paradigm is identified as inappropriate for application of economic feasibility studies within the energy sector due to institutional settings shaping the market. Since neoclassical economics are preferred by actors of the prevailing regime to retain present regulation, the assumption that current revenue cap regulation is tailored towards conventional energy systems arises. Therefore, the design of Swedish revenue cap regulation as described in literature is investigated as a first step.

Current design of revenue cap

In Sweden, caps are determined for each DSO per regulatory period, i.e. four years, and were introduced by the NRA in 2012. [Wigenborg et al., 2016; AF-Mercados EMI et al., 2015] Figure 4.1 outlines the current revenue cap as determined by the Ei. The boxes outline elements forming the revenue cap. Overall, two main cost parameters (box 1 and 2) determine allowed revenues, i.e. operational- (OPEX) and capital expenses (CAPEX) . The boxes to the left side show the variables these main components are based on. The percentage numbers indicate the contribution to total revenues as Swedish average, since the share is varying between different DSOs and years. [Wallnerström et al., 2016]

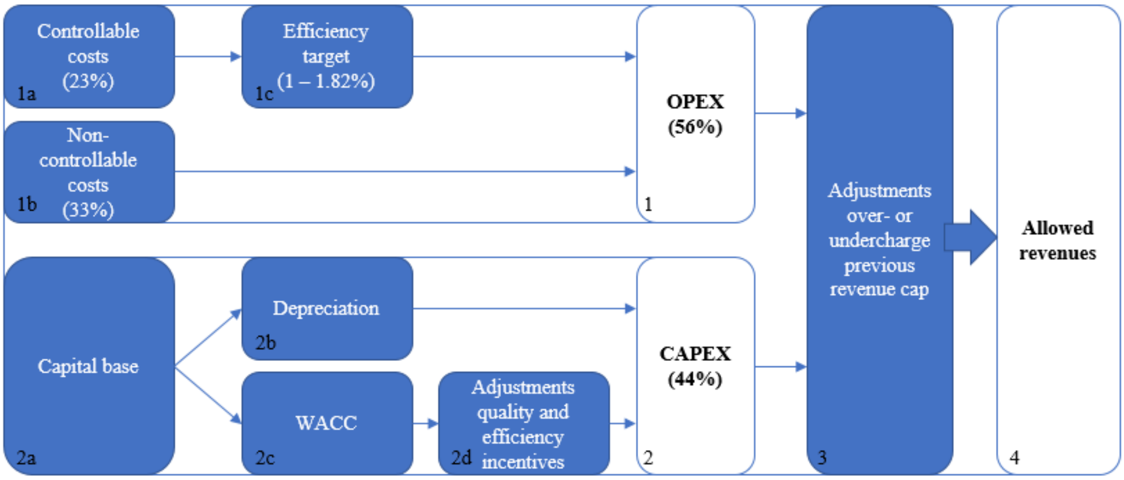

Figure 4.1. Design of the current Swedish revenue cap regulation based on Wallnerström et al. [2016]; Wigenborg et al. [2016]

OPEX are the sum of controllable and non-controllable costs as seen from box 1a and 1b. Further explained in Ei [2016a], the latter is adjusted with an additional efficiency target varying between DSOs. Overall, OPEX are based on historical data of the DSO. Controllable costs include planned maintenance or salaries for employees, whereas costs defined as non-controllable are caused by losses, connection costs to sub-transmission levels as well as agency fees. [Ei, 2016b]

The parameter of CAPEX result from a valuation of the current capital base. The value is calculated based on two parameters, i.e. depreciation and return on investments. While depreciation depends on the age of components, the return is determined by the underlying weighted average cost of capital (WACC). The allowed return is further adjusted based on incentives for quality and efficiency of grid utilisation as seen in box 2d. [Ei, 2016a] The sum of OPEX and CAPEX is further adapted based on the revenue cap of the previous regulation period (box 3). Accordingly, revenues of the current period are lowered or raised based on the amount it exceeded or fell below the previous cap. [Ei, 2016a]

Changes for second regulatory period

Described in Wigenborg et al. [2016], the calculation method was adopted for the second regulatory period, i.e. from 2016 onward. First of all, a real linear calculation method replaces the previously used real annuity method. *Real* implies the calculation of the PPV for each component and the application of a *real* WACC. Whereas the annuity method excluded the consideration of age, capital cost calculation applying the real linear method differs by asset age. Explained in Ei [2016b], this method is introduced to avoid overcompensation of the DSO's assets since it considers the conditions of the asset base for each DSO individually.

The changes for the second regulatory period further included an adjusted calculation of controllable costs, that are still based on DSO's historical data with a 1% annual efficiency target to decrease costs applying for all DSOs, but further extended by an additional individual share per DSO (0 - 0.82%) as illustrated in box 1c. Secondly, non-controllable costs have previously been handled as pass-through costs and accordingly directly transferred to customers. [Wigenborg et al., 2016] Since innovative technologies are recognised as potential enabler to influence costs currently considered as non-controllable, the new regulation enables partly adjustments of these cost elements.

Driven by the EU's 2012 Directive on Energy Efficiency, Ei further introduced incentives for improving efficiency of network design and operation as outlined in Wallnerström et al. [2016]. As explained, new quality and efficiency incentives were introduces to align with expected changes of demand and supply structure in future electricity systems. These are expected to be caused by increased RES shares and non-linear loads as well as higher flexibility through smart grid development involving solutions such as demand response. In this context, Wigenborg et al. [2016] also mention an increasing role of local generation and storage.

Potential future adjustments

Published by Wallnerström and Johansson [2017], Ei modelled the influence of different parameters based on the current revenue cap to investigate additional improvements to be introduced for the upcoming regulatory period by 2020. The sensitivity analysis shows a differing level of impact depending on modelled variables. The largest negative impact on allowed revenues is caused by lower reliability. Accordingly, LECs might positively impact the revenue cap by reducing security of supply problems caused by future feed-in of renewables from DG into the main distribution grid outlined in Section 2.1. The largest positive impact on the revenue cap, however, can be reached by increasing the asset base. Furthermore, the results of the sensitivity analysis rise the assumption that an increased asset base has a comparatively higher impact on allowed revenues than it can be reached by introduced incentives on improved quality and efficiency parameters. Overall, a reflection on the revenue cap sensitivity analysis fosters the relevance of the DSO's asset base. Consequently, the parameter of CAPEX still has a comparatively large influence on allowed revenues despite the newly introduced incentive schemes. This is also seen in the structure of the revenue cap illustrated by Figure 4.1, by determining around 44% of allowed revenues. Realising the EU's provision on allowing LECs to own, establish or lease a DSO grid area, however, are leading to a decreased asset base since both cases of selling or leasing an existing network area involve an exclusion of the affected capital base from the revenue cap calculation. Based on the resulting negative impact on allowed revenues, the following hypothesis arises;

Hypothesis 3: The willingness of DSOs to facilitate LEC establishment is negatively influenced by lacking business-economic feasibility hampered by the current design of the revenue cap that incentives a large asset base.

Testing this hypothesis aims to achieve insights on the actual impact on DSO business and how it should be adjusted. Accordingly, the hypothesis serves for answering the second sub-question;

How should national regulation on allowed DSO revenues be designed to create business-economic feasibility of LEC penetration?

4.3.3 Sub-question 3: Other regulatory areas affecting DSOs

Next to regulation on DSO revenues as captured by sub-question 2, the last step investigates the Swedish context of the remaining relevant regulatory areas identified in Section 2.5, i.e. concession rights and connection charges.

Concession rights

The design of concession regimes differs among Member States. In Sweden, there are two different concession rights, i.e. line and area concession as outlined in Chapter 2 of the Swedish Electricity Act: *"A network concession shall relate to a cable with a basically fixed route (line network concession) or a cable network within a particular area (area network concession)."* [Sveriges Riksdag, 2018a]. Within area concessions as relevant for the scope of LECs, regulation applies for power transports from local distribution systems of 40 kV or below for supplying small customers such as households. [Svenska Kraftnät, 2011] Concession rights last for an infinite period in Sweden. This is in contrast to various other EU countries, where concessions are limited to a certain time-frame, e.g. 30 years in Italy, 20 years in Denmark and Germany or 10 years in Luxembourg. [AF-Mercados EMI et al., 2015] In specific cases, however, an exemption of the concession rights applies. It concerns so-called non-concessionary networks, short IKN. Outlined in Ei.se [2017], applicability criteria include the prerequisite of representing an internal network within one property that supplies electricity for own activities. Listed examples are industrial areas, wind parks, hospitals, military areas etc. If LECs are entitled to apply for IKN cannot clearly be derived from the current regulation. However, there might be barriers since LECs involve networks between various property owners.

Overall, in the Swedish case of infinite concession rights and non-defined possibilities to apply for exemption, an agreement with the DSO seems indispensable for a desired formation of LECs within the concession area. With regards to Hypothesis 3 on low business-economic feasibility, there is little probability of a voluntary agreement. Consequently, the hypothesis regarding present Swedish concession rights is;

Hypothesis 4: Reaching an agreement with the DSO to allow LECs to autonomously manage grids within existing concession areas as proposed by the EU is unlikely based on current regulatory design and requires changes in concession regulation.

Connection charges

Across Member States, there are two main methods of determining connection costs, i.e. shallow or deep charging. [AF-Mercados EMI et al., 2015] Shallow charges are only determined by the costs for connection, while the DSO recovers required grid reinforcement via use-of-system charges that are periodically paid by both producers and consumers. In contrast, the deep charging method applies in Sweden. In that case, all costs related to the connection are included in the connection charges. Next to the costs for actual connection at the closest connection point, such as costs for equipment, this also concerns costs for any other required reinforcements within the distribution grid. [Knight, 2006]
In Sweden, charges for connections and transmission are determined by the responsible DSO, but with the right for the connected party to claim for a review by Ei on the appropriateness of the charges. [Ei, 2016a] Regarding the connection fee for household customers, charges outlined in Ei [2017] increase with the distance to the closest connection. In case of a connection of LECs, however, the community network is assumed to be defined as one large customer. Resulting from exploratory research at the analysed case DSO, the connection charge for large customers such as it would apply for LECs are calculated and negotiated with a grid operators' key account manager. Since the calculation method of these network charges are affecting both DSO business but also financial implications for the community, the following hypothesis arises;

Hypothesis 5: Charges for LEC connection to the main distribution grid need to be reasonable from both DSO and LEC perspective.

Accordingly, the last step of the analysis tests these two hypotheses to subsequently reflect on the third sub-question:

How can other identified national regulatory areas on distribution networks be adjusted to support LEC development?

The next section outlines the concrete steps and methods used for testing the hypotheses and consequently lead to answers of the sub-questions.

4.4 Research design

The research design of the Master Thesis is outlined in Figure 4.2.

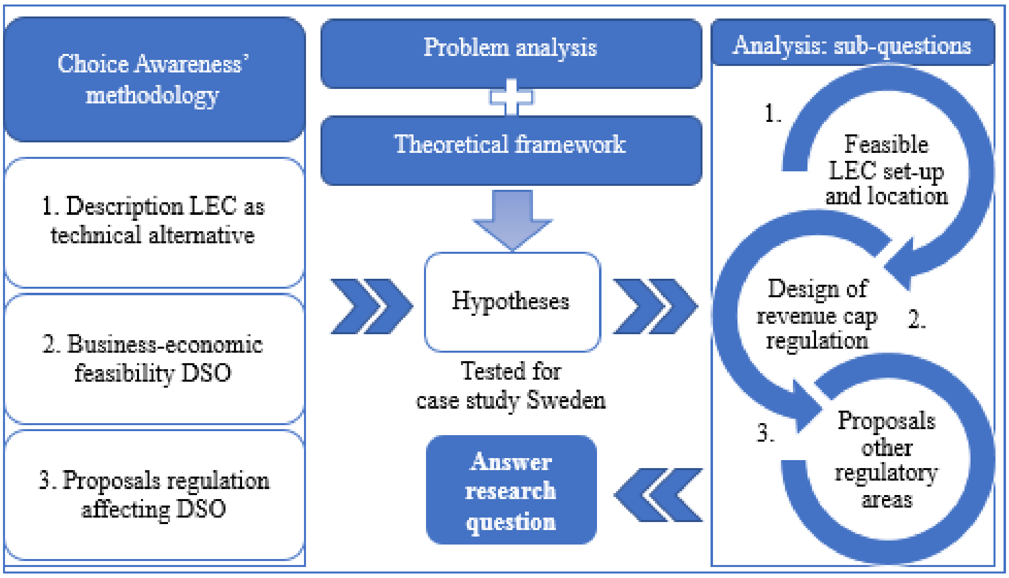

Figure 4.2. Research design

As described before, the analysis tests established hypotheses that are structured based on the first three steps of the Choice Awareness methodology, i.e. for description of LEC as technical alternative, economic feasibility and regulatory proposals respectively. Accordingly, the research design foresees a testing of the resulting hypotheses to answer the sub-questions and finally conclude on the overall research question.

To enable an analysis of national regulation, case study research on the example of Sweden is chosen as methodology for the overall analysis. In addition to the national aspect, answering parts of the sub-questions requires an investigation based on a concrete DSO. In Sweden there are 170 DSOs in total, whereof the 8 largest operators are handling around 50% of total national power demand. [AF-Mercados EMI et al., 2015; Wallnerström et al., 2016] The case study is based on the distribution grid of E.ON Energidistribution, representing the largest DSO by holding a 25% share of the total Swedish power grid. [E.ON Group, 2018]

An overview of used methods per analysis step is summarised in Table 4.4 below.

The following paragraphs explain the outlined steps of the analysis for each sub-question.

Sub-question 1

Hypothesis 1: As outlined in the table, the first hypothesis is tested by analysing collected grid data of the DSO. A comparison of security of supply problems and the installed RES capacity allocated to each bay of the distribution grid is conducted. Results serve to reflect on the existence of existing reliability problems caused by feed-in of DG. Based on the data analysis, a reflection on the potential purpose of LEC as stated within Hypothesis 1 is made. In accordance to the results, criteria for feasible grid networks are developed.

Sub-questions	Steps analysis	Methods
"Which technological set-ups and grid areas are feasible for LEC establishment to facilitate an energy transition in Sweden?"	Testing hypotheses 1 & 2: - Determining feasible grid locations - Case selection within analysed grid - Potential assessment RES integration LEC versions vs. conventional system	- Data collection (DSO's grid software) - Data assessment (Excel) - Criteria development for case selection - Techno-economic modelling (HOMER Pro modelling software)
"How should national regulation on allowed DSO revenues be designed to create business-economic feasibility of LEC penetration?"	Testing hypothesis 3: - Impact calculation for case LEC - Determining influencing parameters - Investigating potential changes of revenue cap design	- Data collection at DSO - Revenue cap calculation (Excel) - Sensitivity analysis (Excel) - Interviews DSO and NRA
"How can other identified national regulatory areas on distribution grids be adjusted to support LEC development?"	Testing hypotheses 4 & 5: - Familiarisation with regulation areas - Determination constraining elements - Developing regulatory proposals	- Exploratory research at DSO - Interviews with DSO and NRA - Literature research

Table 4.1. Steps of analysis: sub-questions and used methods

Based on these criteria, grid data is assessed for choosing a case network location used for testing Hypothesis 2.

Hypothesis 2: For the selected network area, scenarios of a community development with future RES installations are modelled with the software HOMER Pro as explained in Section 4.5. Scenarios include the business-as-usual case, LEC without sector-coupling and LEC using synergies with the thermal grid. For testing the second hypothesis, the resulting achievable RES integration of the different LEC versions are assessed. Furthermore, the modelling results show to the potential of each technological set-up.

Overall, the first sub-question is answered by the defined feasibility criteria for network locations derived from testing Hypothesis 1 as well as from the optimal technological set-up identified via scenario modelling of a case LEC.

Sub-question 2

Hypothesis 3: Resulting from the problem analysis, the third hypothesis assumes inappropriate design of present regulation on allowed DSO business. To propose a feasible adjustments as investigated by the second sub-question, a first step requires to analyse the current business-economic impact. For calculation, the previously selected network area serves as scenario for a future LEC with the assumption of purchasing the grid from the DSO. Since revenue caps are adjusted for each DSO, data on calculation parameters is collected at the chosen DSO.

Derived from the current regulatory design of the revenue cap outlined in Section 4.3 on the second hypothesis, changes in the CAPEX value are largely impacting allowed revenues. Based on the resulting hypothesis outlined in Section 4.3, business-economic assessment quantifies the caused impact of the corresponding CAPEX value for the chosen network area. The evaluation is conducted for both scenarios, with and without LEC. Information on the asset base is collected by extracting data via a grid software at the DSO. This includes type and age of equipment as well as corresponding prices to monetise identified assets. Since capital costs represent around 44% of the revenue cap, the results of the CAPEX calculation are subsequently projected on the total impact on allowed revenues.

