



Framework conditions for flexibility in the district heating-electricity interface

Sneum, Daniel Møller; Sandberg, Eli; Soysal, Emilie Rosenlund; Skytte, Klaus; Olsen, Ole Jess

Publication date:
2016

[Link back to DTU Orbit](#)

Citation (APA):

Sneum, D. M., Sandberg, E., Soysal, E. R., Skytte, K., & Olsen, O. J. (2016). *Framework conditions for flexibility in the district heating-electricity interface*.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



Flex4RES

Flexible Nordic Energy Systems

Framework conditions for flexibility in the district heating- electricity interface



Norges miljø- og
biovitenskapelige
universitet



NIFU



norden

Nordic Energy Research

The Flex4RES project

The Flex4RES project investigates how an intensified interaction between coupled energy markets, supported by coherent regulatory frameworks, can facilitate the integration of high shares of variable renewable energy (VRE), in turn ensuring stable, sustainable and cost-efficient Nordic energy systems.

Through a holistic system approach based on coupled energy markets, we identify potentials, costs and benefits of achieving flexibility in the Nordic electricity market created by the heat, gas and transport sectors as well as by electricity transmission and generation. Flex4RES develops and applies a multidisciplinary research strategy that combines technical analysis of flexibility needs and potentials, economic analysis of markets and regulatory frameworks, and energy system modelling that quantifies impacts.

Through the development of coherent regulatory frameworks and market designs that facilitate market interactions, which are optimal for the Nordic conditions in an EU context, transition pathways to sustainable Nordic energy systems are identified. Flex4RES will comprehensively discuss and disseminate the recommended pathways and market designs for achieving a future Nordic sustainable energy solution with a variety of stakeholders from government, industry and civil society.

More information regarding the Flex4Res project can be found at www.Flex4RES.org or by contacting project manager Klaus Skytte at klsk@dtu.dk

Acknowledgement

The Flex4RES is supported by Nordic Energy Research for which we are very grateful. The opinions expressed in this report do not represent the Nordic Energy Research's official positions, but are entirely attributable to the authors.

WP2 Framework conditions, October 2016

Flexibility in the district heating-electricity interface

Authors: Daniel Møller Sneum (DTU), Eli Sandberg (NMBU), Emilie Rosenlund Soysal (DTU), Klaus Skytte (DTU), Ole Jess Olesen (DTU)

With contributions from: Lennart Söder (KTH), Hardi Koduvere (TTU), Dagnija Blumberga (RTU), Aiga Barisa (RTU), Peter Lund (Aalto)

Reviewed by: Claire Bergaentzlé (DTU) and Luis R. Boscán F. (DTU)

ISBN: 978-87-93458-42-0

The Results at a Glance

- District heating (DH) is centrally produced heat which is distributed as steam or warm water to consumers through pipes. With a natural monopoly structure, municipalities, cooperatives and other local organizations coordinate the provision of heat. The district heating-electricity interface describes the area where district heating and the electricity system is connected
- Combined heat and power (CHP) and power-to-heat (P2H) technologies are identified as the most ideal technologies in the district heating-electricity interface for increased flexibility. CHP can produce electricity and heat simultaneously, while P2H technologies consume electricity to produce heat
- In the Nordic and Baltic countries there are no direct policies for flexibility in the district heating system, which means that flexibility is mainly provided by market incentives and very little by energy policy
- The need for flexibility varies throughout the countries under study. It might become most pronounced on the short term in the Nordic countries that have larger amounts of variable renewable electricity, while sufficient capacity and self-supply are goals of higher priority in the Baltic countries. Hence, there is no one size fits all-solution
- Presently, the power market is what best reflects flexibility needs, but it does not in itself provide a sufficiently attractive business case to invest in CHP and P2H
- Subsidies for CHP and P2H might be necessary. That being said, all Nordic and Baltic countries display potential for changes in other regulatory framework conditions with which subsidies should be compared – socio-economically and in an energy system perspective

Key Findings

This report identifies framework conditions, i.e. existing market or regulatory arrangements that act as drivers or barriers for investment in – and the operation of – flexibility resources that can enable flexibility. The report focuses on flexibility with a time horizon of sixty minutes or more at the interface between district heating (DH) and electricity in the Nordic and Baltic countries.

Initially, a broad range of flexibility resources was surveyed among the selected countries. This range was narrowed down to combined heat and power (CHP) and power-to-heat (P2H) in the form of heat pumps and electric boilers, since these, along with a collective category of general resources, appear to have the largest potential for delivering flexibility. An initial gross list of framework conditions has been refined by addition, removal and modification, based on a survey conducted among experts located in the Nordic and Baltic countries, together with a literature review of previous studies on the topic of flexibility. While the main focus in Flex4RES is flexibility and, hence, on the operational scale, this study additionally considers selected aspects of investment in flexible technologies. Among the 24 framework conditions identified, the following are considered the most important for respectively CHP, P2H and general flexibility-enabling resources:

- **CHP:** Exposure to the power market, since this driver provides the best available proxy for flexibility needs
- **P2H:** Electricity taxes and tariffs increase the cost of electricity consumption, and are barriers for the competitiveness of P2H against other heat-sources
- **General resources:** Operational practice of heat production following heat demand, i.e. load-following by heat production units rather than utilisation of heat storage, may be a barrier for flexible operation

The effect of all the framework conditions has been evaluated through an explorative, qualitative survey, to determine the extent to which they impact the flexible operation of CHP, P2H and general flexibility-enabling resources. Since the DH markets differ between the countries with regard to the technology-mix and fuel distribution, the presence of certain regulatory framework conditions has greater importance in some countries than in others. The results show a large variation in regulation, but at the same time, some similarities and patterns have emerged. Below, the main conclusions of this study are presented along with the findings specific to CHP, P2H and general resources:

General Conclusions and Findings

- **No policy for flexibility**, and insufficient harmonisation of policies. None of the countries in the study have a defined set of policies to increase flexibility in the DH-electricity interface. The typical policy goals are to increase the share of renewable energy, reduce CO₂ emissions, improve security of supply, or to reduce the dependency of electricity as a heating source. Some of these framework conditions may act as barriers for flexibility.
- **Different flexibility requirements imply different solutions.** Variability from renewables might be less relevant for countries with relatively little VRE capacity (Norway, Finland and the Baltic countries). It also appears from the study that in some countries sufficient self-supply of electricity is a more important concern than flexibility. In this case, deployment of P2H is less relevant, and CHP more relevant until VRE deployment has increased. On the

other hand, Norway, with significant and flexible hydropower resources, appears to have most flexibility needs covered from this source.