From the determined extend of the decreasing revenue cap, a first insight on the business-economic feasibility is provided. In addition, the underlying hypothesis of lacking willingness to provide network areas to LECs is tested by conducting interviews at the DSO. To further assess the related sub-question, a sensitivity analysis serves to identify relevant parameters for potential changes. Here, interviews with both the DSO and the regulator (Ei) are foreseen to further generate knowledge. Regarding the latter, interviewees of Ei are further questioned about already planned changes of the revenue cap design for the upcoming regulation period. These are reflected in the light of their contribution for allowing LEC development.

Sub-question 3

Hypotheses 4 & 5: For answering the last sub-question on potential adjustments of other identified regulation areas, the related hypotheses on concession rights and connection charges are tested. To further familiarise with the issues, exploratory research in form of informal meeting with experts at the DSO is conducted. In interviews with both the DSO and Ei, knowledge on barriers as well as potential changes related to these issues are requested. Literature research on received information completes the information-gathering for final reflection on the sub-question.

Overall, the insights gained from hypotheses testing and the resulting answers to the three sub-questions are applied to answer the main research question. The used methods are further described in the next Section 4.5.

4.5 Methods

4.5.1 Case study research

As previously introduced, the overall analysis is based on the example of Sweden. For the purpose of this Thesis, case study research enables an in-depth qualitative assessment of current national regulation as well as quantitative results from the data collected via the cooperation with the DSO E.ON Energidistribution AB. The case study analyses real-life examples of a specific context and accordingly the method is described as unique analysis, since it is based on specific geographical areas or individuals. [Zainal, 2007] Although the generated insights are context-dependent, scholars on case studies such as Flyvbjerg [2006] describe the method as an appropriate tool to collect knowledge in a given research area through experiences. To create validity of the results, a research design with a link to theories is essential. [Zainal, 2007; Flyvbjerg, 2006] This implies the need to link the results to a previously defined theoretical framework. Consequently, the analysis and results of the case study are discussed in the light of the underlying theoretical framework.

4.5.2 Data collection

Depending on the steps of analysis, different methods of data gathering are applied. Next to a literature review, these are represented exploratory research and interviews.

Literature Review

Data gathering from a review of existing literature is used for the point of departure to familiarise with the research area. Before analysing the EU's proposals regarding the concept of LECs in detail, a review of the EU's overall energy and climate policy and resulting goals and strategies is important. It creates an understanding of the overall need for changing parts of the current energy systems and related policies, since it exemplifies the necessity for an energy transition. After investigating implications arising with a resulting higher share of RES from DG is investigated, the purpose behind the concept of LECs and arising regulatory issues regarding distribution systems can be outlined. Consequently, literature research serves to establish the problem analysis, resulting into the research question. Literature research is further used to establish the theoretical framework of the research paper as well as for parts of the analysis. Overall, a thoughtful selection of sources is essential to guarantee objectiveness. Literature used within the Thesis is primarily based on either publications of EU institutions or from scientific databases. Moreover, since the case study analyses Swedish electricity regulation, relevant papers from the responsible authority, Ei, are reviewed.

Exploratory Research

In addition to literature reviews, exploratory research served as a method to gain knowledge about the research area. Exploratory research is usually used when the researchers have little or no scientific knowledge about a research topic, group or activity. The method further requests the author to show flexibility when researching and to be unbiased for interpreting the received information. [Stebbins, 2001] In the context of this Thesis, exploratory research is realised by informal meetings with representatives from different departments of the analysed DSO. The method is applied for familiarisation with the DSO's database and grid software to enable an extraction of relevant data. This is required since parts of the analysis are conducted based on a selected real case of a network area for potential future LEC establishment. The case serves for both the scenario modelling to test LEC potential as well as for the economic impact calculation. The introduction meetings helped to gain an overall understanding on ways of extracting relevant information such as how to analyse grid data as well as input parameters for the business-economic evaluation.

Interviews

Qualitative interviews serve to answer parts of the sub-questions. Familiarisation with the topic is a prerequisite for both formulating questions, but also on elaboration on the received information. [Brinkmann and Tanggaard, 2015] Semi-structured interviews are chosen as a format, i.e. key questions are pre-defined while allowing follow-up questions that arise with discussions during the interview. Consequently, exploration of emerging issues is facilitated by semi-structured interviews. [Wilson, 2014] Considering the subjective attribute of interviews resulting from the respondent's individual perception, the choice of interviewees with sophisticated expertise is required for high-quality data gathering. Based on the investigated issues, respondents from the analysed case DSO as well as the Swedish NRA responsible for regulation on energy markets are selected. An overview of interviews and the respondents' professional experience is provided in Table 4.2. The interviews are quoted in the text as Interview 1 - 4 and refer to the according respondents as summarised in Table 4.2.

Interview	Organisation	Department	Number of interviewees	Years of experience
1	E.ON Energidistribution AB	Financial Controlling & Risk	2	18, 30
2		Strategy & Regulation	1	40
3		Strategy & Regulation	1	13
4	Swedish Energy Markets Inspectorate (Ei)	Network Regulation, Technical Department	3	10, 12, 1

Table 4.2. Overview interviewees

4.5.3 HOMER Pro modelling software

For scenario modelling, the software HOMER Pro is applied. HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a software for micro-grid simulation. [HOMER Energy, 2017] In accordance with a comparison of various other techno-economic modelling programs outlined in Lund [2014], the tool is especially feasible for designing small-scale systems that can be modelled both in island or interconnected mode. For the purpose of the Thesis, the latter perspective is chosen.

Regarding input parameters for system set-up including financial data, various standard values are available. To allow a case-specific scenario modelling as foreseen for the purpose of this Thesis, however, several input parameters need to be adjusted accordingly. By providing the location of the selected island as input, an integrated tool enables to download according solar radiation and wind speed from the NASA Surface meteorology and Solar Energy database available online on [NASA, 2018]. Other case-specific data such as national economic conditions requires further research. This includes national energy purchase prices in Sweden and subsidies for RES such as possible feed-in tariffs. For simplification, a household electricity price of 0.19 Euros/kWh is assumed based on historical prices of the last years published by Statista [2018]. Regarding feed-in for renewables, Sweden provides subsidies in form of the electricity certificate system as outlined in Section 2.3.1. For modelling, the current certificate value outlined in RES-legal [2017a] of 16.4 Euros/MWh is applied as RES electricity selling price. In addition, standard values for technology costs are partly adjusted based on research as further described in Section 5.2.1. An overview of chosen input parameters is outlined in the appendix of the Thesis.

The outputs are on hourly basis for one year. Examples of output data is included in the appendix. Depending on the input parameters and chosen technologies to be included, the software generates different scenarios differing by included technologies and their capacities. The model follows the primary objective to design the system in the most cost-efficient way. The software simulates different designs of the micro-grid project. HOMER concludes on the optimal design that reaches the lowest overall system costs by running the simulations for various possible technology compositions. [HOMER Energy, 2017] Results are used to provide insights to technical and economic aspects, i.e. to reflect on the optimal technological set-up while receiving the lowest system costs.

4.5.4 Revenue cap calculation

To investigate the business-economic impact providing part of the network area to LECs, the effects on the current revenue cap are analysed. First, this requires information on relevant economic data. Based on exploratory research at the DSO, the revenue cap is determined for each of the three reporting areas of the analysed DSO, i.e. region North, Stockholm area and South. For the calculation, the revenue cap of the Stockholm reporting area is considered since it is the according area of the analysed island. The decision on the revenue cap for the regulatory period 2016-2019 for the analysed reporting area Stockholm is published in Ei [2018b].

Secondly, the impact on the current revenue cap by LEC establishment following the proposals of the EU is tested. Consequently, this implies a loss in the asset base by either selling or leasing the network area. Outlined in Figure 4.1 of Section 4.3 on the revenue cap structure, the allowed revenues are the sum of CAPEX and OPEX. To test the LEC impact, the CAPEX value of the chosen island case is determined and deducted from the total CAPEX value of the Stockholm reporting area, to finally determine the new resulting allowed revenues.

To familiarise with the calculations of the asset base value and subsequently the revenue cap, exploratory research at the DSO is conducted. Insights show that the calculation method is highly complex. Next to the parameters defining the revenue cap illustrated in Figure 4.1, other DSO-specific data is influencing the calculation. Since the allowed revenue cap is determined for the regulatory period of four years, staff from the Strategy & Controlling department explain that the actual calculation includes forecasts for planned changes in infrastructure. To still enable a determination of the economic impact on DSO revenue cap within the scope of the Thesis, a simplified calculation is required. Consequently, the impact of the revenue cap is calculated for one year. For conducting such a simplified calculation, the DSO provides an Excel spread-sheet including numbers for the current asset base of the Stockholm reporting area. The calculation is based on equation 4.1 as outlined below and is designed to calculate the revenue cap for one year.

The equation determining the CAPEX value is explained in Wallnerström et al. [2016]. Accordingly, a real linear calculation method replaces the previously used real annuity method since the new regulatory period starting in 2016. *Real* implies the calculation of the PPV for each component and the application of a *real* WACC. Whereas the annuity method excluded the consideration of age, capital cost calculation applying the real linear method differs by asset age. The equation as published in Wallnerström et al. [2016] is as followed;

$$Capital\ cost\ = Depreciation + Return\ = \begin{matrix} (\frac{1}{LT} + \frac{LT+1-age}{LT} * WACC) * PPV & if\ age\ \leq LT \\ (\frac{1}{age} + \frac{1}{age} * WACC) * PPV & if\ LT < age \leq (LT+\alpha) \\ 0 & if\ age > (LT+\alpha) \end{matrix} \tag{4.1}$$

Where;
$LT = depreciation\ time$
$\alpha = additional\ years\ after\ depreciation$
$WACC = weighted\ average\ cost\ of\ capital$
$PVV = present\ purchase\ value$

Based on the equation outlined above, the CAPEX value results from the sum of the component value and corresponding age. Typical depreciation time is 40 years for equipment such as cables, transformers and substations the analysed components and ten years for meters and IT equipment. The constant α provides CAPEX for some additional years after depreciation, i.e standard ten years and two years for meters and IT equipment. The WACC value is determined by law and constantly negotiated between regulatory periods, with a current value of 5.85% as published in Ei [2018b].

5 LECs as technical alternative

By testing the first two hypotheses, this chapter serves to answer the first sub-question of the Thesis, that is;

Which technological set-ups and grid areas are feasible for LEC establishment to facilitate an energy transition in Sweden?

5.1 Hypothesis 1: purpose of LECs in the Swedish context

The following section tests hypothesis 1;

For the case of Sweden, the establishment of LECs can potentially facilitate future integration of distributed RES rather than solving existing technical network problems.

5.1.1 Analysis on network problems

To investigate the assumed lacking ability to solve existing network problems, the relation between present RES installations and existing reliability problems for the collected data at the DSO is analysed. For the evaluation, values of the system average interruption duration index (SAIDI[1]) as a reliability indicator and the installed RES capacity for all bays of the network area are extracted from the database. In fact, a comparison of the parameters in Figure 5.1 shows an overall minor correlation between security of supply issues and currently connected RES generation units.

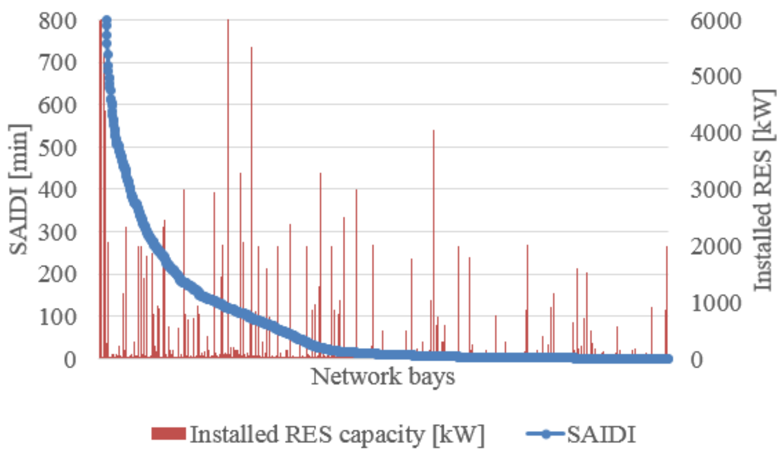

Figure 5.1. Comparison SAIDI and installed RES values capacity per network bay

[1]SAIDI = total outage time / number of customers [minutes/customer and year]

A further filtering of the data shows that the top ten distribution network areas with the highest SAIDI values contain relatively low installed renewable capacity of below 300 kW. Nevertheless, some areas with both high SAIDI and high RES are identified, as further reflected in Figure 5.1. An investigation of the DSO's grid database on outage reasons within these networks bays, however, shows other causes than RES feed-in. These are mostly represented by external reasons such as extreme weather patterns like storms.

5.1.2 Conclusion

As a conclusion from this analysis, the defined functions of a LEC cannot contribute solving existing reliability problems within Swedish distribution grids. Considering the national energy objectives implying a 100% RES share in electricity by 2040, a future integration of DG is expected. The following analyses for both testing the potential of LECs for a cost-efficient RES integration (Hypothesis 2) and for calculating the business-economic impact of LEC establishment (Hypothesis 3) are conducted for a selected case of the analysed distribution grid. Based on the findings of the first hypothesis, criteria for selection are chosen to apply LEC establishment as a tool to integrate expected future RES generation from DG. The determined criteria and the reasoning for their choice is further explained in the next section.

5.1.3 Criteria for LEC location

Based on foreseen LEC functions and purposes derived from the problem analysis and the theoretical framework, the following criteria are developed for selecting a case for the upcoming analyses;

1. *RES potential:* No/little installed RES capacity but potential for solar and wind
2. *Sector-coupling:* Existing electricity and district heating grids
3. *Community characteristics:* Focus on residential customers selection of technically possible LEC scenario

The reasoning on the choice of each criteria and an elaboration is explained below.

RES potential

The first criteria is defined to enable the LEC's purpose of future RES integration. Therefore, networks with currently low or no installed RES capacities from DG units, but a high potential are considered. Since the simulation foresees solar PV and wind integration, the focus is set on areas with relatively high solar radiation as well as wind potential.

Sector-coupling

The second criteria is based on testing the potential of sector-coupling resulting from the theoretical approach of SES as explained in Section 3.2.1. Therefore, a location with both electrical and thermal grids is chosen. Areas with pre-existing grids are selected based on expected limited financial resources of the community. Here, higher costs and lack of knowledge of the community as derived from the theoretical approach in Section 4.2 are assumed to hamper the establishment of new infrastructures rather than buying or leasing existing grids.

Community characteristics

As outlined in Section 3.2.2, the scale of community systems is not specified within literature and accordingly can vary from single properties to large districts. However, as further explained in the theoretical framework the characteristic of locality is important, i.e. LEC members are physically located within the community boundaries. In addition, the majority of LEC members should represent residential customers to fulfil the purpose of citizen empowerment. Consequently, areas with high share of industry, public buildings or other non-residential properties are excluded. The selection is further tested on the technical possibility to operate the network area autonomously from the remaining grid. Analysed with the DSO grid database and software, the consideration of taking out selected community bays should not technically interfere with other bays that are still operated by the DSO. For these other bays, there must be another possibility for supply than via community networks.

Overall, selecting a case for a potential LEC out of the entire analysed distribution network of the analysed DSO is an intensive process. Next to research on RES potential, it involves familiarisation with the DSO's grid software as well as a profound analysis of extracted grid data. The steps for testing each criteria are outlined in the next section.

5.1.4 Selection process

First of all, data collection of network parameters at the DSO is required. For the first criteria, the data is filtered to only consider regions without pre-existing RES generation units. To define the potential, research on solar radiation and wind speeds is conducted. While insights on Swedish solar potential are derived from findings of the European Commission's Joint Research Centre published in Huld and Pinedo-Pascu [2014], wind speeds per location are available online at the Global Wind Atlas developed by the Technical University of Denmark. [DTU, 2017] Once the locations with future RES potential are determined, the resulting areas are considered for testing the remaining criteria.

The DSO's grid software serves for defining locations with both power and thermal networks since it provides a geographical view on different available networks. Here it needs to be noted that area selection is restricted to district heating networks operated by the E.ON corporation since available grid data only covers thermal networks operated by the district heating division of the analysed case DSO.

With the help of the grid software, the resulting areas fulfilling the previous criteria are analysed on customer type and technical possibility to operate a potential LEC network autonomously. First, the geographical view provides a first guess on defining residential areas. For some feasible areas, the technical possibility of hypothetically operating the network autonomously is further analysed by reviewing the network typology with the grid software. Here, exploratory research in form of informal meetings and introduction to utilising the software tool was required.

Overall it has to be noted that within the entire distribution grid of the analysed DSO, there are various options for selecting a case fulfilling the above described criteria. The final choice is consequently not representing the one and only possibility, but is assumed to be a feasible network area for the purpose of the analysis, i.e. testing the potential of different LEC functions to integrate future distributed RES.

5.1.5 Selected case - island in the Stockholm area

After a grid analysis process, the case of an island in the Stockholm area is selected for the scenario modelling and economic impact calculation. Figure 5.2 shows the view of the network typology extracted from the DSO grid software.

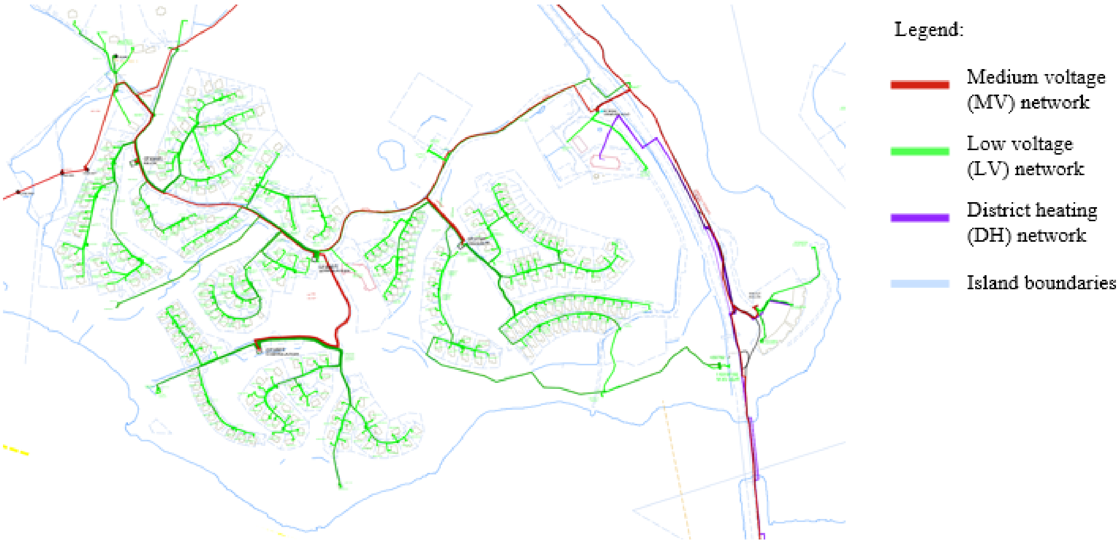

Figure 5.2. Grid typology of the selected case for LEC scenario modelling and economic impact calculations

The case fulfils the three selection criteria. Firstly, an analysis of the collected grid data shows no present RES installations connected to the distribution grid. According to the references for Swedish RES potential outlined in Section 5.1.3, however, there is both relatively high solar radiation as well as wind speed. Regarding sector-coupling, the figure shows the existence of a thermal network. As illustrated, the buildings of the selected community are not connected to DH, however, a DH production facility is located on the island that is connected to the larger neighbouring island. Consequently, there is an ability for the chosen LEC case island to make use of sector-coupling by converting and feeding in surplus RES into the district heating network. Thirdly, the selected area fulfils the technical possibility of potentially operating the affected bays without hampering operation of non-included bays. Here, the introduction meetings as part of exploratory research explained in Section 4.5 provided support for testing the technical feasibility.

The selected case serves for testing Hypothesis 2 as outlined in the next section.

5.2 Hypothesis 2: LEC ability to facilitate RES integration

In accordance with the first step of the Choice Awareness methodology, this part of the analysis tests the potential of LECs as an alternative to conventional integration of distributed RES. The analysis steps are further based on Hypothesis 2;

Hypothesis 2: Next to customer empowerment, the functions of LECs including self-consumption and flexibility via storage, DSM and sector-coupling can facilitate a cost-efficient integration of RES from DG.

5.2.1 Steps for HOMER modelling

Scenario definition

To test the ability of LEC functions for RES integration, the software tool HOMER Pro is used as explained in the methodology Chapter 4. To test the impact of sector-coupling versus electricity-only systems as derived from the theoretical approach of SES described in Section 3.2.1, the following three key system set-ups are modelled;

1. *BAU*: System with conventional RES integration, i.e. without LEC functions
2. *LEC electricity-only*: LEC functions including electrical storage and DSM
3. *LEC sector-coupling:* LEC functions plus sector-coupling with the thermal grid

The system set-up of the models is built upon defined LEC functions resulting from the problem analysis and the theory, summarised in Section 3.4. Resulting models are illustrated in Figure 5.3.

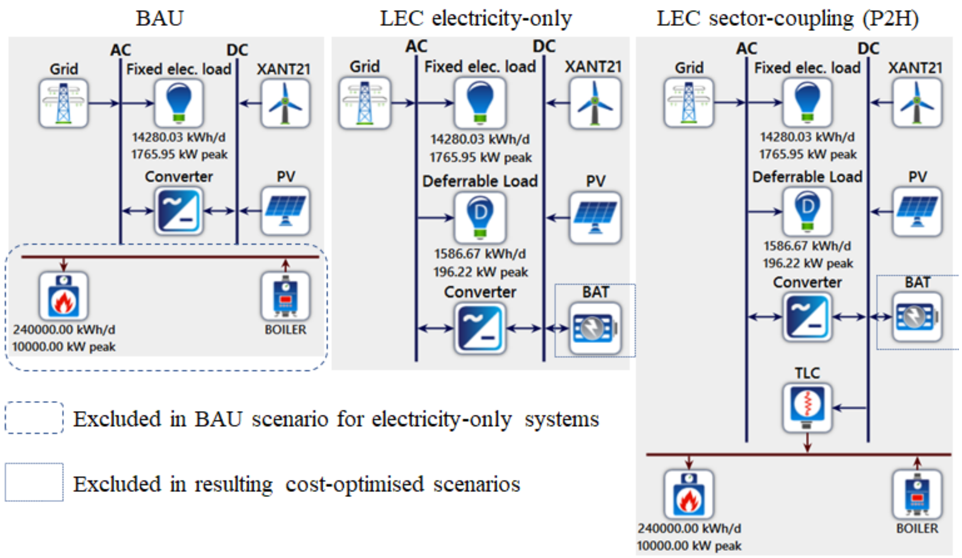

Figure 5.3. Schematic view of modelled scenarios, comparing technological set-up between BAU and LEC scenarios

Accordingly, the LEC electricity-only case is modelled with the functions of electrical storage and load shifting via DSM as flexibility options. Here, the ability to shift 10% of the peak load is assumed as parameter for DSM. Next to these functions regarding optimised local usage of electricity, the sector-coupling model further makes use of a thermal load controller (TLC) that enables a conversion and feed-in of locally generated surplus RES power into the DH network. Each LEC model is compared to a business-as-usual case (BAU). This base scenario is modelled as system with a conventional RES integration, i.e. without any additional flexibility functions as included for the LEC models.

Here, it has to be noted that the DC network illustrated on the figure results from modelling and is not present in the chosen community case in reality. Since all models include the DC side, a comparison of the scenarios is still enabled and fulfils the purpose of testing LEC functions.

Overall, eight scenarios are modelled. Firstly, the scenarios are made based on the SES theory by comparing electricity-only systems and systems with an additional thermal grid. For each category, scenarios are further divided into limited and unlimited RES capacity. Here, scenarios with limited RES capacity as input parameter represent the selected island case. The determined capacity is based on the restricted available area for PV and wind integration on the island[2].

Regarding the sector-coupling scenarios, the surplus electricity is feed into the DH grid supplying the neighbouring island as explained before. The existing DH boiler capacity is set to 10 MW and assumed to be fed by natural gas. The first scenario with equal RES capacity primarily serves to compare the resulting self-consumption and system costs for the BAU or different LEC possibilities respectively. In addition to insights on self-consumption and system costs based on equal RES capacity, the second scenario is conducted without limit of RES installations. Here, a fictive case with sufficient area is assumed. The scenario serves to test the potential of RES integration achieved by differing technological set-ups. In particular, such a scenario is interesting to evaluate the potential of sector-coupling.

Resulting scenarios

As explained in Section 4.5, HOMER is a cost-optimisation modelling tool. Consequently, for each model the optimal technology combinations and capacities are simulated based on the resulting lowest system costs. RES capacities are fixed input parameters in the limited scenarios. For unlimited scenarios, the simulation determines the optimal installed RES capacity to reach the highest integration at the lowest system costs. Table 5.1 captures the resulting eight models including installed wind and PV capacities. For scenarios with unlimited capacities, a first conclusion can be made on the higher RES installations when choosing LEC rather than a BAU integration.

[2]Assumption PV capacity: average 4 kW PV size for the total of 280 subscriptions = 1,12 MW
Assumption wind capacity: three turbines à 100 kW = 300 kW

RES integration	**Electricity only**				**Sector-coupling**			
	Limited		*Unlimited*		*Limited*		*Unlimited*	
	BAU	**LEC**	**BAU**	**LEC**	**BAU**	**LEC**	**BAU**	**LEC**
PV kW	1 120	1 120	1 205	1 202	1 120	1 120	1 041	1 505
Wind turbines	3	3	19	20	3	3	18	135
Wind kW	300	300	1 900	2 000	300	300	1 800	13 500
SUM kW	***1 420***	***1 420***	***3 105***	***3 202***	***1 420***	***1 420***	***2 841***	***15 005***

Table 5.1. Overview of modelled scenarios including installed RES capacities

In accordance with defined LEC functions in the theoretical framework, batteries are provided as input parameter. Research on national subsidies show a current 60% investment grant for batteries applicable between 2016-2019 as outlined by the government. [Sveriges Riksdag, 2018b]. The HOMER standard price is adjusted accordingly. As marked within Figure 5.3, however, the optimised system set-ups resulting from the simulations exclude battery utilisation in all scenarios. This indicates a lower economic feasibility of electrical storage via batteries compared to other options within the scenarios. The overall results are further discussed in the following section.

5.2.2 Modelling results per scenario

Figure 5.2 summarises the main modelling results. To test the second hypothesis, the modelling results are used to interpret both the aspect of ability to integrate a higher RES capacity by LEC establishment and secondly achieving lower costs for the system (cost-efficiency). The colour-code indicates if the LEC model of the respective scenario shows preferable result compared to the BAU case.

Scenario overview			**Electricity only**				**Sector-coupling**			
			Limited RES		*Unlimited RES*		*Limited RES*		*Unlimited RES*	
Sector	**Parameter**	**Unit**	**BAU**	**LEC**	**BAU**	**LEC**	**BAU**	**LEC**	**BAU**	**LEC**
	Installed capacity (PV + wind)	MW	1.4	1.4	3.1	3.2	1.4	1.4	2.8	15.0
Electri-city	Electricity demand	MWh	5 791	5 212	5 791	5 212	5 212	5 212	5 212	5 212
	Net purchases	MWh	4 072	4 052	1 896	1 732	3 516	4 073	1 615	- 139
	RES produced	MWh	1 862	1 862	5 632	5 859	1 862	1 862	5 230	32 636
	Deferrable load served (DSM)	MWh	-	579	-	579	-	579	-	579
	RES self-consumption	%	92.4%	93.4%	69.2%	69.3%	91.1%	92.3%	68.8%	18.2%
Heat	Fuel* consumption (boiler 10 MW)	MWh	-	-	-	-	109 500	109 454	109 500	78 989
	Fuel* compensated by RES	MWh	-	-	-	-	-	46	-	30 511
	RES self-consumption	%	-	-	-	-	0%	0.04%	0%	27.9%
Total	Total demand	MWh	5 791	5 791	5 791	5 791	114 712	115 245	114 712	84 781
	System RES self-consumption	%	92.4%	93.4%	69.2%	69.3%	4.1%	4.7%	3.1%	27.2%
	Peak power (grid purchases)	MWpeak	1.85	1.86	1.85	1.75	1.66	1.84	1.66	1.66
	Peak per installed capacity	MWpeak /MW	1.30	1.31	0.59	0.55	1.17	1.30	0.59	0.11
	System costs	M€	13.3	13.2	10.5	10.0	83.4	84.9	81.1	72.0
	System costs/installed capacity	M€/MW	9.34	9.31	3.38	3.11	58.77	59.76	28.55	4.80

* Natural gas assumed fuel for existing DH production and electric heater as P2H unit

Table 5.2. Results overview for all scenarios with comparison of highlighted key parameters; colour-code: green indicates better results while red implies lower feasibility of LECs compared to the BAU case

To reflect on the potential of RES integration, the calculated parameter of RES self-consumption can be interpreted. Consequently, a higher amount of the installed capacity is used locally within the community for self-consumption in all scenarios. With regards to problems related to a connection of DG to the main distribution grid as outlined in Section

2.1 of the problem analysis, a higher self-consumption is preferred when integrating future RES. Based on the same set of problems, the modelling results are used to define the resulting peak demand within the electricity network as an indicator on eventually caused demands for grid upgrades. This as assessed based on the resulting peak of grid purchases, since it indicates the maximum capacity needed to supply the community in the hour of the year with the highest demand. To further specify the actual influence on the peak, the value is further calculated per installed RES capacity. In the scenarios for the chosen case island with limited RES integration, there is no reduction of the peak whereas the scenarios with unlimited RES integration show a positive impact.

Regarding the aspect of cost-efficiency, the overall system costs are compared. To achieve a fair evaluation, the value is once again calculated per installed capacity. Overall, three out of four comparisons show lower energy system costs with LEC establishment compared to an integration without LEC functions, i.e. BAU case. Only in the scenario for the selected island (limited RES) with sector-coupling, the costs are slightly increasing. An further investigation on modelling results reflect higher costs for grid operation and the needed conversion into heat as causes for the comparatively higher values.

A comparison between electricity-only and sector-coupling scenarios serves to reflect on the SES theory. The resulting RES capacities in the unlimited scenarios prove the ability to integrate a higher share of RES when allowing synergies. Also the peak per installed capacity is clearly lower in the sector-coupling scenarios that results into potential lower needs for grid upgrades. Only the system costs are higher compared to the electricity-only scenario. This, however, might be caused by the fuel costs for natural gas.

5.2.3 Conclusion

Overall, it can be concluded that LECs show a higher potential to integrate RES from DG with increased local self-consumption and consequently lower feed-in to the distribution grid. However, the results show that LEC establishment has a higher feasibility from both economic and technical perspective if the community area shows ample potential to install distributed RES capacities. For the selected island case, the restricted area for PV and wind installations led to a lower feasibility compared to scenarios with larger RES integration.

In general, results show that LECs can serve to integrate future RES from DG and accordingly, the second part of Hypothesis 1 is validated. Regarding Hypothesis 2, the modelling results show that LEC functions can lead to larger installed RES capacities within the system while achieving lower overall energy system costs. Since this majorly applies in scenarios with higher abilities to integrate RES, the actual potential of LECs depends on local circumstances for RES integration. Therefore, a validation of Hypothesis 2 is case dependent and cannot be generalised for an establishment in any Swedish distribution grid. In addition, batteries are excluded from the resulting optimised scenarios. This implies a lower cost-efficiency of electrical storage in the scenarios compared to the other modelled flexibility functions. Furthermore, synergies between energy carriers such as tested for electricity and heat show a higher potential to lower the capacity needs when integrating such sources from DG.

Economic feasibility on DSO business 6

This chapter tests Hypothesis 3 to reflect on the second sub-question;

How should national regulation on allowed DSO revenues be designed to create business-economic feasibility of LEC penetration?

6.1 Hypothesis 3: inappropriate revenue cap design

The analysis within this section serves to reflect on the following hypothesis;

The willingness of DSOs to facilitate LEC establishment is negatively influenced by lacking business-economic feasibility hampered by the current design of the revenue cap that incentives a large asset base.

6.1.1 Interview results

Barriers in revenue cap design

First of all, the derived assumption of lacking incentives for selling a network area is confirmed by interviews with representatives of the DSO. Relevant statements in Interview 2 are expressing the opinion: *"[...] it is not economic for the DSO to sell parts of the grid. The current regulatory model is not supporting LEC development, since the DSO's asset base should be kept as large as possible."*

As tested by the HOMER modelling, some scenarios show a positive contribution of LECs to decrease the peak demand while integrating a higher share of RES. This would imply a potential reduced need for the DSO to reinforce the networks. As stated above, however, the DSO is currently not incentivised to save investments in grid upgrades. This is further explained in Interview 1: *"The current regulation is based on the age of the grid. If you invest in grid upgrades, you get a higher return."* Accordingly, providing a network areas to LECs is not favoured even if a contribution of LECs would decrease the need for grid upgrades.