- **Electricity prices may be in a valley of death for both CHP and P2H.** The survey indicates that current electricity prices might be in a range where neither the operation of, nor the investment in CHP and P2H, is profitable. This *valley of death* is observed in the Baltic countries and in Denmark. In Denmark and Lithuania specifically, it is discussed whether subsidies for CHP can and will continue. In Sweden, stable low electricity prices may be a threat to CHP, because it makes heat pumps more profitable. Conversely, at high electricity prices, CHP would make a better business case than P2H. All other things being equal, deviations from the current valley of death, to generally high or generally low electricity prices, would favour only one of the two technologies, since CHP and P2H in that case would compete against each other; a finding also confirmed by the literature review. It seems reasonable to conclude that for a market-driven deployment of both technologies, there would ideally be large variations in prices throughout the year. When that is not the case, as it is now, it can indicate that there presently is not a need for flexibility originating from these technologies. Other parts of the Flex4RES project will investigate whether that will continue to be the case.
- **The dichotomy of low-cost, inflexible heat production by locally available biomass against flexibility-enabling production of heat** is pertinent in all countries. In other words, biomass-based heat-only (HO) boilers are locally considered to be secure heat sources due to local biomass resources, and are favoured through lenient taxation. Generally, this makes HO based on biomass more competitive than CHP and P2H. This calls firstly for a socio-economic analysis of HO vs. CHP and P2H, which can feed in to a subsequent political weighting of the trade-off between security of supply and the gains from flexibility.
- **Heat storages are the result of economic incentives.** Where heat storages have been implemented in the Nordics, they have been the result of economic incentives, rather than a regulatory decree. Ideally CHP, P2H and more storages should continue on the same path, given the right framework conditions.

Findings Regarding Combined Heat and Power

- **All surveyed countries support CHP**, but in different ways. The motivation for promoting CHP seems to be security of supply and/or increasing energy efficiency; not to increase flexibility in the energy system. In the Baltic countries, CHP is supported by feed-in tariffs and/or mandatory procurement schemes. This incentivizes electricity output but does not stimulate flexible operation of such plants.
- **Preservation of existing CHP can be challenging.** In Denmark, the large capacity of especially smaller, decentralised CHP is challenged by low power prices, out-phasing of support payments and tax exemptions for bio-fuels. In both Lithuania and Denmark, the subsidy to CHP poses a financial challenge, given current unfavourable energy market conditions which have increased the requested CHP support intensity. Finland considers phasing out coal-based CHP, while nuclear capacity is expected to increase. The latter might negatively impact the competitiveness of remaining Finnish CHPs. In tandem with other

framework conditions, this potentially creates a business case for CHPs, where biomass-based HO is more attractive.

- **Reduced exposure to market prices.** For the Baltic countries, feed-in tariffs and mandatory procurement schemes prevent CHP from operating flexibly, since the financial incentive is disconnected from the market or system real-time stresses. The baseload-like operation of CHP creates an additional barrier for P2H, since also heat pumps are baseload units.
- **Security of supply – and of investments – more important than flexibility?** The priority in the Baltic countries of self-supply, and thereby decreased import-dependency, is a main incentive for subsidising CHPs. The subsidy measures improve the business case for investment in CHP, but perhaps other solutions are possible. One example is the Danish case of the 2000's, where CHPs' electricity generation was exposed to market prices, while maintaining their economic feasibility through non-production-based subsidies, i.e. capacity payments.
- **Possible solutions to remove the barriers to flexible operation of CHP** include tax breaks for CHP, as seen in Sweden, Denmark, Finland and partly in Estonia. These increase the competitiveness of CHP without impeding the capability of operating flexibly. For subsidies, these should incentivise investment in CHP and P2H, and allow them to operate flexibly. Finally, as seen in Sweden and Norway, CHP plants based on biomass may become profitable with a sufficiently high green certificate price.

Findings Regarding Power-to-Heat

It should be noticed, that the type of flexibility provision from electric boilers and heat pumps differs, but that both require sufficiently low electricity prices to operate. As electric boilers are more sensitive to electricity prices than heat pumps, they have larger short term flexibility potential. Heat pumps are usually seen operating as mid- to baseload, and are thus likely to contribute to flexibility by ceasing heat production.

- **Presence of P2H is limited in the Nordic and Baltic** energy sectors today. This indicates saturated markets, lacking structures for participation and the relatively smaller experience with - and deployment of - P2H, especially compared to CHP and fuel-based HO. In the countries where the electricity production has traditionally been based on thermal generation technology, taxation has been used for preventing the usage of electricity for heating.
- **All countries have some kind of additional levies on electricity used for P2H.** Tariffs and taxes on electricity used for DH production increase the marginal costs of P2H and restricts the flexibility such technologies can offer.
- **Regulatory priority for specific heat sources is seen for some countries**, where there is a wish to ensure production from certain generators. For Denmark that would be waste-based DH (often CHP), while it is CHPs with mandatory procurement or biomass-based producers in the Baltics. In all cases, regulatory priority can leave little room for production on P2H, when it is needed, particularly during summer, where heat supply might be larger than demand. In order to address the issue, it is necessary to consider the larger, long-term system context. This would be the interplay between waste/CHP and P2H, where heat storages might be able to mitigate the problem on the short term, and consideration on choice of heat supply on the longer term.

- **Possible solutions to remove the barriers to flexible operation of P2H** include decreased levies on the power price for P2H. This goes for taxation as well as tariffs, and could be dynamic to increase the price signals for flexibility needs. For the deployment of P2H, there needs to be sufficient economic incentives, which can be ensured by investment-subsidies.

Findings Regarding the General Resources

- **All countries display flat heat tariffs**, discouraging flexible demand from the consumers. Before venturing into the field of heat demand-response, it should be considered whether large heat storages could provide a solution which might be easier and less costly to implement.
- **Profit caps are present in Denmark, Estonia and Lithuania.** This can decrease the investment incentive especially for commercial operators. Both Denmark and Lithuania have a significant share of public ownership in DH, which can mean that the barrier might not be significant in these cases.
- **Heat storage capacities are generally not supported, nor hindered.** The deployment is directly related to the flexible operation of both P2H and CHP, which is also reflected in the operational practice of countries with less deployment of storage, where production follows load (Norway and the Baltic countries). Regarding Norway, it should be noted that storage can be disincentivised by the availability of low cost flexibility and electricity from hydropower.
- **Support through direct subsidies or absence of taxation is applied for biomass in all countries**, except Estonia. All things being equal, this increases the comparative advantage of biomass-based units compared to P2H, and for CHP in the cases where smaller CHP is not competitive with HO boilers.
- **Possible solutions for the barriers**, specifically relates to the application of storage and the operational practice of production following demand. This goes hand in hand with power market exposure, where the benefits of heat storages would become apparent.