Another idea of incentives for the DSO to allow LECs to own and operate the grid are the potential benefit of a higher local self-consumption of RES as derived from the previous modelling. As explained in Section 5.2.1, this would imply a lower feed-in of DG into the main grid that potentially decreases problems including voltage fluctuations. Consequently, improvements on quality and efficiency in the main DSO network might be achieved via LECs. However, the DSO is not expecting that such improvements create positive impacts on the overall revenue cap, as explained in Interview 1: *"In a case where the LEC network is sold, the incentives on improved quality and efficiency most likely do not compensate the loss of CAPEX."* Interview 4 with the regulator Ei confirms that current regulation is not incentivising investments in alternative solutions to increase efficiency and quality in the grid: *"Ei's vision is that the DSO should invest in the most cost-efficient solution but right now the CAPEX is important. DSOs can increase the efficiency and quality in the network by taking the option of increasing CAPEX. Ei knows that there is a problem."* As a conclusion, the DSO is currently rather investing in CAPEX-based solutions such as grid upgrades than choosing less capital cost-intense alternative solutions despite the improved incentives on quality and efficiency for the current regulatory period.

The interviewees of the DSO are further asked on potential other options for investing the saved grid investments in case of such reduced needs due to LEC establishment. The idea is to increase the efficiency or quality in other areas of the distribution grid. According to Interview 3, the saved investments could be used for improving networks with high security of supply problems or investing in expanding areas due to industry or population growth. Overall, the DSO is generally incentivised to invest because the interviewee concludes on the question by stating: *"If the DSO is not investing at all, it has a negative impact on the overall business since the revenue cap decreases over time."* Overall, interviewees highlight that the DSO would like to support a transition and alternative solutions, however, the regulation is lacking incentives. Interviewee 2 explains it as followed: *"It is needed to find the best way for society and new business models to allow building more optimal networks. [...] Key for success is that more RES can be connected."* In addition, the interviewees outline that the current high life time applied within regulation further hampers the DSO to invest in innovative solutions. Based on that, there is a high risk to invest in technologies that might have a lower life time, as explained in Interview 4.

Potential changes in regulation

Accordingly to Interview 4, there is awareness on the inappropriate design of the revenue cap regulation for reaching a transition to less CAPEX-base alternative solutions. Ei is currently working on revising incentive indicators to re-design regulation accordingly. Results are published in summer 2018. However, the respondents further explain that the concept of LECs is not specifically considered in these adjustments. This is because the EU proposals regarding LECs are still under negotiation and regulatory adjustments need to comply with the final phrasing within the CEP. Furthermore, the interviewees stress that the DSO needs to be informed on potential regulatory changes in advance. Therefore, regulatory changes with regards to LEC might be implemented for the regulatory period starting in 2024 the earliest.

One idea within present work on regulation adjustments is to increase the OPEX weighting within the revenue cap design. This is stated in Interview 4: *"In the future, the DSO might choose OPEX such as services provided to solutions such as LECs but not today. Example of services would be to provide flexibility to LEC to lower the peaks that might bring benefits to the grid."* The mentioned possibility to provide flexibility services is also wished to be incentives by the interviewees of the DSO. Here, one key discussion is about operating storage as a backup for such local communities such as mentioned in

Interview 2. This could potentially substitute grid reinforcements. The interviewee further stresses the positive aspect from socio-economic perspective: *"The DSO wants to build the optimal solutions to integrate more RES and e.g. storage etc. so that there is no more need to reinforce the main grid. This might decrease tariffs because of a more optimal infrastructure."* However, both respondents from Interview 2 and Interview 3 highlight the lacking right of DSOs to operate storage as a key barrier in current national regulation. The issue on allowing DSOs to operate storage units is also addressed within the CEP. The initial proposal by the Commission confirms the statement of interviewees: *"Distribution system operators shall not be allowed to own, develop, manage or operate energy storage facilities."* [EC, 2017c] Latest amendments in European Parliament [2017b], however, add a relevant phrase: *"[...], except equipment used by the distribution system operators for local short-term control of the distribution system where there is no influence on energy and non-frequency ancillary services markets, and where the national regulatory authority has granted its approval."* Accordingly, depending on the final outcome of interinstitutional negotiations and national decisions, the DSOs' suggestion to provide flexibility services to the LEC from storage facilities might be feasible.

As outlined the problem analysis and theoretical framework, the development of smart grid solutions is further stressed as essential parameter for reaching an energy transition. In accordance, the regulator is currently working on developing a "smart grid incentive scheme". Explained during Interview 4 with the respondents of Ei, however, the new incentives are not targeting specific technologies. This is explained by the purpose of reaching a technology-neutral regulation, i.e. with focus on outputs such as increased efficiency rather than on how to reach it. Accordingly, respondents suggest: *"The DSO should give the customer the incentive to work with the smart grid. One thing to include in smart grid incentives is to incentivise customers by a different tariff design."* This is in line with the desire of the DSO to have more incentives for smart grid development. Interviewee 2 explains it as followed: *"The DSO wants that the regulation is changed e.g. to give incentives to build more optimised networks for handling RES feed-in, including smart grid development."* Therefore, Ei proposed a change of tariff provisions lately, including flexibility options for customers of areas with high RES capacities from DG. Explained in Interview 4, the investigation resulted into a new law to be introduced by 2019 allowing the DSO to apply such flexibility tariffs for customers in relevant areas. Since LECs are including smart grid characteristics as defined in Section 3.4, introducing incentives for smart grids in some way could contribute to a higher willingness for the DSO to allow LEC developments.

Respondents of Ei further outline that the present parameters defining the capital costs for DSOs are too high. One factor influencing the capital costs is a newly introduced rule for the second regulatory period. The so-called *38-rule* defines that no assets are considered older than 38 years for the capital cost calculation. This rule was introduced to as compensation to the change from real annuity to the real linear method. Ei is currently discussing and to eliminate the 38-rule for the upcoming period. The influence of this rule on allowed revenues is dependent on the age of the DSO's infrastructure. Consequently, the impact of an elimination of the rule will have a stronger affect on asset base with a high share of older infrastructure. Another discussed aspect to decrease the current high weighting of the capital costs is a change of the WACC.

The interviewees of Ei further suggest that the DSO should charge a reasonable price for selling parts of the grid: *"If the DSO should sell the network, the DSO should be compensated. They are allowed to charge a price for it."* However, here the question on the appropriate calculation method for deciding on the price arises, to avoid high financial barriers for LECs. The calculations conducted in the following section are used to determine the actual loss for the DSO based on the selected LEC case. Furthermore, the economic calculations in include a sensitivity analysis on potential changes caused by a decreased WACC. Lastly, the required OPEX weighting is determined for reaching the same revenues in case of selling parts of the network area.

6.1.2 Economic impact calculation

To test the actual economic consequences of a decreased asset base for the DSO due to LEC establishment as proposed within by the EU, the impact on the revenue cap is calculated for the previously selected island as LEC case. The idea is to determine the impact of a decreased asset base, i.e. selling or leasing networks to LECs, on the total revenue cap by comparing the loss of the asset base to the loss in the revenue cap. The conducted steps for calculation are explained below.

Calculation steps

Based on the calculation method outlined in Section 4.5, the DSOs grid database is used to extract data. Here, details on all assets compromising the selected case network area are required, including type and age of each component. Consequently, a first step requires to determine the boundaries of the LEC, i.e. which bays are included. Since the case selection assumes the entire island as a potential energy community, data on all bays supplying customers on the island is extracted. Since the potential LEC is expected to take over the LV network, the calculation captures according cables. Other installed equipment within the network area includes substations and transformers. Meters are excluded due to the proposed replacement through smart meters in Sweden by 2025. [Ei, 2018a] Accordingly, LECs are assumed to purchase smart meters rather than taking over existing meters from the DSO.

Table 6.1.2 shows an example of the derived data for cables, capturing resulting length per cable type sorted by age. The same is conducted for transformers and substations, where the counting is based on units rather than the length. The resulting cable lengths per type as well as units per type of installed transformers and substations are monetised based on a standard price list developed by the regulator. The list includes prices for each components and is provided by the DSO for the analysis within this Thesis. Based on the resulting monetary values and the age per component, the age adjusted asset base value of the analysed island network is determined. A comparison of the resulting value to the current total asset base value of the chosen reporting area leads to the first result, i.e. the LEC's percentage asset value of the total assets.

Cable length [m]	Cable type								
Installation year	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
1984	-	56	-	-	-	-	-	-	-
1991	329	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	111
1999	-	-	-	-	780	-	-	-	-
2000	-	2 708	669	-	5 574	144	308	-	1 061
2001	-	448	-	-	-	-	-	-	194
2003	-	1 732	-	18	-	-	-	-	608
2004	-	745	-	83	260	-	-	-	182
2005	-	2 344	-	-	-	-	-	-	-
2006	-	858	-	88	-	-	-	-	-
2007	-	141	-	12	-	-	-	-	-
2008	-	86	-	-	-	-	-	-	341
2009	-	74	-	19	-	-	-	1 779	-
2010	-	49	-	206	-	-	-	-	-
2014	-	-	-	-	-	-	-	265	-
2015	-	3	-	-	-	-	-	-	-
2016	-	9	156	-	119	4	-	-	-

Table 6.1. Example of extracted data from the DSO database showing cable data for the selected network case, summarising length per cable type and year of installation

Next, the reduced CAPEX of the total reporting area is determined in case of decreasing the asset base due to LEC establishment. Since the real linear calculation method is applied for determining the capital costs as outlined in equation 4.1 in Section 4.5.4, the previously determined monetary values and related age of components serve as input parameters within the simplified calculation method based on equation 4.5.4 for defining the CAPEX value for 2018. To finally calculate the decreased revenue cap, the LEC capital costs are deducted from the total capital costs. Based on in Ei [2018b] published revenue cap, including CAPEX and OPEX values, for the Stockholm reporting area, capital costs contribute to 47% to the allowed revenues. Consequently, the revenue cap calculations are based on 47% and are calculated for the revenues of one year.

Impact of LEC based on current revenue cap

Resulting from the conducted steps as explained above, the impact of deducting the network area of the chosen LEC case is determined. Results on comparing the decreased asset base, CAPEX and revenue cap is summarised in Table 6.2 in million Euros[1].

[M€]	Total (Stockholm reporting area)				LEC (case Kullön)		Total - LEC				
Asset base*	CAPEX share	CAPEX Total	OPEX Total	Revenue cap	Asset base*	CAPEX LEC	CAPEX reduced	Revenue cap reduced	Reduced revenue cap %	Reduced asset base %	Ratio**
243.6	47%	30.1	33.9	64.0	0.9	0.1	30.0	63.9	**0.14%**	**0.36%**	***0.39%***

* age adjusted value; ** ratio reduced asset base / loss revenue cap

Table 6.2. Impact of taking out case LEC from the DSO asset base on total DSO asset base value and revenue cap

[1] 1 EUR = 9.63 SEK (2017 average) based on European Central Bank [2018]

Consequently, selling the network area of the analysed island would lead to a loss of 0.36% of the total age adjusted asset base. Subsequently, this loss results into a 0.14% decreased revenue cap. As explained before, the results show the values for the revenue cap for one year. For this simplified calculation, no changes at the OPEX value are assumed, since these are based on historical data of the DSO. To make a generalised conclusion on the economic impact of selling networks to LECs, the ratio between decreasing asset base and resulting loss of asset base is calculated. Derived from the calculated ratio of 0.39% seen in Table 6.2, a loss of 1% of the asset base leads to a loss of 0.39% of the revenue cap for one year.

Based on the results, a reflection on the regulators suggestion for allowing the DSO to determine a reasonable price for selling the network is made. One solution could be to charge the value of the age adjusted asset base, i.e. 0.9 million Euro for the calculated example. This calculation method is assumed by the respondents in Interview 1. In that case, however, the DSO might not be compensated in a fair way compared to the actual caused loss. This is based on the long-term perspective, since the loss will lead to a decreased revenue cap in subsequent years. When applying the simplified assumption of an equal decrease of the revenue cap each year, the losses equal to the age adjusted asset base value would be reached within less than ten years. Even if the LEC is leased, the life time of the community project might be longer. Another calculation method is to base the price on the sum of yearly losses of the revenue cap. With regards to the results in Table 4.5.4, however, such a method could led to a very high financial barrier for LECs.

It has to be noted that these figures only apply under current revenue cap design, e.g. CAPEX share of 47% and WACC of 5.85%. To further determine the impact of changes in the WACC as currently discussed by the regulator, a sensitivity analysis is conducted.

Sensitivity analysis

For the first part of the sensitivity analysis, the calculations are conducted with decreased values for the WACC. Once again, only the value of the capital base changes in that scenario when since the OPEX calculation method remains the same. Results are reflected in Table 6.3.

[M€]	Total (Stockholm reporting area)				Total - LEC			
WACC	CAPEX share	CAPEX Total	OPEX Total	Revenue cap Total	reduced CAPEX	Reduced revenue cap	Loss revenue cap %	Ratio**
5.85%	47%	30.1	33.9	64.0	30.0	63.9	0.14%	***0.39%***
4.85%	45%	27.7	33.9	61.6	27.6	61.5	0.13%	***0.36%***
3.85%	43%	25.2	33.9	59.2	25.2	59.1	0.12%	***0.33%***
2.85%	40%	22.8	33.9	56.7	22.7	56.7	0.11%	***0.31%***

** ratio reduced asset base / loss revenue cap

Table 6.3. Scenario of selling network of chosen case LEC assuming unchanged OPEX; Sensitivity analysis by decreasing WACC

As reflected in the table, a decreased WACC has a strong influence on the resulting revenues. In the analysed network area, a 1% decrease of the WACC causes an approx. reduction of 4% of the total revenues (from 64 to 61.6 million Euros). The caused decrease of capital costs results into a lower contribution to the total revenues, i.e. a 2% reduction when applying 47% as point of departure. Consequently, the impact of selling the same network area decreases with a lower WACC, as displayed by the calculated ratio.

A second calculation is conducted for calculating the needed increased OPEX to reach the same revenue cap in case of selling the grid. An increased OPEX could be reached by previously outlined ideas of both the regulator and the DSO to provide flexibility services to the LEC such as storage solutions. Results including the WACC sensitivity are displayed in Table 6.4 below.

[M€]	Total (Stockholm reporting area)				Total - LEC					
WACC	OPEX share	CAPEX Total	OPEX Total	Revenue cap total	Reduced CAPEX	Required OPEX	Revenue cap total	Increase of OPEX share	Increased OPEX value	Ratio**
5.85%	53%	30.1	33.9	64.0	30.0	34.0	64.0	0.14%	0.26%	***0.73%***
4.85%	55%	27.7	33.9	61.6	27.6	34.0	61.6	0.13%	0.23%	***0.66%***
3.85%	57%	25.2	33.9	59.2	25.2	34.0	59.2	0.12%	0.21%	***0.58%***
2.85%	60%	22.8	33.9	56.7	22.7	34.0	56.7	0.11%	0.18%	***0.51%***

** ratio = reduced asset base / increased OPEX value

Table 6.4. Determination of required OPEX share for the scenario of selling network of chosen case LEC; Sensitivity analysis by decreasing WACC

According to the numbers, the case of selling the network area of the analysed island network would require to increase OPEX by 0.26% with the current WACC of 5.85%. The displayed ratio translates the needed increase of the OPEX value to compensate a 1% loss of the asset base. As a result, an increase of 0.73% would be required under current revenue cap design. Such an increase is assumed to be quite difficult to reach. This is especially the case since only around one quarter of total operational expenses are controllable, i.e. can be increased by the DSO, as outlined in Figure 4.1. Here the assumption arises that even if the DSO would provide services such as storage to LECs, the generated OPEX would most likely not compensate the loss caused by selling the asset base under current regulation.

6.1.3 Conclusion

Derived from the analysis including economic calculation and interviews, current regulation design incentives DSOs to increase or at least keep a high asset base. Accordingly, CAPEX-base solutions such as grid reinforcements are preferred to solve or prevent technical problems within the network and guarantee quality and efficiency. The regulatory body is aware of the inappropriateness of present revenue cap design to facilitate the establishment of alternative solutions needed for a transition.

In general, the DSO shows an interest in supporting a transition, but the current design of the revenue cap hinders actions. Calculations on the business-economic impact of decreasing the asset base clearly show a large impact on allowed revenues. This is further a problem when LECs are charged the according price to compensate the caused loss in the revenue cap over time, since the high amount will most likely cause financial barriers for the LEC. One key parameter deciding on the asset base impact is the applied WACC. Secondly, the theoretical loss of CAPEX can be compensated by increasing the weighting of operational expenses within the revenue cap. A combination of both a lower WACC as well as a higher incentive to focus on OPEX could be one potential solution for improving the likelihood of LEC development.

In relation to a higher share operational costs, a solution suggested by both the DSO and the regulator is to allow DSOs to operate storage facilities. Such flexibility services provided by the DSO could replace investments in grid upgrades by serving as backup to LECs. This would imply a shift from CAPEX to OPEX. Accordingly, changing the revenue cap design to a more OPEX based calculation method would facilitate such a solution and consequently increase the willingness of DSOs to allow LECs to own networks. The idea of providing services to LECs is further discussed in Section 7.2 on connection charges.