List of abbreviations

CHP: Combined heat and power

COP: Coefficient of performance

DH: District heating

EU: European Union

EUR: Euro

FiT: Feed-in tariff

FiP: Feed-in premium

HO: Heat-only (boiler)

LRMC: Long-run marginal cost

MW_{EL}: Megawatt electrical energy

MW_{FUEL}: Megawatt fuel

MW_{TH}: Megawatt thermal energy

MWh: Megawatt hour (electrical energy or thermal energy)

P2H: Power-to-heat

RE: Renewable energy

RES: Renewable energy sources

SRMC: Short-run marginal cost

VRE: Variable renewable energy

Content

1. Introduction	2
1.1. Flexibility Definition	2
1.2. District Heating-Electricity Interface Fundamentals.....	3
1.3. District Heating in the Nordic and Baltic Countries.....	5
1.4. Problem Formulation and Report Structure	7
2. Previous Studies on Framework Conditions for Flexibility	8
2.1. Framework Conditions for Combined Heat and Power	8
2.2. P2H and Heat Storages as Flexibility Options	9
2.3. Contradictory Policy Effects	10
2.4. Summing Up: Takeaways from Previous Studies	10
3. Methodology	11
3.1. Definitions of Barriers and Drivers	11
3.2. Survey.....	12
4. Framework Conditions	14
4.1. Combined Heat and Power	14
4.2. Power to Heat	16
4.3. General Resources	18
5. Results: Drivers and Barriers for Flexibility in the District Heating-Electricity Interface	22
5.1. Country Profile: Denmark.....	23
5.2. Country Profile: Estonia	26
5.3. Country Profile: Finland	28
5.4. Country Profile: Latvia.....	30
5.5. Country Profile: Lithuania.....	33
5.6. Country Profile: Norway	36
5.7. Country Profile: Sweden	38
6. Comparative Analysis of Identified Drivers and Barriers for Flexibility	40
7. Conclusion	47
8. References	49
Appendix.....	52
Literature on Flexibility Options	52

1. Introduction

This report is a component of work package 2 in the Flex4RES project. Flex4RES deals with the study of flexibility provided by integrated energy systems in the Nordic and the Baltic countries. The specific focus of this part of the project is on the identification of framework conditions, i.e. existing regulatory or market arrangements that affect the flexibility offered in the district heating (DH) sector, and specifically the combined heat and power generation (CHP) and power-to-heat technologies (P2H), ideally both with heat storage capacity.

1.1. Flexibility Definition

In Flex4RES, flexibility is defined as a measure to keep balance between generation and consumption of electricity, since the variability in generation and in consumption is to be balanced in flexible supply and flexible demand as illustrated in Figure 1. I.e., electricity supply or demand is considered flexible when it is possible to regulate the increase or the decrease of the generation or the consumption. This can be handled locally as well as it can originate from other regions through the transmission lines to the surrounding countries.

Furthermore, the supply and demand of electricity can satisfy final electricity consumption directly, or be coupled to the heat, gas or transport sectors, or even storage facilities. The Flex4RES project focuses on flexibility at an hourly level. The term *variable* defines fluctuating variations which are not possible to control.

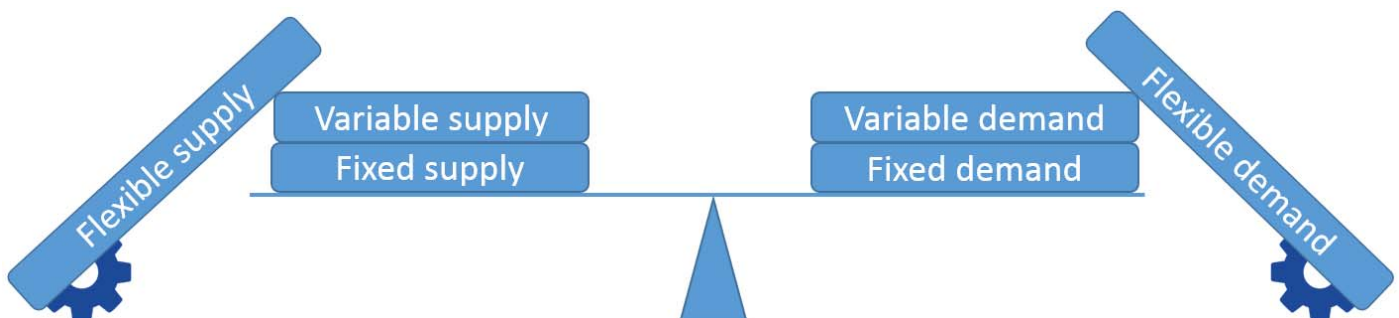


Figure 1 Flexible supply and demand balance the variability in generation and consumption of electricity.

This can be written as:

$$\text{Flexible demand} - \text{flexible supply} = \text{variable supply} + \text{fixed supply} - \text{variable demand} - \text{fixed demand}$$

And illustrated as in Figure 2, where the remaining excess production or demand on the right side must be balanced out by the flexibility on the left side.

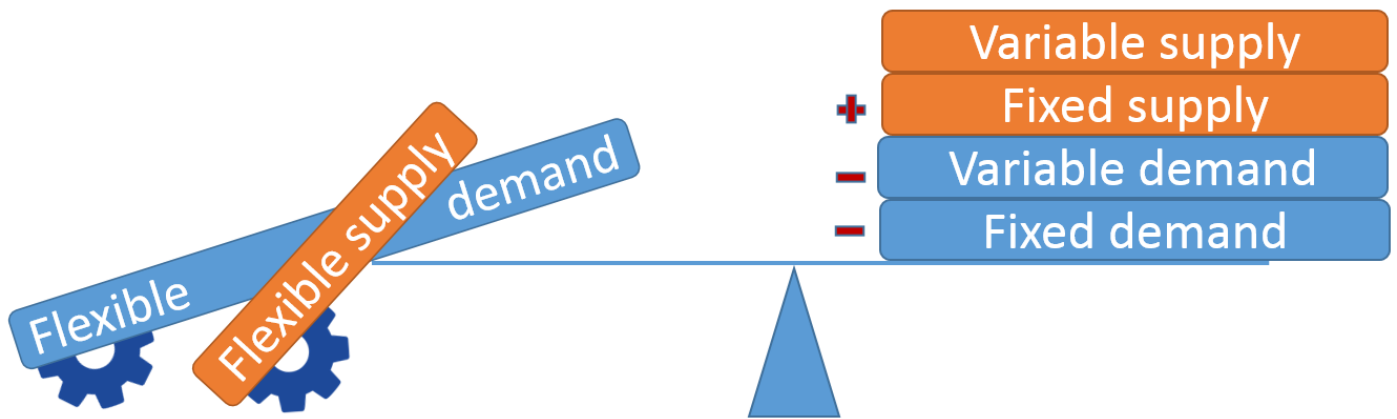


Figure 2 Illustration of flexibility divided into flexible and non-flexible production and demand.

Figure 2 shows that the variability in production (from wind power, solar power, outages, etc.) and in demand must be balanced by flexible demand and flexible production.

Electricity demand and production can be local but it can also originate from other regions through the transmission lines to the surrounding countries. The electricity demand can either be for traditional electricity consumption or by the coupling to the heat, gas or transport sectors, or even storage facilities.

1.2. District Heating-Electricity Interface Fundamentals

This study focuses on the interface between DH and electricity. DH is centrally produced heat, distributed to consumers through pipes, across an area (the *district*) in the vicinity of the heat producer. The concept of DH was introduced commercially in Europe in the early 20th century (Frederiksen & Werner 2013), while the concept of circulating hot water from a central source for heating purposes was already seen in ancient Rome (Skov & Petersen 2007). Just as with electricity, transport of heat is affected by losses. Losses in transmission of DH are relatively higher than for transmission of electricity, and DH is thus only relevant in areas with a certain density of consumers and heat demand, to ensure relatively short transmission distances.

Heat sources for DH are multiple, since hot water can be generated in many different ways, including combustion in CHP and electricity in electric boilers and heat pumps. The different options are explained in what follows.

CHP, combined heat and power, generates electricity and heat at the same time. This enables a high energy efficiency, since both electricity and heat are generated, instead of either one or the other.

P2H, power-to-heat, generates heat in two different ways. For electric boilers, the heat is generated as electric resistance, much like in an electric tea-kettle. For heat pumps the heat is, in simple terms, generated by pumping fluids in a circuit with different levels of pressure, allowing a concentration of heat from a low-quality heat source (e.g. sea water) to DH temperature. In the present study, these two P2H technologies are considered.

Figure 3 displays an example of a Danish DH plant with a gas boiler, heat pump and CHP gas engine. The vertical axis corresponds to the marginal cost of producing 1 MWh of heat, and the horizontal axis shows the day ahead electricity price.

1. The cost of producing heat from a gas boiler is horizontal because it is unrelated to the price of electricity (horizontal line)
2. The cost of producing heat from a heat pump is increasing with the electricity price (increasing line). COP 2.6 means that the heat pump produces 2.6 MWh heat for each MWh electricity it consumes
3. The cost of producing heat from a CHP plant is decreasing with the electricity price (decreasing line). This is because electricity production can be sold in the spot market

From an electricity price of 0-37 EUR/MWh, the heat pump has the lowest marginal heat production cost. From an electricity price of 37-44 EUR/MWh, the gas boiler has the lowest marginal heat production cost. The gas engine has the lowest marginal heat production cost from 44 EUR/MWh and up. It is evident that electricity prices and heat production costs are related.

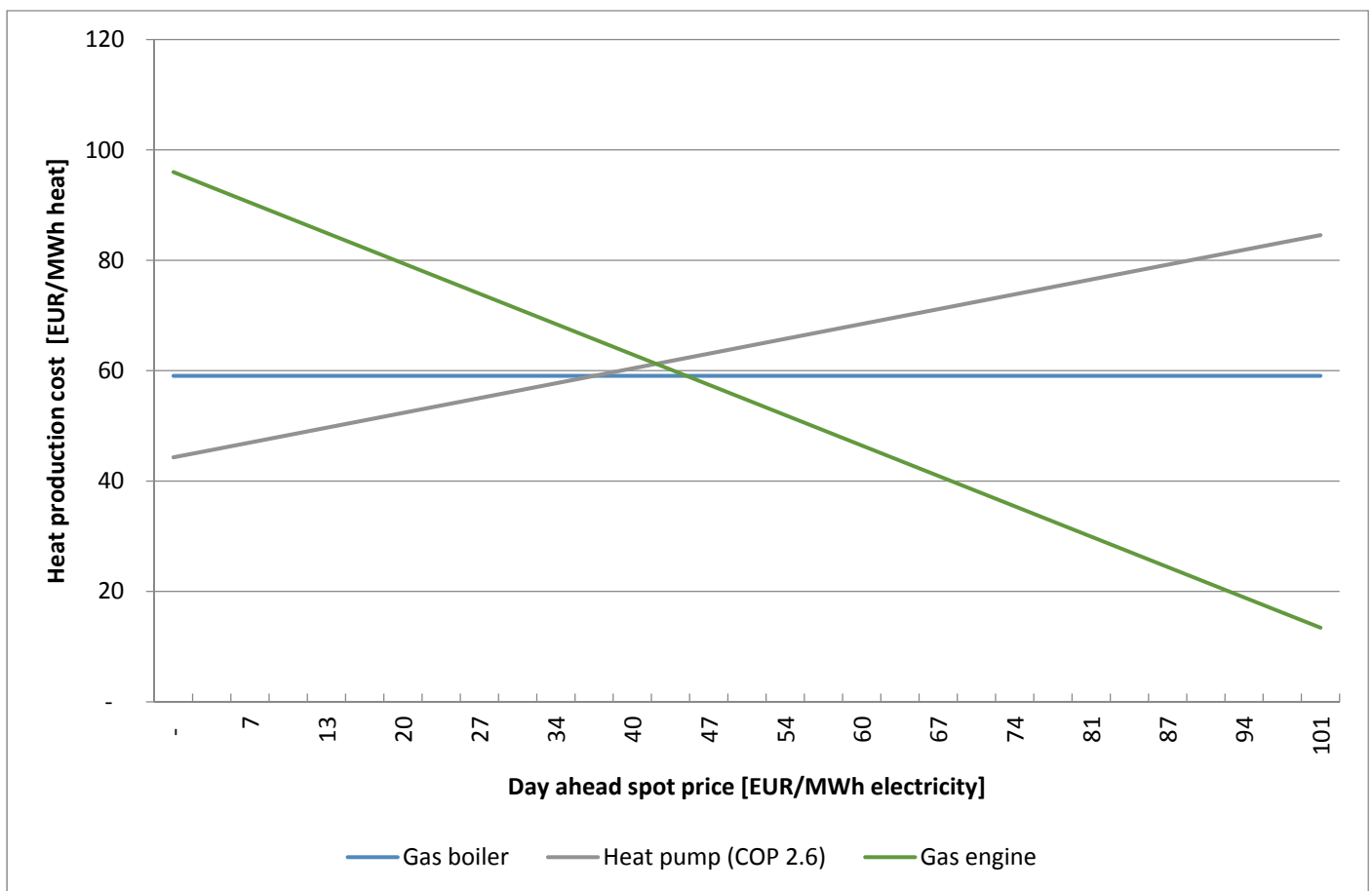


Figure 3 Diagram of marginal heat production cost in a Danish DH plant with gas boiler (HO), heat pump (P2H) and gas engine (CHP). Based on data from the energyPRO model (EMD International 2016).