Based on the interviews with the regulator, currently developed regulatory changes targets incentives for smart grid development. This includes a new tariff design allowing customised tariffs depending on local circumstances such as high availability of RES. Smart grid incentives are not only relevant for LEC development, but for a transition towards RES-based energy systems in general.

Overall, these conclusions validate the established Hypothesis 3. Accordingly, changes in the current design of the revenue cap are essential for allowing LEC development as one alternative solutions to facilitate a transition towards RES-based energy systems in Sweden.

Other regulatory issues 7

This chapter compromises the last step of the analysis. By testing the remaining hypotheses 4 and 5, the following sub-question is investigated;

How can other identified national regulatory areas on distribution grids be adjusted to support LEC development?

7.1 Hypothesis 4: changes of concession rights

An analysis of conducted interview within this section investigates the following hypothesis;

Reaching an agreement with the DSO to allow LECs to autonomously manage grids within existing concession areas as proposed by the EU is unlikely based on current regulatory design and requires changes in concession regulation.

7.1.1 Selling network area

Firstly, legal conditions for providing grid ownership to LECs as proposed within the CEP are requested during the interview with the regulator. Explained by the respondents, there is no example of selling network parts of an existing concession area and such a case is currently not covered by law. According to Interview 4, the situation is as followed: *"Per current legislation, the DSO can sell a concession area but not clear if it is also possible to sell only a part of it. [...] If DSOs sell the grid, then they need to sell part of the concession right but it is not being accounted for in the current Electricity Act."* Further explained, all distribution networks in Sweden are currently either covered by concession rights or are defined under the previously discussed IKN exemption. In this context, the respondents further suggest to adjust the regulation in the future to allow LEC establishment.

In case that national law would be adjusted for enabling selling parts of a concession area, the interviewees of the DSO are questioned about the willingness to provide parts of their networks to communities. In addition to the economic loss that would be caused by the current design of the revenue cap, interviewees see disadvantages from a technical perspective. Here, the issue on the role and connected duties of the DSO arises. As outlined in Wallnerström et al. [2016], network operators must guarantee reliable and efficient power distribution for all customers within the network. The proposals within revised Directive 2009/72/EC address the responsibilities by requiring LECs to fulfil the duties of a DSO when operating the community grid. Amendments of the Parliament additionally introduce the provision that LECs shall *"be subject to balance responsibility"*, including financial responsibilities in case of caused imbalances in the main system. [EC, 2017c; European Parliament, 2017b] The opinion of respondents from DSO interviews, however, is that reaching the most efficient network operation is only possibly if the entire concession area is under control of the DSO rather than having “black holes” within the network.

Although the existing classification of *technical expertise projects* described in Section 3.1.1, the knowledge of local actors might not cover all aspects of the energy system such as the operation of power networks. The DSO’s assumption of LECs’ lacking ability to operate and maintain the network in an equally secure manner can be connected to the multi-purpose character described in the theoretical approach in Section 3.3.1. In relation to the Choice Awareness theory, Lund [2014] mentions typically limited access to financial resources for multi-purpose organisations which can pose another problem to fulfil roles and responsibilities sufficiently. Further outlined in the theory, this is especially relevant for investments and maintenance in energy infrastructure that is capital intense and characterised by long lifetimes of typically 40 years. These theoretical assumptions comply with the responses from interviewees that fear poor network maintenance due to comparatively lower financial resources as well as lacking interest to dimension the grid for potential future connections. Consequently, the willingness to allow community ownership of the grid is also hampered by the fear of risking technical problems within the remaining DSO network. This statement can be connected to the previously discussed revenue cap design, showing incentives for maintaining or increasing a high network efficiency and quality.

Potentially resulting higher costs for the DSO to maintain the overall network are further relevant from a socio-economic perspective, as stressed by interviewees of the DSO. Accordingly, this is related to the shrinking number of total customers within the DSO customer base if ownership of networks is transferred to communities. The respondent of Interview 2 explains the consequences of potential higher need for investments as followed: *“On a system-wide perspective, it might be unfair. [...] if customers are taken out, then the remaining have to cover a higher share of required investments.”* The Parliaments’ amendments on EU’s provisions include the issue by including the provisions for Member States to ensure that: *“conditions and standards are set up for local energy communities with networks in order to preserve efficient network planning.”* [European Parliament, 2017b] Derived from the explanations within the interviews, it is important for LECs to comply with these provisions to avoid negative effects from a socio-economic perspective. Further related to the socio-economic perspective, the respondents from Interview 3 highlights an avoided double-infrastructure as fundamental purpose of concession rights. When allowing LECs to decide on infrastructure upgrades, the problem is faced in Interview 2 as followed: *“A main issue would be to have a double infrastructure because it would be bad in a socio-economic way as all costumers need to pay more.”*

7.1.2 Leasing network area

At this point the question arises, if the proposed option within the CEP of leasing the network area leads to higher economic and technical feasibility. For that case, all interviewees at the DSO highlighted the definition of roles and related responsibilities as decisive factor such as stated in Interview 3: *“If the DSO is voluntary allowing a third party to establish, buy or lease part of the grid, the main question is about responsibilities, since* *the DSO has to ensure security of supply within the concession area."* The respondents fear that LECs might postpone needed grid upgrades resulting into poor conditions affecting the overall concession network area. This is further relevant in case of leasing, i.e. if the agreement is limited to a certain period of time and the grid is given back to the DSO thereafter. In addition, there is the risk for a needed double-infrastructure. Explained in Interview 4, the DSO builds for a long-term perspective. This implies a forecast when deciding on grid dimensions by considering potential future connections, including synergies between LECs that might further evolve. Private grid owners, however, typically focus on their individual needs only. The respondent of the DSO in Interview 2 highlights the problem of capacity dimensioning: *"By forecasting, the DSO wants to prevent optimisation needs at a later stage. Main issue would be to have a double infrastructure because it would be bad in a socio-economic way as all costumers need to pay more."* A transfer of ownership to the community in case of leasing the network area would further imply equal negative impacts as selling the grid. Consequently, the interviewee in Interview 2 suggests a cooperation between the LEC and the DSO: *"It is desired that the DSO can keep the rights to operate the network, meaning that the network can still be part of the DSO that is managing re-investments."*

As explained, if ownership and consequently the capital costs stay at the DSO, a cooperation would be more likely. This form of leasing, however, might constrain LECs in its functions by resulting into restricted local decision-making. Motivations of LEC members as further described in the theoretical framework in Section 3.1.1 are expected to drive the integration of RES by installing small-scale generation units. A realisation, however, implies needed connections to the distribution network. Since the EU's provisions allow LECs to own and autonomously manage the community network, decisions on investments within the network are decided locally rather than by the DSO. Within conventional energy systems, however, Swedish DSOs are entitled to refuse the connection of additional RES from DG if the network capacity is insufficient. [RES-legal, 2017b] As already mentioned in the problem analysis, delays in grid reinforcements are hampering a transition. Based on current regulation, however, only the network owner is entitled for conducting investments as explained in Interview 3. Consequently, decision-making at the DSO could negatively affect a potentially accelerated transition, e.g. if investments related to DG connections require an agreement with the DSO.

In this context, the issue the institutional barrier of lacking democracy as described in Section 3.3.2 might evolve. Next to comparatively limited financial resources and the previously mentioned lack of knowledge, also power within decision-making processes of new actors such as emerging multi-purpose organisations is typically lower compared to embedded organisations of the current system. [Lund, 2014; Geels, 2002] The desired leasing design from DSO perspective is therefore contradictory to the objective of customer empowerment including the EU's proposed right to autonomously manage the community network. This is in line with findings of previously reviewed literature. Accordingly, both Alarcón Ferrari and Chartier [2016] and Hvelplund and Djørup [2017] conclude on a required shift away from the current top-down regulatory framework, such as decision-making of the DSO, to a bottom-up regulation where attention is given to the public including municipalities and communities.

At that point, however, the question on how to deal with the case of bankruptcy of autonomously managed LECs arises. In such a scenario, there need to be solutions to further guarantee security of supply to members and customers within the LEC. This is especially complex since communities are not unbundled by definition, i.e. are responsible for both generation and supply, including grid operation. Consequently, regulation should include provisions on such a case. One idea is to introduce an independent third party that is handles such incidences.

7.1.3 Non-concessionary networks (IKN)

Outlined in Section 4.3, current Swedish regulation includes the possibility of non-concessionary networks (IKN) that are exempted from concession rights. Based on experience with existing non-concession areas such as wind farms, the previously explained problem of grid dimensioning arises. In addition, respondents from Interview 1 mention that applying for an IKN might be more feasible for newly established LECs rather than for existing networks. Questioned in the interview with the regulator, this assumption is fostered: *"There could be instances to apply the IKN but normally you can't if the grid is already established."* Respondents from Interview 4 further explain that legal aspects around the IKN regulation are complex since it involves various different provisions. As LECs are not covered within national regulation, there is also no clear answer whether LECs are applicable for the exemption from concession rights. In general, however, adjusted regulation might be required. This is based on the current provisions for applicability: *"In most instances, property boundaries and the type of business conducted within an area will be a barrier when setting up a LEC."* Overall, the respondents further explain that IKN regulation is not in line with EU law. Derived from the interviews with the regulator, present concession rights are currently undergoing re-examination. Accordingly, policy makers recognise the need for changes. The interviewees in Interview 4 explain: *"The government is currently investigating the IKN and concession right laws and there will be changes so that they correspond with the EU law. [...] There is progress in Swedish regulation on that."*

7.1.4 Conclusion

The analysis proves Hypothesis 4 on barriers related to infinite concession rights that require a voluntary agreement with the DSO to sell or lease networks. This is based on the fear of both economic and technical disadvantages. Consequently, it is essential to clearly define roles and responsibilities for LECs within regulation to avoid negative effects on the overall distribution grid. Also the case of grid leasing requires clarification of roles and responsibilities. Respondents of the analysed network operator suggest that grid ownership or at least responsibilities for O&M shall still be covered by the DSO. Since this involves the risk of restricted functions of the community, however, local decision-making shall be given priority in any form of grid leasing.

In this context, conditions for LECs need to be set up that ensure quality and efficiency of the overall distribution grid. This is further important from a socio-economic perspective. Societal disadvantages would be caused if the DSO faces higher costs to operate the grid when selling pieces of the network ("black holes"). Based on the decreasing DSO customer base resulting from LEC establishment, this might lead to higher costs for remaining customers. Consequently, LECs need to comply with provisions within the CEP allowing efficient network planning.

Secondly, the insights gained from the interviews show the absence of regulation on selling or leasing parts of the concession area. The same applies for IKN exemptions, that currently do not include any provision for the case of LECs but might be most feasible for newly established community networks. Overall, there is a clear need to re-design Swedish concession rights to create a possibility for LECs to own and operate existing networks.

7.2 Hypothesis 5: fair connection charges

Lastly, the design of connection charges is analysed as resulting from Hypothesis 5;

Charges for LEC connection to the main distribution grid need to be reasonable from both DSO and LEC perspective.

7.2.1 Problem with calculation method

Overall, the DSO prefers interconnected LECs rather than having LECs in island mode. According to Interview 2, the DSO would have an income from connection charges while also benefiting the LEC by providing backup capacity. As outlined in Section 4.3 on Hypothesis 4, the DSO decides on the connection charges for large customers such as LECs individually, i.e. through a key account manager. The regulator is solely outlining the general requirement of having non-discriminatory and reasonable charges. Provisions on the issue of charges applying to LECs in case of a connection to the DSO are also part of the EU's proposal. Accordingly, Member States shall ensure that LECs: *"are subject to fair, proportionate and transparent procedures and cost reflective charges."* [EC, 2017c]. Amendments of the Parliament further include the provision for LECs to: *"adequately contribute to the costs of the electricity system to which they remain connected."* [European Parliament, 2017b]

Based on the interviews with the DSO, there are two main problems of deciding on reasonable connection charges. Firstly, the charges typically depend on the required capacity. However, the method of conducting grid upgrades is based on future developments, as explained in the previous section. This might lead to a higher installed capacity than actually needed by the LEC itself. Since the DSO does not want to take a risk and needs to recover the full costs, the respondent of Interview 1 raises the question on who should be charged for the resulting costs. Interviews with regulator react on the issue as followed: *"If the DSO builds more capacity than needed, then the community is not responsible to pay for the overcapacity. [...] If there will be a second village or more homes connected in the future, then these additional customers should pay."* Derived from that suggestion, a solution for calculating reasonable costs for the community is to base the costs on the actual required capacity. However, the next problem arises with determining this actual needed capacity for the LEC. According to Interview 1, the DSO calculates the required backup for the LEC for the worst case scenario: *"In solar and wind production which is fluctuating you must dimension grid for both extreme cases, both ways of energy flow."* When applying this suggested calculation method, it is based on maximal possible

PV and wind production as well as the case of no RES availability. However, such a calculation neglects local self-consumption and relevant flexibility options such as storage, DSM and in some cases also sector-coupling possibilities. These possibilities, however, can potentially reduce the actual required maximum capacity, as shown for some of the HOMER scenarios. Consequently, the DSO should include the potential of implemented flexibility options when determining the needed grid capacity. As a solution to that problem, the operating entity of the LEC should be requested to conduct a technical study before community establishment. Such an investigation can provide information on the actual requirement to the DSO.

As already suggested in discussions on the economic impact, the interviewees of the DSO once again mention backup services to LECs from storage facilities as a solution. By substituting grid reinforcements, network charges could further be decreased. Here, the DSO once again highlights the desire to be entitled for operating storage facilities in the future. In this context, however, the respondent from Interview 3 raises the problematic on how to design the charges for such backup services. Accordingly, new alternative solutions involve the establishment of adjusted future tariffs.

7.2.2 Conclusion

Hypothesis 5 on required fair connection charges for both the DSO and the community is confirmed by the conducted interview analysis. Respondents working for the regulator stress the need to compensate the DSO for selling the network area. At the same time, the community should only be charged for the actual required capacity. These criteria are in line with EU proposals.

However, difficulties on price determination occur. Based on future planning, DSOs typically invest in grid upgrades with higher capacity than currently needed. Consequently, there are difficulties to determine the actual fee for LECs. Derived from the functions of LECs and tested with scenario modelling within the Thesis, various flexibility options within the community can decrease the needed capacity provided by the DSO. Consequently, LECs shall provide a technical study to the DSO that outlines information on the actual required capacity in extreme cases. Another possibility to decrease network charges is suggested from DSO side, i.e. to allow DSOs the operation of storage facilities as backup service to the community.

To conclude, the last hypothesis on a required fair calculation method for LEC connection charges is validated. Charges need to both compensate the related costs for the DSO while only charging the community for the actual required capacity to further avoid financial barriers for the LEC. In case of overdimensioned grid connections built for anticipated connections, resulting additional costs shall be covered by those customers to be connected in the future. Connection charges could be further reduced by allowing DSOs to provide backup services from storage units as a substitution to grid upgrades.

8 Discussion & conclusion

8.1 Discussion of key results

8.1.1 Sub-question 1: Definition LEC as technical alternative

As a conclusion from the first hypothesis testing, LECs might not be a solution to solve existing technical problems within Swedish distribution grids. This conclusion results from an investigation of causes for reliability problems in the analysed network area, that are primarily caused by external factors including extreme weather patterns rather than by large feed-in of distributed generation. Consequently, the defined functions of LECs such as flexibility options leading to a higher local self-consumption cannot contribute to solving existing reliability problems within the analysed network area.

One point of discussion is on the intention of LECs. Within this Thesis, the defined purpose is in contributing to an accelerated transition while further creating economic and technical benefits to the energy system. In contrast, during exploratory research at the DSO, opinions that LECs might primarily follow the aim of customer empowerment occurred. Consequently, instead of the defined criteria for LEC choice, another possibility would be to focus on areas with already existing RES capacities that could be used within a LEC to achieve self-autarchy. Since the defined LEC purpose within this Thesis is derived from the aims of the CEP as well as the overarching EU policy objectives, however, the decision stayed with the defined selection criteria. Nevertheless, defining the potential of forming communities in areas with already existing capacities when primarily following the aim of customer empowerment could be a field for further research.

Overall, the modelling results prove the assumption derived from theory and literature research that LECs can contribute a cost-efficient integration of RES from DG compared to a conventional integration. Furthermore, the theoretical approach of applying sector-coupling for achieving a higher integration of distributed RES is validated by scenarios modelling. However, higher cost-efficiency is achieved in areas with ample RES potential. Since locations with thermal networks in Sweden are mostly found in more densely populated areas, it might be challenging to find optimal locations. Nevertheless, scenarios of high RES availability without sector-coupling show potential for cost-efficient RES integration, too.