As it appears from the above description, CHP *produces* electricity, while P2H *consumes* electricity. It is exactly these characteristics that qualify these technologies to be in the DH-electricity interface. Figure 4 explains their respective contribution to flexibility in the ideal market.

1. Low VRE production. High electricity prices incentivise the CHP to produce, where the heat is delivered to the consumers and to the heat storage.
2. High VRE production covers the electricity demand. Low electricity prices incentivise supply of heat from the storage.

3. Very high VRE production. Very low electricity prices incentivise consumption of electricity in the P2H-unit for heat production (here an electric boiler), which in turn is stored or used to cover the heat demand.

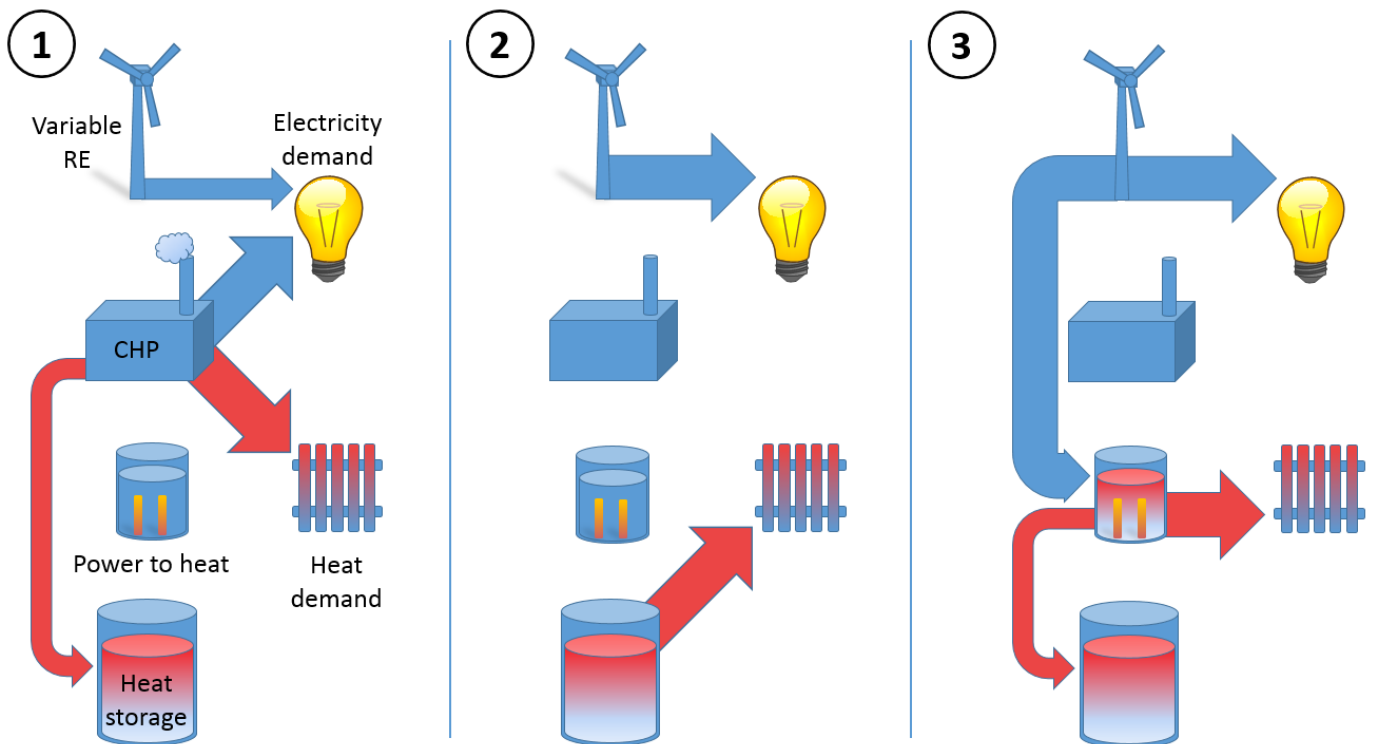


Figure 4 The interaction between VRE, CHP, P2H and heat storages with the consumption of electricity and heat. Based on IEA (2014b) and Connolly (2015).

1.3. District Heating in the Nordic and Baltic Countries

DH is an important contributor to heat supply in the Nordic and Baltic countries in which 52 - 65% of the citizens are served with DH (Euroheat 2015). Therefore DH has a significant potential for providing flexibility to the future electricity system (Lislebø et al. 2011). Norway is the only exception to this, as DH plays a minor role in the total energy system. The total production of DH from the countries subject of this study added up to 135 TWh heat in 2013 (Euroheat 2015), while, for comparison of scale, the electricity production amounted to 370 TWh electricity (Eurostat 2016). In the six countries with a large amount of DH, CHP contributes with a very large share of the supply (41 – 73% of DH heat supply (Euroheat 2015)) whereas the remaining part is mostly supplied by heat-only (HO) boilers. P2H, in the form of heat pumps and electric boilers, counts for a visible part of supply of DH only in Norway (respectively 13% and 9%, (Statistics Norway 2016a)) and Sweden (9% and 0.5%, (Svensk Fjärrvärme 2015)), but are insignificant in the other countries. Daily heat storages are common in Nordic DH, except in Norway, and have a limited use in the Baltic countries. The potential for DH to provide flexibility to the electricity system is thus only partly exploited today.

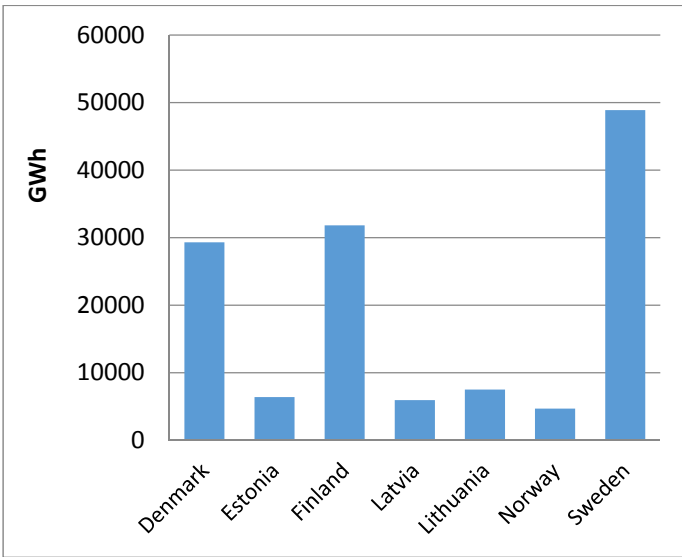


Figure 6 Total DH sales (2013) in the Nordic and Baltic countries. Source: Euroheat, 2015

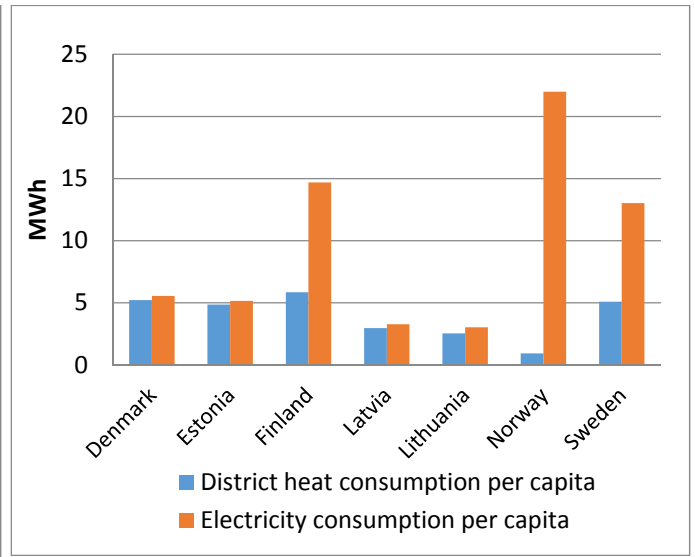


Figure 5 District heat and electricity consumption per capita. Source: Euroheat, 2015

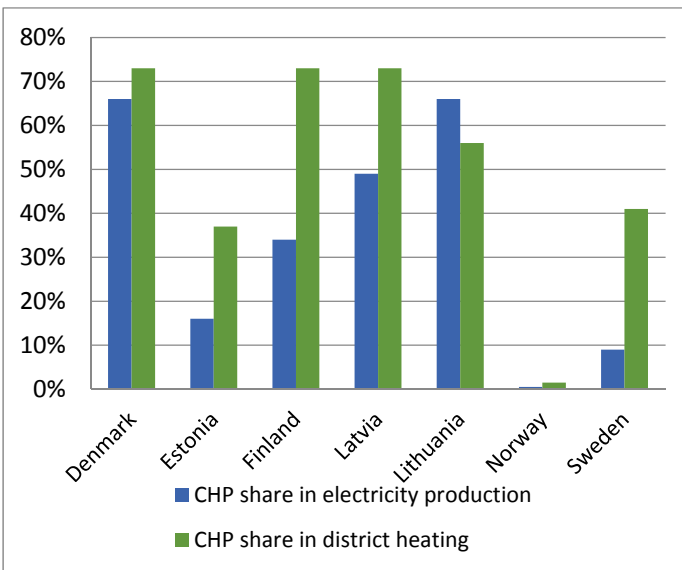


Figure 7 Share of CHP in the inland electricity and DH production. Source: Euroheat, 2015

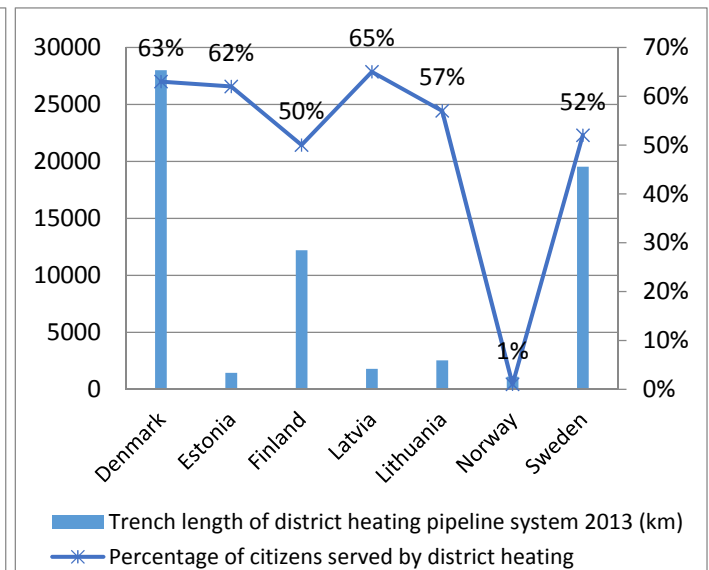


Figure 8 DH coverage in terms of length of pipeline system and percentage of citizens served by DH. Source: Euroheat, 2015

1.4. Problem Formulation and Report Structure

Despite different national traditions and different technology mixes, the Nordic electricity market is today integrated and regulated by the same EU-defined rules. The situation is completely different for DH. DH is still a local phenomenon applying different technology mixes and regulated differently by a combination of national and local rules. The financial framework conditions are complex and vary largely between the countries subject to this study. Some policy regulations that the DH producers are facing appear to focus on reducing greenhouse gas emissions or fiscal concerns, while it may at the same time counteract flexibility rather than promote it.

While technical potentials for flexibility from CHP and P2H with heat storage might be high, realised deployment and operation might be low due to market and regulatory barriers. This study addresses the framework conditions for flexibility from CHP and P2H in the DH-electricity interface of the Nordic and Baltic countries in the timeframe down to hourly level. It does so by identification of framework conditions which act as drivers or barriers for flexible operation and investment, and furthermore by analysing the current state of each framework condition in the respective countries. The present study intends to respond to the following questions:

Which framework conditions in the district heating-electricity interface of the Nordic and Baltic countries are drivers or barriers for operation of - and investment in - CHP and P2H?

How are the identified framework conditions affecting flexible operation of - and investment in - CHP and P2H in the respective countries?