Regarding the chosen tool of HOMER for modelling, the strong relation of results on chosen input parameters must be noted. Since designing optimal HOMER models is not the main focus of this Thesis but serves for testing one hypothesis, further modelling improvements with more detailed input parameters would have been possible. However, such an optimisation is not expected to majorly influence main results required for the scope of this Thesis, i.e. testing and comparing the ability of LEC functions. In addition, scenario modelling with HOMER has some restriction. Firstly, there is a lacking ability to change the thermal load controller unit from the generic unit. Here, a scenario using a heat pump with a resulting higher efficiency might further benefit the sector-coupling scenarios. Regarding determination of the potential for reduced grid upgrades, another deficit is the exclusion of network-specific data such as transformer capacities or potential voltage problems. For such an analysis, a detailed network calculation including the exact location for RES installations within the grid would be required and exceeds the scope of the Thesis. Nevertheless, such a calculation might be conducted for real case simulations.

8.1.2 Sub-question 2: Economic impact on DSO business

Resulting from the business-economic impact analysis in Chapter 6, the interview interpretation is a first indicator on lacking incentives for the DSO to allow grid ownership of LECs as proposed within the CEP. Accordingly, the current design of the revenue cap is seen as inappropriate, proving Hypothesis 3. Consequently, adjustments for enabling economic feasibility for DSOs to support a transition are required. This conclusion is further fostered by conducted calculations and sensitivity analyses on the revenue cap design for the selected case LEC. Here, the focus is set on testing the impact of a decreasing network area on the capital costs. It must be noted that the calculation excluded an investigation of potential benefits caused by local self-consumption such as improved efficiency or quality to the main grid. An investigation and inclusion of these factors might have led to a lower overall decrease on revenues when selling the network area. Nevertheless, the calculation fulfils the purpose of showing the strong impact caused by a decreased asset base on total revenues. As confirmed by interviewed respondents from the DSO, this factual situation hampers the willingness to allow LEC development.

While the sensitivity analysis shows the impact of the applied WACC, another parameter mentioned by interviewees is the underlying life time for the capital cost calculation. The life time is based on conventional infrastructure, which hampers the DSO to invest in innovative alternative solutions with a potential lower life time. A sensitivity analysis on changing the applied life time can therefore create an understanding of the impact and should be a field for further research. In relation to changes in economic parameters determining the capital costs, a shift from the current CAPEX to a more OPEX-based calculation structure is derived as one potential regulatory change. Next to a lower impact on selling parts of the network, the DSO would further be incentivised to offer OPEX-related services to LECs. One discussed option is to replace investments in grid reinforcement by providing backup to LECs from storage facilities operated by the DSO. Based on current unbundling rules, however, DSOs are not entitled to provide such a service. This requires the introduction of provisions allowing DSOs to operate storage facilities, which is already proposed by the Parliament within the revised Directive 2009/72/EC on the internal market in electricity. The issue is further discussed when reflecting on Hypothesis 5 on connection charges.

8.1.3 Sub-question 3: Other regulatory areas affecting DSOs

Concession rights

Both previously identified regulatory areas of concession rights and the calculation method for connection charges require an appropriate design for allowing LEC development. Regarding the practically infinite concession rights in Sweden, the DSO needs to voluntary agree to sell or lease a network area. Based on the investigated issue of lacking economic incentives, however, such a cooperation is unlikely in most cases and requires adjustments of the revenue cap regulation. Secondly, LECs need to fulfil certain duties to avoid any technical disadvantages that affect efficiency and quality within the main distribution grid to which they remain connected. In this context, the CEP include provisions for LECs to comply with. At that point, however, the multi-purpose character of LECs as outlined in the theoretical approach arises as a potential barrier. Accordingly, communities might face both lacking financial resources and level of expertise to ensure an equally reliable network operation.

Here the question arises if the proposal of allowing LECs to own and autonomously manage the network while being required to fulfil all related duties is appropriate. In case of lacking ability to meet the demands, such a development might result into disadvantages for both the DSO and the community. One solution is to cooperate with external actors, i.e. single-purpose organisations. Such agreements, however, should in any case still allow LECs the power of decision-making while achieving cost-efficiency.

This is connected to the issue of lacking democracy of actors with interests in alternative solutions, as outlined in the theoretical framework. Consequently, the current regulatory framework allows a top-down decision by the DSO on grid investments. With regards to the high weighting of capital costs determining the business model, the interview analysis raises the assumption that the DSO prefers investing in grid upgrades rather than innovative solutions including smart grids. A shift of power from private actors to value-oriented entities such as communities might lead to lower grid investments. However, ensuring no negative effects on the overall distribution grid is critical, which once again leads to the barriers related to the multi-purpose character of LECs.

Connection charges

Currently, there is no regulated calculation method on connection charges since regulation merely outlines the need for ensuring "reasonable" prices. In case of large customers such as LECs, the price is typically negotiated via a key account manager of the DSO. Derived from the analysis, the main point of contention is about the chosen capacity to connect LECs. The conclusion is that DSOs typically built for a long-term perspective with forecasts to additionally connect future customers but LECs shall not be charged for related costs to capacities exceeding the need of the community. Here the idea is that LECs should provide studies to the DSO on actually required backup needs for worst-case scenarios, under consideration of various flexibility options within the community network. Once again, the potential lacking level of expertise might require the involvement of an external actor to conduct such a study.

Secondly, the DSO suggests to provide backup services by operating storage facilities to lower connection charges. A point of discussion are the resulting costs and consequently if such a service would reduce financial barriers for the community. The question is, if the community is charged for the service only or also for the storage investment costs. In the latter case, the same problematic of who should be charged for potential overcapacity of the storage would arise. Consequently, regulation should not only cover rules on entitled parties operating storage facilities but also on charges posed to customers.

8.2 Discussion of methodology and limitations

8.2.1 Methodology

Choice Awareness' methodology

Firstly, the chosen research design explained in Chapter 4.4 is based on the methodology developed within the Choice Awareness theory. As explained before, the aim of the theory is to promote technical alternatives for reaching an energy transition, including regulatory changes. Since LECs are seen as such an alternative solution, the methodology is chosen for the purpose of this Thesis. Therefore, the established sub-questions are based on the first three steps of the Choice Awareness methodology.

Strategy of hypothesis testing

Next, the overall strategy of the research paper that is based on hypothesis testing can be discussed. The formation of hypotheses is chosen to structure the analysis steps of developed sub-questions and to navigate the questions asked within the interviews. Overall, the validity of results from hypothesis testing can be discussed. Since the establishment is built upon knowledge gained from both the problem analysis and the underlying theories that is supplemented with further research, the hypotheses are expected to be relevant for investigation. Nevertheless, the researcher is aware that there may be other research strategies to reflect on the overall research question.

Case study research

In addition, case study research is applied. This is in accordance with the purpose of the research question to define required changes in national regulation to translate the EU's provisions into national law. Here, Sweden is selected for the analysis. Based on national energy objectives and currently highly centralised energy generation, Sweden shows a potential for a high share of future integration of distributed RES. Since LECs are defined as a potential facilitator of such developments, Sweden is seen as an appropriate choice for analysis. Notwithstanding, other Member States might show similar potential for LEC development and could therefore be also feasible choices. Applying the analysis to other countries is therefore an interesting field for further research.

8.2.2 Limitations

Regulation affecting distribution systems

As explained in Section 2.8, the overall focus of the Thesis is on regulation of distribution systems and their impact on LEC development. Although there are various other regulatory areas to investigate, the limited time-frame of the research required to narrow down the scope. The selected regulation area is based on provisions within the CEP, where those involving ownership and operation of networks are seen as fundamental issues to analyse. Related to the choice, the economic investigation is conducted from a business-economic perspective of the DSO. An investigation from the perspective of the LEC, however, would be another highly important area to analyse when discussing the regulatory design. Overall, it is further necessary to shape regulation towards reaching the optimum from a socio-economic view. As explained within the Choice Awareness theory outlined in Section 4.2, conducting a business-economic assessment is therefore the first step of an overall evaluation on economic feasibility.

Analysed network area

One point of discussion is based on the analysed data, that only represents distribution networks operated by the selected case DSO. A complete investigation of all Swedish distribution networks in such detail would require an extensive study by collecting data from all 170 DSOs. By analysing networks of the largest network company operating one fourth of all networks, however, the results are expected to provide required insights for reflecting on the overall research question. Regarding the first hypothesis, a positive aspect of the analysed DSO is the broad geographical network coverage, since concession areas are found in both rural and urban areas as well as in northern and southern parts of the country and in the region of Stockholm. Since the same revenue cap calculation method applies for all DSOs, testing the economic impact of LEC establishment is further guaranteed by applying data from the selected case. An example of an individual parameter is the CAPEX share, that is above the average. Here, the sensitivity analyses provide insights on results for different CAPEX shares.

Selected LEC case

Another limitation to discuss is the chosen LEC case for scenario modelling and economic calculations. Selected criteria are expected to be feasible since these are derived from the defined community purpose as further resulting from the problem analysis, theoretical framework as well as further validated by testing the first hypothesis. As already mentioned in the analysis, however, during the selection process the impression occurred that there might be various reasonable cases rather than one perfect location. The investigation of the entire network area has been complex and required the knowledge of experts from the DSO, i.e. to define technically feasible areas for LECs. Also, the restricted ability to install RES capacities is related to the criteria of choosing a location with existing DH networks. For the analysed Swedish distribution network, thermal networks are majorly found in densely populated areas without ample free areas for RES integration such as wind turbine installations. Consequently, the criteria are to some extend contradictory for the analysed case. For that reason, the HOMER scenarios were conducted with unrestricted capacities. Such a scenario could apply in other network areas or even other countries, with the existence of thermal networks in areas with larger availability to install DG units.

8.3 Conclusion

By testing various established hypothesis, the three sub-questions can be answered.

1. "Which technological set-ups and grid areas are feasible for LEC establishment to facilitate an energy transition in Sweden?"

With regards to EU's proposals within the revised Directive 2009/72/EC on common rules for the internal market in electricity, the potential of LECs in the Swedish context is proved to go beyond customer empowerment. Resulting from the analysis, LECs can contribute to a cost-efficient integration of distributed RES in areas with a high potential for future distributed RES installations. For the case of Swedish distribution grids, however, LECs might not solve exiting reliability problems since these are majorly caused by external factors rather than RES feed-in. With regards to national energy objectives, LECs are expected to serve as future solution.

Regarding the technological set-up, the scenario modelling indicates that feasible technologies include the possibility of peak shifting such as via DSM. Synergies with other energy carriers such as in areas with existing thermal networks are further validated to achieve higher local self-consumption while potentially decreasing the need for grid upgrades.

2. "How should national regulation on allowed DSO revenues be designed to create business-economic feasibility of LEC penetration?"

An investigation of the business-economic impact on DSOs when selling or leasing networks results into an inadequate design of the present revenue cap. Consequently, lacking incentives provided within regulation result into low economic feasibility of supporting the development of LECs in existing network areas. A key issue is the high weighting of capital costs, caused by underlying economic parameters.

One suggestion is to shift the regulation from the current CAPEX to a more OPEX-based calculation method. In addition, a further implementation of incentives for smart grid development are expected to support LEC development.

3. "How can other identified national regulatory areas on distribution networks be adjusted to support LEC development?"

An investigation on the last sub-question raises awareness on several potential barriers within present national regulation. Firstly, current regulation does not address the issue of selling or leasing grids within existing concession areas. In addition, the practically infinite concession right of the DSO requires a voluntary agreement that is hampered by lacking economic incentives.

Secondly, the DSO is concerned about lacking ability and interest of LECs to operate the network in an equally secure manner. Since this might cause negative impacts on the overall distribution grid, LECs need to fulfil certain duties when autonomously managing the network. Such provisions, however, might be challenging due to potentially limited financial resources and level of expertise. In this context, the question on how to deal with LEC bankruptcy is further relevant.

Next, interviewees of the DSO stress the problem on defining appropriate network charges. One difficulty is to define the actual needed capacity that is influenced by flexibility options of diverse LEC functions. In this context, interview respondents from both the analysed DSO and the regulatory body see a possibility in allowing DSOs to operate storage facilities as an alternative backup solution for LECs. This could decrease the need to invest in grid upgrades and is further fostering the shift to a more OPEX-based revenue cap design.

Overall, the following regulatory changes to answer the overall research question, of;

"Which regulatory changes within national regulation of distribution systems are required for the establishment of Local Energy Communities as proposed by the EU to contribute reaching an energy transition?" are identified:

- Overall, LECs should be acknowledged as a feasible alternative solution for the purpose of integrating future distributed renewable capacities contributing to Swedish energy objectives. Therefore, national regulation shall include clear provisions to allow LEC development.
- Present design of the revenue cap requires a shift from the current CAPEX-intense design to facilitate a transition. A combination of both a lower WACC as well as a higher weighting of operational expenses is identified as a potential solution reduce economic impacts when providing grid ownership to LECs.
- Incentives for smart grid development are considered as an effective way for both an overall transitions as well as allowing LEC development as part of the solution. Next to the already decided introduction of smart tariffs, further adjustments of incentive regulation shall be conducted.
- Current regulation on concession rights requires the inclusion on the possibility to sell or lease parts of an established network. This is required to enable LECs the right to autonomously manage the network.
- Roles and responsibilities of LECs concerning a secure network operation need to be clearly introduced. This is important since LECs should not cause technical disadvantages for the DSO, which might result into socio-economic disadvantages.
- LECs shall be given priority within local decision-making to enable functions of the LEC allowing an accelerated transition. This is further relevant in case that network leasing includes an agreement where O&M is under control of the DSO to avoid technical disadvantages.
- Clear rules on dealing with the scenario of LEC bankruptcy are required to guarantee security of supply for affected customers. This could be handled by an introduced independent third party.
- Steering or monitoring the calculation of LEC connection charges by the regulator is necessary to allow a compensation of DSOs based on the actual required capacity. The LEC shall not be charged for larger capacities based on future planning of the DSO. A technical study can serve to determine the actual needs.
- Allowing DSOs to operate storage facilities as an alternative backup solutions for LECs could decrease the need to invest in grid upgrades. In that case, provisions on fair charges need to be clarified, too.

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HOMER background data A

A.1 Input parameter

Section	Parameter	Value	Unit	Comment/Source
General project setup	Discount rate	8	%	Predefined value
	Inflation rate	2	%	Predefined value
	Project lifetime	25	a	Predefined value
Electrical	Community load profile without explicit peak load month			
	Day-to-day variability	10	%	Own choice
	Timestep variability	20	%	Own choice
	Annual average consumption	15,867	kWh/day	Based on selected LEC case
Electricity	Constant tariffs			
	Power tariff	0.19	Euro / kWh	[Statista, 2018]
	Feed-in tariff	0.0164	Euro / kWh	[RES-legal, 2017a]
	Sale capacity	200	kW	Own choice
District heating grid	Heat Unit	Boiler		
	Fuel	Natural gas		
	Price	0.5	Euro/m³	Predefined value
PV modules		BenQ SunVivo 300Wp PM060MW2 - Solarmodul Monokristallin 300Wp		
	Investment costs	700	Euro / kW (pea	Including 170 Euro for installation
	Operation and maintenance	10	Euro / kW*a	Predefined value
	Lifetime	25	a	Predefined value
	Nominal efficiency	18.4	%	This corresponds to the cited module
	Temperature coefficient	-0.42	% / K	This corresponds to the cited module
	Temperature NOCT	46	°C	This corresponds to the cited module
	Ground reflectance	20	%	Predefined value
	Panel slope	59.41	°	Predefined value
	Azimuth angle	0	°	Predefined value for southern orientation
	Derating factor	80	%	Predefined value
Converter	This is the standard HOMER AC <-> DC converter			
	Investment costs	300	Euro / kW	Predefined values
	Operation and maintenance	0	Euro / kW*a	
	Lifetime	15	a	
	Efficiency AC -> DC	95	%	
	Efficiency DC -> AC	95	%	
Wind	Model	XANT 100 kW		
	Investment costs	86,000.00	Euro / piece	IRENA
	Operation and maintenance	1,720.00	Euro / piece*a	Approx. 2% of the initial investment costs
	Lifetime	Determined by HOMER	a	Predefined values
	Hub height		m	
	Cut-in speed		m/s	
	Rated speed		m/s	
	Cut-out speed		m/s	
	Cut-in power		kW	
	Rated power		kW	
Battery	This is the standard HOMER Li-Ion battery (without Advanced Storage Module option)			
	Investment costs	240	Euro / kWh	Standard value - Swedish state grant of 60%
	Operation and maintenance	10	Euro / kWh*a	Predefined values
	Lifetime	15	a	
	Initial State of Charge (SoC)	100	%	
	Minimum SoC	20	%	
Deferrable load	Average load	1586.67	kWh/d	10% of the original, total load
	Storage capacity	588.65	kWh	3 hours of operation at 10% peak demand
	Peak load	196.22	kW	10% of the original profile's peak demand