How can the barriers for flexible operation of - and investment in - CHP and P2H, be addressed?

The motivation of this study is to provide insight for regulators, enabling an alignment between energy policy and regulation, regarding increased integration between DH and electricity.

The report starts by providing a brief introduction to DH in the Nordic and Baltic countries, followed by Section 2 that provides an overview of existing studies on the subject of flexibility and regulation in the DH-electricity interface. Section 3 presents the methodology used for analysing the framework conditions affecting flexibility, and Section 4 provides details on these framework conditions. Section 5 describes the results of evaluating framework conditions for specific countries. This leads to the comparative analysis in Section 6 and the conclusion in Section 7.

2. Previous Studies on Framework Conditions for Flexibility

To identify other studies on the subject, this section presents a literature review on framework conditions for flexibility. This is done to explore the current research context of flexibility in the DH-electricity interface, and to compare and supplement the findings of the survey, presented in Section 5.

There are many *technical* studies conducted on flexibility in electricity systems with an increasing share of variable renewables. Some of them are reviewed in Appendix 0. In contrast, only a few studies address *framework conditions* affecting flexibility. A large part of the existing literature focuses on documenting the impact of various policy instruments on their target, which often are the impact on CO₂ emissions. Such policy instruments will only partially affect the DH sector's ability to provide flexibility to the electricity market, and indirectly through the effect on fuel composition and technology mix.

2.1. Framework Conditions for Combined Heat and Power

Sovacool (2013) argues that the CO₂-tax on fossil fuels has been positive for the development of CHP in Denmark, due to the DH industry's adaptability. Jacobsson (2008) gives green certificates and the EU quota system credit for the growth in large CHP plants in Sweden. Gustavsson & Truong (2011) prove that a carbon tax increases the competitiveness of biomass-based CHP in Sweden and demonstrates that flexible cogeneration plants with a high electricity to heat ratio are less sensitive to changes in energy taxation. An increasing share of renewables, however, generally lowers electricity prices and thus reduces the profitability of electricity production in CHP plants.

2.1.1. *Shifting Conditions for Combined Heat and Power Plants*

Studies from Linköping in Sweden conclude that fluctuating electricity prices and high winter prices will promote CHP above HO, while stable low electricity prices, also during winter, may increase the share of heat pumps in the Swedish DH (Åberg et al. 2012). Jacobsson (2008) mentions three obstacles for biomass-based electricity generation to evolve further in Sweden.

1. Uncertainty of the future green certificate price affects investments in CHP production based on biomass
2. Large windfall profits are a problem for the green certificate scheme as a whole and threatens its legitimacy
3. Natural gas is also making its way into cogeneration, thus competing with biomass

It leads to a decreased share of biomass-based CHP, but is positive in an energy flexibility perspective since natural gas fired cogeneration plants are more flexible than CHP plants based on biomass. Biogas plants are flexible, but a gas storage is essential and there is a need for an investment subsidy to cover the investment costs (Grim et al. 2015).

In Denmark, the high penetration of wind energy has caused an important drop of classical power plants load factor as well as decreased operating hours for distributed DH plants with CHP. Sorknæs et al. (2015) show that the viability of CHP plants can increase through increasing their task in balancing the electricity system (Sorknæs et al. 2015). Lund (2007) finds that by inducing a better coexistence between cogeneration and wind power, Denmark can reduce the budget on increasing transmission capacity. A coupling of the thermal and electricity sector has proved to be cost efficient (Lund & Clark 2002). Sorknæs et al. (2015), however, point out that increasing the balancing tasks

of CHP plants may not be sufficient to guarantee profitability of Danish CHP plants. They introduce participation in additional markets as one option, where a capacity market and a balancing market are proposed. Hvelplund (2006) suggests establishing local markets to cope with the technical barriers of integrating a larger proportion of wind and solar power in Denmark. He further argues that local cooperation, considering local energy resources, technologies and infrastructure, is a more efficient way of handling this integration.

The DH systems in the Baltic countries need modernization, and CHP is encouraged by law. Studies from the Baltic States, however, show that for the DH sector to invest in new technologies, financial incentives need to be introduced (Miskinis et al. 2006). Electricity feed-in has proved to be a useful tool to increase the CHP capacity based on renewables (Blumberga et al. 2014). Only Latvia experiences a delay regarding renewable energy development due to a lack of support scheme. Roos et al. (2012) point out that there is a lack of support schemes to deploy renewables in Latvia. This has an effect on cogeneration and the DH sector in general.

So far, dependency of electricity has not created major problems for the security of supply and the electricity prices need to increase to make CHP plants in Norway profitable. Tradable green certificates for electricity with a minimum value of 31 EUR/MWh seem to encourage power generation from biomass-based CHP plants. However, having energy conservation measures simultaneously, makes CHP less profitable. (Gebremedhin & De Oliveira Granheim 2012). Small-scale applications are not cost effective for the Norwegian energy market, even after accounting for support schemes (Kempegowda et al. 2012). Kempegowda et al (2012) however prove that biomass CHP options are profitable with support of green certificates, grid fee deduction and investment subsidy.

2.1.2. Small Scale Operation

Given the market characteristics of densification of heat demand, flexibility options in a smaller scale could be a solution to increase flexibility. Due to economies of scale, small-scale CHPs are non-profitable given current framework conditions (Salomón et al. 2011). A higher electricity price and/or lower investments costs are necessary to make CHP attractive in small DH systems (Keppo & Savola 2007).

2.2. P2H and Heat Storages as Flexibility Options

A variety of sources suggest a benefit of utilising the heat sector-flexibility in the energy system, as presented in this section. Kirkerud et al. (2014) conclude that ensuring high levels of flexibility in the heat sector is important in order to efficiently adapt more VRE, and hence fulfil renewable energy targets. In addition to cogeneration in Denmark, additional flexibility solutions are necessary to increase the supply of new renewable energy to the electricity market (Lund 2007). A study of West Denmark has shown that integration of electric boilers and heat pumps with the existing CHP can increase the variability-friendliness (Blarke 2012). Lund & Clark (2002) point out heat storages and heat pumps as necessary flexibility options. To achieve an additional use of electricity for heat generation and increase the storage capacity, Klinge Jacobsen & Zvingilaite (2010) point out that there is a need for regulatory changes, and suggest to remove barriers to the use of low price electricity. The flexibility offered by P2H is impacted by electricity grid tariffs, which are applied on the electricity consumption in P2H units, as shown by Kirkerud et al. (2016). IEA (2014a) suggests that policymakers should enable compensation for the additional value storages create for the energy system.