Table A.1. Applied input parameter for HOMER scenario modelling

A.2 Illustrations and hourly values

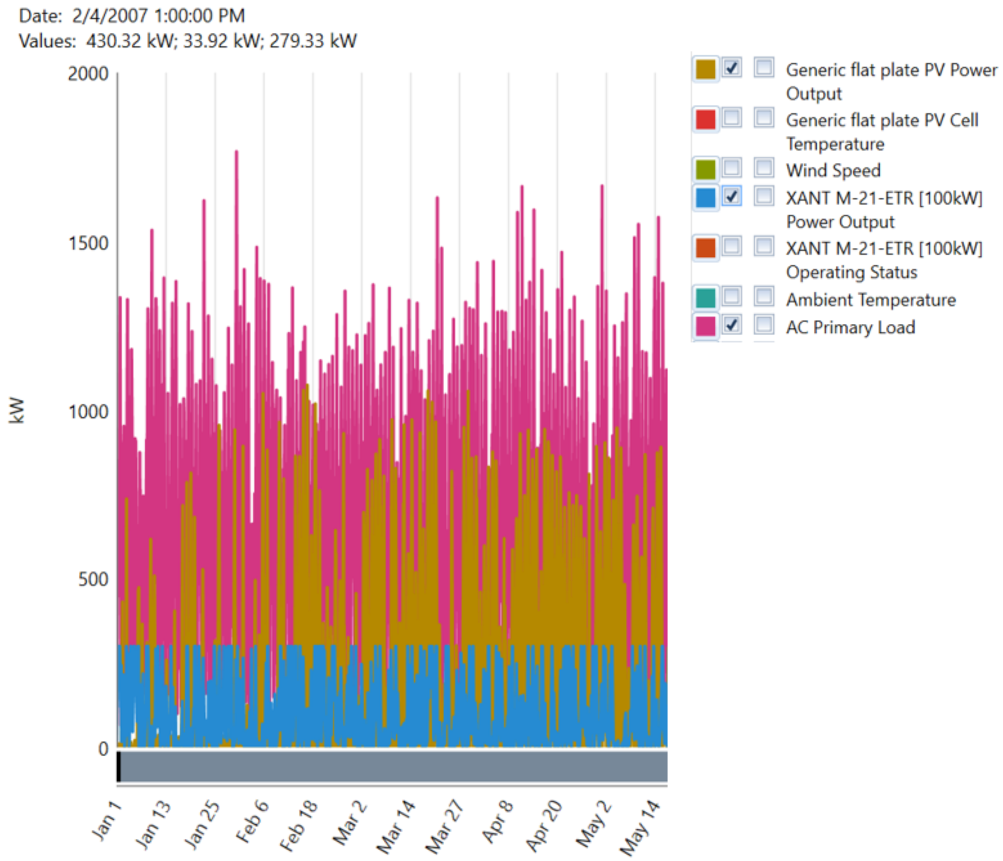

Figure A.1. Graph on hourly values of renewable output for the electricity-only LEC scenario with limited RES capacity

Time	AC Primary Load	Deferrable Load Served	Deferrable Load Storage Level	Grid Purchases
	kW	Deferrable Load Served	kW	kW
01/01/2007 00:00	151.3	29.3	551.8	-
01/01/2007 01:00	146.2	-	485.7	16.6
01/01/2007 02:00	215.3	-	419.6	71.6
01/01/2007 03:00	265.0	-	353.5	41.6
01/01/2007 04:00	266.2	92.0	379.4	-
01/01/2007 05:00	384.9	93.4	406.7	-
01/01/2007 06:00	474.7	196.2	536.9	-
01/01/2007 07:00	638.5	117.9	588.7	-
01/01/2007 08:00	732.3	66.1	588.7	-
01/01/2007 09:00	849.2	66.1	588.7	-
01/01/2007 10:00	691.6	66.1	588.7	-
01/01/2007 11:00	896.8	66.1	588.7	-
01/01/2007 12:00	860.7	66.1	588.7	-
01/01/2007 13:00	803.6	66.1	588.7	-
01/01/2007 14:00	733.0	66.1	588.7	-
01/01/2007 15:00	449.2	66.1	588.7	-
01/01/2007 16:00	866.1	66.1	588.7	-
01/01/2007 17:00	758.0	66.1	588.7	-
01/01/2007 18:00	1,110.1	-	522.5	7.3
01/01/2007 19:00	1,177.0	-	456.4	74.1

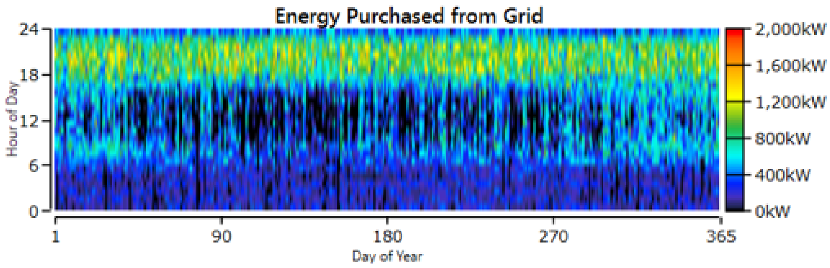

Table A.2. Hourly values of deferrable load and grid purchases for the electricity-only LEC scenario with limited RES capacity

B Interview transcripts

B.1 Interview 1: DSO, Financial Controlling & Risk

1) Current concession regulation

a) Does the DSO have an infinite concession right in any case in Sweden?

The DSO can lose concessions if the job is not done in a good way, e.g. in case of very low reliability of the grid. The concession right has to be renewed after a certain period of time (40 years) but in general, if the DSO fulfils the duties for a secure operation, it can be considered as an infinite right.

b) What are current regulatory requirements to sell or lease a network area?

If it is sold, the value of the asset base is paid once. This is based on components and age. The case of leasing a network area is not yet addressed in the regulation. A concept of leasing the grid would be that the affected asset base has to be defined as leased but it still counts for the calculation of the revenue cap. The leased network area is still part of the asset base and therefore for the CAPEX calculation. However, the DSO is not maintaining this part of the grid anymore, since this is done by the community. Accordingly, the OPEX value has to be reduced by that amount. If the network is leased, it is still owned by the DSO. Only the party that owns the network is allowed to make investments. Accordingly, the community cannot make investments in the current infrastructure. The charged amount for leasing the grid has to be based on a leasing contract. The leasing fee might be based on how much the DSO gets on return in the capital base.

c) Could IKN regulation apply for LECs?

When applying IKN regulation, the DSO measurement only goes until the connection, as done e.g. for an apartment building. IKN might be an option for LECs but it might be tricky because the DSO does not only feed-in to the community but the community also feeds-in to the main DSO grid. If the DSO only has one connection, the DSO cannot predict. This results into more responsibility on the community because they have to divide the energy costs and they have to be responsible for their system. IKN would probably work best for totally new community since having a concept as a community from the beginning would help.

2) Connection charges

How should the charges for LEC connection to the main distribution grid be calculated?

There is a question on how to calculate the connection costs. The DSO must connect all customers. And the DSO builds based on a forecast e.g. if there are more connections such as communities nearby expected in the future. For example, there are 10 households right now. The DSO will probably wait for better economic conditions but from the beginning the plan is based on a forecast. The question arises, if the first LEC needs to pay for the whole connection or just for a part. One example where the same problem is faced are wind parks. They do not want to be the first one because they have to pay for the connection. Same problem might arise with the LEC. If the LEC is connected, i.e. not operating in island mode, there is the question on the needed capacity. In solar and wind production which is fluctuating you must dimension grid for both extreme cases, both ways of energy flow. It is difficult to calculate because the DSO does not want to take a risk. The best solution is to have a good storage solution.

3) Revenue cap regulation

a) What are problems of the present calculation method?

The current regulation is based on the age of the grid. If you invest in grid upgrades, you get a higher return. The return is highest when the grid is new and in general, the return is going down based on depreciation. There is a so-called “38-rule”. The oldest asset is counted as 38 years, even if the real age is older. The DSO counts from the maximum age of 38 years onward. That “38-rule” was introduced as compensation for shifting the model. For the next period, they will change it probably. One problem for the DSO is that the regulator is constantly changing the regulation but the DSO has long-term investments, because of 40 years’ life time.

b) Can an improvement of quality and efficiency factors substitute the loss in asset base?

In total, the three quality and efficiency factors can only contribute to maximal improvements of 5%. The load factor only brings positive impacts. For smaller network companies that have not invested so much the incentives could probably earn money. However, in a case where the LEC network is sold, the incentives on improved quality and efficiency most likely do not compensate the loss of CAPEX.

c) Are you aware of any changes affecting DSO business in current plans of Ei to introduce “smart grid incentive scheme”?

The workforce of the DSO is working on potential regulatory changes. However, focus is on other parameters such as influencing the decision on the WACC, or technical life time for assets. Accordingly, the focus is not so much on the incentive scheme.

d) How is the WACC determined?

Ei is deciding on the WACC. It is the same for every DSO and for the entire regulatory period of 4 years. However, there is a forecast that it will be changed and consequently it will be updated every year in the future regulation.

4) What are other barriers for RES development?

There are lacking incentives for DSOs.

The regulator should provide more incentives for being proactive in the transition to RES. It is risky to invest in new technologies. This is because the defined time frame for assets in regulation is 40 years. If the DSO invests in new technologies, you don't know how long it lasts. Currently there are no incentives in regulation to invest in a new technology that might not last for 40 years. There are not enough incentives to invest in the new energy market. The DSO does not want to take risks so the regulation needs to fit. If the DSO should drive the progress, there need to be regulatory changes. The DSO also wants to be part of the transition, but then the risks need to be lowered.

There are also barriers from a socio-economic view. Rich customers that can afford to invest are in the community, but the question is, who is paying for the rest of the grid? The other society will have to cover the costs. There is a question on who is paying for the results of expanding micro-generation and for LEC integration? The remaining society has to pay off the investments. The grid as a whole must still function if LECs cut off from the grid. The DSO has still the same costs than before, but less customers are paying for it. The connection of LECs to the grid needs to be financed. There is the question on who is responsible to recover that costs? In Germany, it was a problem because customers do not pay for the connection fee. Rich people that can afford investments in RES installations benefit from self-consumption and high feed-in tariffs. But the DSO has to guarantee to connect everyone and provide access for feeding in electricity from all installations and guarantee the resulting right level of capacity. These investments have to be paid off by the entire society.

B.2 Interview 2: DSO, Strategy & Regulation

1) Current concession regulation

a) According to the CEP, LECs "are entitled to own, establish, or lease community networks". Which option do you see as most realistic/feasible based on the current design of Swedish concession regulation?

Within the current regulation, none of these options are feasible because the DSO does not want to sell the grid, since it is not a good business according to the current regulation. Firstly, legislation needs to be changed by regulation and then the DSO needs to adapt to it. For the moment, it is more economic for the DSO to have a larger network, i.e. economics of scale apply. From the DSO perspective, it is better to own the entire grid rather than selling pieces inside that area. However, the economic impact also depends on the income the DSO gets from connection charges. Also from a technical perspective, it is better to own the entire network. From the economical perspective, it is really hard to say what the most economical option is.

b) Do you see any barriers in the current concession system for each of these three options, and if yes, can you briefly explain how the current regulation hinders a penetration of LECs?

Overall: The DSO owning a concession has both the monopoly over the infrastructure and electricity distribution but is also responsibility to connect consumers within the area. There is also the possibility to apply for IKN where you don't need the concession rights. Today, IKN only applies for special cases where the area is a property of one owner e.g. industry area, ports, university etc.

Selling: In case of selling the grid, the LEC takes full responsibly while DSO loses part of the concession. Here, the DSO cannot optimise the network. Normally, DSO can see full picture, but when LEC network is sold it is like a "black hole" for the DSO since there is no control on that part anymore.

Leasing: When leasing a network, it is very important to clarify the responsible parties for maintenance and re-investments. For the DSO, an optimal functioning of the network is really important. If someone else takes care about the network, there is the risk of a less efficient grid operation. There is the possibility for shift re-investments for a few years, but then larger problems might occur at some point. Here, skipping dentist appointments can be used as a metaphor. Probably the LEC wants to maintain and operate the network as cheap as possible. For the DSO, however, it is always a long-term perspective, since most components life time of 40 years. If LEC lease it for 10 years with poor maintenance, DSO does not want it back afterwards. In contrary to LECs, the DSO does not limit the investment plans to one network area since the DSO aims to predict in a way to optimise the grid infrastructure. DSO wants the possibility to maintain, re-invest and conduct new investments. In case of LEC establishment, the main question arises: who is responsible for these duties?

Establishment of new grid: It is not possible within a concession area to build your own grid. The DSO is the only one that is allowed to connect customers. The DSO is at the same time obligated to connect while being the only one allowed establishing a new grid.

c) From the perspective of the DSO, which option would have the highest potential of willingness for cooperation?

Leasing, but depending on the contractual conditions. Here, it is desired that the DSO can keep the rights to operate the network, meaning that the network can still be part of the DSO that is managing re-investments. It could probably be done in partnership/cooperation with the LEC. In this case, however, the DSO wants to be able to influence what is happening within the network because it might be given back to DSO in the future and it should be in a good condition. Networks without concession already exist today, e.g. between wind power plant. Here the problem is that these are typically dimensioned based on their individual need at the moment. If given back to DSO, however, there is a lacking possibility to connect new consumers and consequently a parallel cable might need to be built. DSO wants to do long-term planning and to reach the most optimal solution also from a socio-economic perspective. DSO typically builds for a 40 years perspective, whereas in case of private investments it is likely to be built for a shorter time frame, since they build for existing capacity whereas DSO includes a forecast. This forecast includes the possibility of synergies between communities next to each other, e.g. there could be a connection between them and it might be cheaper to build in a larger scope. By forecasting, the DSO wants to prevent optimisation needs at a later stage. A main issue would be to have a double infrastructure because it would be bad in a socio-economic way as all costumers need to pay more.

2) Connection charges

a) The CEP defines LECs as "efficient way of managing energy at community level [. . .] with or without a connection to distribution systems". Which option do you see as more feasible?

From the perspective of the LEC, it would be a benefit having a connection since it serves as a backup. Also from a DSO perspective a connection generates income since the LEC has to pay for connection point and also for the need they have for backup capacity.

b) In case of choosing to be connected, which potential barriers might the LEC face with regards to connection charges?

In general, the calculation of connection charges is based on the maximum capacity needed. Customers pay for what they use. The DSO needs to invest to enable LECs the required capacity. The LEC has to contribute to the costs because otherwise the remaining consumers have to pay since someone needs to cover the caused additional investments. From a fair perspective, everybody should contribute to the costs that they are demanding from the network. One related part in the CEP is the issue on energy poverty. If LEC does not pay for it, it could lead to the same situation as in Germany where prices increased for households.

Connection charges are regulated in a sense that the connected consumers can ask for review, similar to a small court. Charges should be fair and depend on needed conditions.

3) Revenue cap regulation

a) Do you see any barriers within the current regulation defining DSO business models for a penetration of LECs?

LEC would represent large customer, where special tariffs apply. E.g. industries have a key account manager, as the price is negotiated. Local energy grids exist for example in small towns, which also have their own price negotiations.

b) How would you estimate the impact of LECs on overall customers within the reporting area, including those outside LEC boundaries?

On a system-wide perspective, it might be unfair. Areas with a high customer density would probably like to form a LEC because of economic motivation. Consequently, those remaining in the larger network need to cover more investments per customer. DSO investments are transferred to remaining customers. If some customers are taken out from the DSO customer base because of LEC establishment, then the remaining have to cover a higher share of required investments. If the LECs doesn't pay for it and if they operate in island mode disconnected from the main grid and have a diesel generator for backup, the amount of total customers shrinks. If the LEC has other than economic incentives, than it might be different but the main driver for LEC is most likely economic because they could also use RES in existing grid. If the LEC owns the grid, no taxes need to be paid. There is already a new legislation, saying that if production is used as self-consumption, then no taxes need to be paid for what is used by themselves.

c) Do you see a potential of LECs to contribute to overall lower tariffs?

Depending as it is put; If there is a potential to accelerate the transition for RES, then yes. In combination with energy storage, there is no need to reinforce the network. The DSO takes full responsibility to build for the future and for the energy transition. It is needed to find the best way for society and new business models to allow building more optimal networks. The DSO wants to build the optimal solutions to integrate more RES and e.g. storage etc. so that there is no more need to reinforce the main grid. This might decrease tariffs because of a more optimal infrastructure. Key for success is that more RES can be connected. But there is a need to find solutions such as storage and innovative technologies for flexibility because otherwise there is an increased capacity need in the network. DSO wants that the regulation is changed e.g. to give incentives to build more optimised networks for handling RES feed-in, including smart grid development. This goes beyond integrating more RES, e.g. also electric vehicles and other changes in society like changing consumer behaviour.

4) From your experience, are there any other regulation areas of distribution systems that might constrain LEC development and overall benefits for society?

The problem with double infrastructure has a main negative impact on society.

The problem on lacking regulation on energy storage as explained before is further relevant. The possibility to build storage outside the LEC boundaries could be used as a tool by the DSO instead of grid upgrades and to balance the LEC. However, within current national regulation and also within the CEP, DSO is not allowed to operate storage.

Also consumer rights are an issue. From a consumer perspective, they might feel to have lower rights than the ones living outside/connected to main DSO grid. Equal rights need to be ensured.

B.3 Interview 3: DSO, Strategy & Regulation

1) Current concession regulation

a) According to the CEP, LECs "are entitled to own, establish, or lease community networks". Which option do you see as most realistic/feasible based on the current design of Swedish concession regulation?

Within the existing concession rules, there are two different concession types, i.e. line and area concession. An area concession includes 20 kV networks. Within an area concession, no other party is allowed to build inside that area. Changes in these concessions would be required. The fundamental idea of the concession system is to avoid double infrastructure . Also, security of supply is connected to concessions. If the DSO is voluntary allowing a third party to establish, buy or lease part of the grid, the main question is about responsibilities, since the DSO has to ensure security of supply within the concession area.

b) Do you see any barriers in the current concession system for each of these three options, and if yes, can you briefly explain how the current regulation hinders a penetration of LECs?

Overall, there is the question about responsibilities as explained before. In case of establishment of new grid, it might be defined as IKN. The introduction of the IKN rule was a decision from the regulator.

c) From the perspective of the DSO, which option would have the highest potential of willingness for cooperation?

In general, the regulation should allow that LEC can do both, either take over and own the grid or lease it. Also, in cases of no existing networks it should further be possible for LECs to establish a new one. Business cases for all of the three options need to be found. In case of leasing, the DSO should still own the grid so that there is an interaction with the DSO. In that case the DSO is still earning money. If the LEC owns it, then the network area and consequently the asset base of the DSO is decreasing. That causes negative impacts on DSO business based on the current design of the revenue cap regulation. If the DSO is not allowed to own but if LEC establishes the energy system themselves, it might pose a benefit for the overall network if the LEC can operate the system and the DSO can have a more effective solution for feeding the local energy system.

2) Connection charges

a) Do you see problems within the current structure/design of tariffs for a penetration of LECs?

If the LEC has some connection to the grid it is very much depending on how they use it. In case that LECs use the DSO grid as backup, the question on how to take payment for that kind of service is important. The network causes a certain amount of investments for the DSO and tariffs serve to cover that. The LECs' need for backup applies for a very short time frame. It needs to be clarified how to take out the costs of that, which is very challenging. In general, self-consumption by prosumers, e.g. by installing PV on the roof, decrease energy usage of the grid. This is resulting into decreased energy consumption. The costs for the network, however, still remain the same. So it is very challenging to develop the future tariffs. In general, charging for power could be an alternative, but this would result into very expensive prices during short peaks, which will not be preferred by consumers. In general there are problems with the current tariff structure, not only regarding LECs.

3) Revenue cap regulation

a) Do you see any barriers within the current regulation defining DSO business models for a penetration of LECs?

The existing law, the Electricity Act, is the main barrier. The ownership of actors is not clear at the moment, including questions of who can build and own a grid. Based on unbundling rules, the DSO is not allowed to own production or storage facilities. A producer cannot be a network owner. Current electricity laws do not address LECs and storage, which can serve for both generation and supply.

b) Any suggestions on how these should be changed?

Regarding above mentioned roles and ownership, the Electricity Act should be re-written in three main points. These are firstly a more clear definition on local energy system, secondly a re-design of concession definitions and thirdly a clear definition about storage. The current law does not address storage at all. These are the basic issues. The rest of the framework can be developed after these. There might be new actors in the regulation. The question is, what is in the regulation regarding the DSO.

c) Are there already plans/discussions within E.ON and/or from Ei to change current incentive regulation?

A change is up for discussion in general. E.ON is involved in different categories e.g. smart grid development in Sweden, flexibility projects etc. These issues are up for discussion. The investigation on smart grid development in Sweden sets up an action plan on how to increase the flexibility in the system. There are twenty different things to do and the above mentioned three key issues are part of the action plan. It is in discussion but there is no active work right now that clarifies it. A new Electricity Act will come into force by 2019, but it is not clarifying these issues either.

b) How would you estimate the impact of LECs on overall customers within the reporting area, including those outside LEC boundaries?

Tariffs are determined by two main elements, i.e. grid costs and energy costs. Energy will continue to be very cheap because of the large amount of new generation. Trends show an increase of decentralised PV as well as increased amounts of wind power from wind parks of both on large- and small-scale. This will lead to an oversupply of electricity, resulting into decreasing electricity prices. Both on the generation side when short on power (dark, cold, no wind etc.) and also on the network there are limitations of maximal power to take out. If the capacity in the network needs to be increased, it is more costly. Overall the development leads to cheaper prices for electricity but there is a risk that prices for the network might increase. There is a need for more effective grid solutions. A solution is to focus on smart grids instead of grid upgrades, by means of flexibility. The more expensive the system is, the more LEC development, the more challenging for the DSO.

c) Do you see a potential of LECs to contribute to overall lower tariffs?

Yes. LECs are part of the solution to get a more effective grid structure, independent on who is the owner of it. It can also be possible with other owners than the DSO.

4) Potential other areas to invest

a) Assuming that LECs would reduce the need for grid upgrades, what is the impact on DSO business if the saved investments are a. not invested or b. invested elsewhere?

There is no clear answer because it is up to the DSO. It depends on the need for investments. The questions are on how big the need is and how easy the access to capital for investments is. The general, the financial situation is changing and it depends on the owners' financial situation. In a situation where a lot of investments are needed in some areas of the grid e.g. old infrastructure and high need for re-investments, this would be an area where saved money is invested. In a situation, however, where there is no demand to invest right now and/or unfavourable financial conditions, it would be better to wait before investing. The DSO is free to decide, the NRA is not steering it. However, if the DSO is not investing at all, it has a negative impact on the overall business since the revenue cap decreases over time. Then it is hard to predict when to start investing.

If the DSO chooses option b., which other areas could the DSO invest into, that can contribute to overall benefits for society?

In situations as described before where a lot of investments are needed e.g. old infrastructure or poor security of supply. It further includes network areas that are experiencing growth of consumers such as growing population (urbanisation) and/or industry growth, since there are higher capacity needs. Also, there are investment needs because of the energy transition such as new generation e.g. new wind power parks, where the establishment of completely new networks is required. Networks with high integration of PV in the low voltage grid can further cause the need for grid upgrades.

B.4 Interview 4: NRA, Technical Department and Department of Network Regulation

1) Overall concession regulation

Can the DSO lose its concession right after a certain period of time and if yes, what are the concrete reasons?

DSOs do not have an infinite concession right in an absolute way. Overall, there are two different concession rights, i.e. area concession and line concession. Considering line concessions, it can be re-examined after 40 years. But someone needs to call upon such a renewal. They are linked to certain permit processes. After a certain time, you can re-examine the terms of concession. Consequently, the concession rights are not absolute and could be reconsidered in some regards. There is one example where a DSO was not sending documents, not charging customers in a right way etc. So, if the DSO is not following the law, there is possibility for Ei to take charge of the network company. That is a special case. It is not common.

Currently, concession rights are covering networks throughout all of Sweden, so no one can apply as new DSO. If you apply for line concession, you can still apply. The company for area concession can also apply for line concession.

There are thousands of area concession rights. As a general rule most DSOs will report these concession rights together. This also means that they need to apply the same tariff in such an area.

Selling network areas

a) In case of selling a network area, are there rules on the calculation method for determining the purchase price?

There are no special rules. Ei only considers the permit. The DSO can sell the permit and Ei must do a smaller investigation.

b) Are there any other regulatory requirements for selling a part of the grid?

Per current legislation, the DSO can sell a concession area but not clear if it is also possible to sell only a part of it. Probably right now the DSO can't sell parts of the network if that part of the grid is part of the concession. They can sell an asset and then lease the same asset. If the DSO sells anything then it is an income for the DSO. Ei re-examines only the permit. If there is a concession right and the DSO wants to sell all the permits to another company, then Ei conducts a consideration of all the permits and that's it. There is no other case of this now. It is totally a thing that is not experienced when talking about area concession. Right now, the only way to have the LEC would perhaps be if you can apply the IKN regulation. It is not sure because that does not happen currently. There is however a possibility to change the area e.g. if there are old network areas and new residential areas are built. If the new area goes beyond the border to the concession area of another network company, it would be expensive for the other company to connect. In that case, the part can be transferred. There is no other case of selling parts of the concession right now. It should still be a concession area since every part must have a concession area. That could be an example for changing regulation. Since there are currently no LECs but only the IKN regulation, Ei sees networks either accounted in the Electricity Act, i.e. concessions, or in IKN. Meaning that if a network area is outside the concession rights it is an IKN. If DSOs sell the grid, then they need to sell part of the concession right but it is not being accounted for in the current Electricity Act.

c) Are there any current plans for changing/ introducing regulation on selling parts of the network area and would it be accounted for within the revenue cap?

If selling the grid is included in the revenue cap is quite hypothetical right now, but in the future, it should be included. DSOs are not forced to sell it. So, they can sell it for an appropriate price. If LECs become the cheapest way for them to do it, then they should could sell the grid. If some new smart grid development is better for the grid, then they should do it, otherwise not. Perhaps some LEC establishment is in terms of that they build a new network. But if the DSO should sell the network, the DSO should be compensated. They are allowed to charge a price for it.

Leasing network areas

a) Is the case of leasing a network area currently captured within regulation?

DSOs can lease assets, the one who has the permit is the one that is accounted for it. If you have the permit than you can lease equipment from someone else. Current examples are if the DSO leases transformers but it is still in the asset base. For example, DSO Vattenfall leases transformer to other area like E.ON area. If there would be such a thing like permits for LECs, LECs could lease assets from E.ON and they would have a permit.

There are no current plans for changing or introducing regulation on leasing parts of the network area.

b) If a grid is leased, does it go out of the DSO's asset base?

The concessions don't have anything to do with the ownership. Another company can own the equipment and you lease it. And the equipment is part of the regulation as well. If there is a LEC and they would have the permit for assets, then even if the assets are owned by the DSO like E.ON they are not part of the DSO's revenue cap. This is in case that the LEC is taking ownership of the permit. In the revenue cap is everything that is part of the concession. Is like the IKN concession. Even though the IKN is located within the concession area, it will never be a part of the CAPEX of the concession right owner. It is a bit messy with the IKN since different companies apply for IKN differently. It is hard to be any more specific about leasing.

c) Are there any rules on the calculation method the DSO must use for determining the leasing fee that a LEC would need to pay? If yes, is the price-setting regulated?

If there would be a regulation on LECs, I guess in respect to wording of the Commission LECs should be able to lease but right now there is no provision. We have energy communities in a way, like cooperatives owning a wind farm, but not local energy communities with the local aspect. There is nothing in law about someone owning parts of the concession. Regarding IKN, most questions are concerning issues like if this is a region applicable for IKN or by owner of the concession. Maybe one company operates another companies' assets to secure the network. That case might be a reason to re-investigate concession rights.

IKN regulation

Overall comment: IKN is probably not in alignment with EU regulation. By EU legislation, customers can choose where to buy the energy from. However, this does not apply within an IKN area and therefore IKN does not correspond to EU law. However, the government is currently investigating the IKN and concession right laws and there will be changes so that they correspond with the EU law. There is a Directive on concession rights what should apply for concession. There is progress in Swedish regulation on that.

a) Does it pose a barrier that members of a LEC are owners of different properties (e.g. households, public buildings, small enterprises etc.) and could there be a way to re-design IKN regulation?

You can't apply for IKN if a grid is built by the permit holder/ DSO. Then there could be instances to apply the IKN but normally you can't if the grid is already established. We look at it in this way: if you apply for a permit for a concession for a grid where you can also apply the IKN provisions, we would not give it to you because it is within IKN permit. One example is a small wind farm with a grid between the turbines. So, for existing networks, IKN might not be possible. If there are many residents in one house, they could use it. But for individual houses it could not apply because there are different property owners.

In short, in most instances property boundaries and the type of business conducted within an area will be a barrier when setting up a LEC.

Do you see IKN as a feasible option or should there be other changes in regulation allowing the development of LECs?

There are quite a few terms that need to apply if you want to use the IKN. There are quite a few provisions in the IKN. There is one paragraph for example for house owners. E.g. right now if I have a house, I can build a small grid within my property and cannot cross the border to neighbour except if you are owner of the neighbouring property. I do not think that you can apply IKN for LEC in that case. You can have this only for your own use because you have many users. So, this provision cannot be applied but other provisions in IKN such as multistory buildings. You can build a grid within the house. There are many provisions e.g. for farms, harbour, industry etc. so quite a few provisions.

2) Connection charges

a) Does the regulator foresee any rules on the allowed connection charges posed by the DSO?

Is the same as everyone else. In the Electricity Act is says a reasonable price. If the DSO builds more capacity than needed, then the community is not responsible to pay for the overcapacity. The remaining costs need to be distributed to remaining customers. It is always the question who builds first but there should be a sharing of the costs. The rules are the same for everyone. Community pays for what they need. If there will be a second village or more homes connected in the future, then these additional customers should pay. There is a method the Ei applies for households but for higher levels it is individual fees. It needs to follow the Electricity Act.

3) Revenue cap regulation

a) Are there plans to adjust the revenue cap regulation for the upcoming regulation period?

If in the future there is regulation where you can sell parts of the grid, so then when you sell the part you get a revenue of what you sell. So, you have a lower asset base but you get paid for it. When calculating the revenue cap then the aim is that you get compensated by the asset base in a fair way. The opinion is that they get to much paid in the revenue right now. But in the future they hope to get a fair regulation. If you have a lower asset base, you get paid for the sold part in a fair way. If you improve your indicators such as the losses than you get a bonus on the revenues.

Changes are developed at the moment and there will be the same incentive indicators but Ei is trying to make them more effective and calculate them differently. There will be some changes in the calculation method for the next regulatory period for 2020-2023. LECs are not considered because there is no Swedish law yet and then it would be risky to develop regulation. Ei is also not allowed to take it into effect right now because the text is not yet in place. A changed IKN regulation might not be legal either.

One important thing is that Ei needs to finish most of the changes this year because the DSO needs to know in advance. Ei cannot wait for next year. Changes with regards to LEC would be in the regulatory period from 2024. It takes several years to develop rules and DSO needs to have a chance to know.

b) In a publication of Ei regulation is described as targeting "technology-neutrality". Can you elaborate on the meaning?

Technological neutral indicates that the focus is on the output e.g. how much are losses, what is the quality etc. Incentives are based on indicators so that the DSO can improve the indicators how they want. So Ei only looks at the outcomes reached and not if they use better technologies. They should not buy expensive technologies. DSOs must evaluate the proposition of the costs related to achievable improvements and how it influences the quality and the resulting incentives. The costs should not be higher than the bonus. Overall, we want them to be cost efficient and not necessarily to buy the most expensive technologies.

c) In case of LECs, is it reasonable to assume that lost CAPEX could potentially be compensated by a higher capacity in the grid and lower network losses?

Ei's vision is that DSOs should invest in the most-cost efficient solution but right now the CAPEX is important. DSOs can increase the efficiency and quality in the network by taking the option of increasing CAPEX. Ei knows that there is a problem. DSOs can solve the same problem by either choosing OPEX or CAPEX based solutions but currently they will choose CAPEX based solutions. In the future, they might choose OPEX such as services provided as solutions such as LECs but not today. An example of services would be to provide flexibility to LECs to lower the peaks that might bring benefits to the grid.

4) Connection charges

a) Does the regulator have any influence to steer the tariff design of the future?

If a customer thinks that the tariff is not accurate, then Ei can examine. Ei does not have any direct power but there has been a report for flexibility from Ei and the result was the proposal for flexibility tariffs.

b) If yes, are there plans to tailor tariff design towards more local production?

There was a request from DSOs to use smarter tariffs for different customer groups. Resulting from the proposals of the report on flexibility, there will be a new law next year. Right now, all customers living in the same type of house should have the same tariff but in future, if you live in this area where you have PV etc., there can be a special arrangement for the tariffs to better use the grid. DSO will have the possibility to apply a different tariff for certain customers having specific circumstances such as much PV and wind in the area. This law should allow DSOs to try out new tariff structures with the aim to have more effectiveness of using the grid. The final wording is not done yet but there has been a proposal from the government.

So overall, when working with smart grid incentives in the regulation, the DSO should give the customer the incentive to work with the smart gird. One thing to include in smart grid incentives is to incentivise customers by a different tariff design. Norway is one example where load based tariffs were introduced instead of energy based tariffs.

5) Other regulatory changes

Is Ei already developing any other aspects of regulation not mentioned above?

The rule with 38 should be removed in the future and there are ongoing discussions on the WACC. Discussions on the WACC took place for the current regulatory period and Ei's decision on applying 4.53% was overruled by the court. The final WACC is 5.85% for the present period.