2.3. Contradictory Policy Effects

As Difs (2010) points out: “National energy policies can result in contradictory outcomes even though the intentions are good”. By including the national policies in her model, biomass CHP is the most cost effective technology (compared to biomass HO and natural gas CHP). When national taxes and policy instruments are excluded, natural gas fired CHP is the most cost efficient technology. Lines can be drawn from Difs’ study on framework conditions regarding CO₂-emissions, to the present study on framework conditions for flexibility, since Difs’ study shows that the national policy both works as a barrier for flexibility, but also a barrier to its aim of reducing CO₂-emissions most efficiently, considering coal fired thermal power at the margin, because natural gas fired CHP plants have a much higher P2H ratio (Difs 2010). The Danish ban on using electricity for heating in new dwellings is another example of a barrier designed to increase cogeneration, but that has been counterproductive from a flexibility point of view (Klinge Jacobsen & Zvingilaite 2010).

An explanation for why the regulatory framework for DH is different in the different countries and regions can be attributed to that local conditions and lobbying are taken into account when policy framework conditions are formed. Gothenburg Energy in Sweden struggled through a favourable tax policy for natural gas for their plants on the south coast (Jacobsson 2008). Vattenfall managed for a long while to prevent the emergence of CHP in Sweden (Magnusson 2012). Energy policy in Denmark has for long been characterized by financing of the Danish North Sea natural gas project (Skov & Petersen 2007). Norway has a strong power-intensive industry that has forced through that the tax for the Energy Fund no longer depends on electricity consumption, but is currently an annual lump sum tax (Møller 2016).

Considering energy issues in a system perspective, and taking several affected stakeholders or sectors into consideration when forming policies can help prevent opposing political effects. Several studies indicate the importance of energy system analysis rather than power system analysis when modelling high renewable electricity share scenarios (Lund et al. 2015). Johansson et al. (2006) states that policies for reducing dependency of electricity and reducing CO₂ emissions in residential heating should consider the entire energy sector including infrastructure, and by doing this shows that it in certain cases is more efficient to convert to DH than heat pumps. Stupak et al. (2007) mention the problem that rules for forestry sometimes can stand in the way for the utilization of forest biomass for energy purposes.

2.4. Summing Up: Takeaways from Previous Studies

The studies reviewed in this section confirm the benefits of a coupling in the DH-electricity interface, for integration of VRE through flexible operation of CHP and P2H. Also in focus is the economic feasibility of CHP and P2H, i.e. the investment conditions. These conditions stand out as lacking additional incentives, before CHP and P2H becomes economically attractive. Electricity prices, impacted increasingly by VRE, is mentioned as a factor, where periods with high prices increase the incentives for CHP, and vice versa for P2H. Uncertainties, including prices on electricity, green certificates and income on balancing markets, decreases investment incentives for both CHP and P2H. A common denominator is that the power market alone does not provide sufficient investment incentives. Among suggestions for the improvement of investment conditions, is to supplement with capacity markets, or combinations of reduced levies for CHP and P2H, and green certificates. On the regulation side, the literature review shows that policy for low-carbon production might not necessarily go hand in hand with flexibility. Finally, and on the same note, the review shows that the local nature of DH also means local differences in regulation.

3. Methodology

This section presents the methodology used for identification and analysis of the framework conditions affecting flexibility in the DH-electricity interface in the Nordic and Baltic countries.

The process of collecting and analysing information was iterative. In the first iteration, information regarding the framework conditions for all potentially relevant flexibility resources was collected from experts in each of the countries through a survey-questionnaire. Based on the survey results, flexibility resources with particular importance were identified and a list of related framework conditions took shape. In the second iteration, additional information regarding the identified framework conditions was collected for each country and the list was adjusted accordingly.

The first part of the section defines framework conditions and related concepts, providing the necessary terminology for understanding how drivers and barriers to flexibility are identified in the report.

The second part of the section describes the content of the survey-questionnaire. The surveys served two purposes: 1) to identify relevant flexibility resources and related framework conditions, and 2) to provide information on each country's DH sector. While the list of framework conditions presented in Section 4 is the result of the former, the country profiles, presenting the presence or absence of each condition in each country in Section 5 originates in the latter. Finally, the comparison of the country profiles is presented in Section 6.

3.1. Definitions of Barriers and Drivers

Some of the technical potential for flexibility in the DH-electricity interface cannot be realised due to a number of barriers to flexibility. The aim of the report is to identify these barriers alongside the drivers that promote flexibility. We distinguish between the ways the drivers and barriers affect the realisable potential, i.e. how they influence investment and operational incentives. A number of concepts needed for understanding the definition of drivers and barriers are presented in this part. Each new concept introduced is italicized, and Figure 9 illustrates the relation between the mentioned concepts.

Flexibility resources are all physical measures that have the technical potential for providing flexibility. There are plenty of technological solutions with the ability to provide flexibility at the interface between DH and the power systems. However, they may not exist in each country, or if they are, they may not be operated flexibly.

A subset of the flexibility resources is the *available flexibility resources*, which are resources present in the energy system. The number of available flexibility resources can be increased by investment in new flexible solutions, or by adapting existing technology through re-investment. In graphical terms, investment or re-investment would have the effect of increasing the size of the corresponding oval in figure 9.

However, even if a flexibility resource is available, it might not be effectively activated in the energy system. The *utilized flexibility resources* are, therefore, only a subset of the available resources. By enabling flexible operation, the available flexibility resources can become utilized.

Example 1: CHP technology has the technical potential for providing flexibility and can therefore be considered a flexibility resource. By investing in CHP it becomes an available flexibility resource. If

instead of running the CHP installation with constant output, operators respond to price signals and run it flexibly, the flexibility resource is utilized.

While the definition of flexibility resources is purely related to the technical performance, the size of the subsets of available and utilized flexibility resources relates to *investment* in the flexibility resources and their flexible *operation*. *Framework conditions* determine the investment and operation incentives, and may either work as *drivers* or *barriers*, i.e. promote or impede investment in flexibility resources or its flexible operation. In this way, the framework conditions influence the amount of available and utilized flexibility resources.

Example 2: State subsidies for CHP in the form of feed-in tariffs (FiT) is a framework condition that provides an investment incentive, as it helps to increase the available CHP capacity. However, when CHP generation is remunerated with a FiT it is no longer exposed to market prices, which impedes its flexible operation. CHP receiving FiT is therefore not a utilised flexibility resource. FiT for CHP is a driver for investment but a barrier to flexible operation.

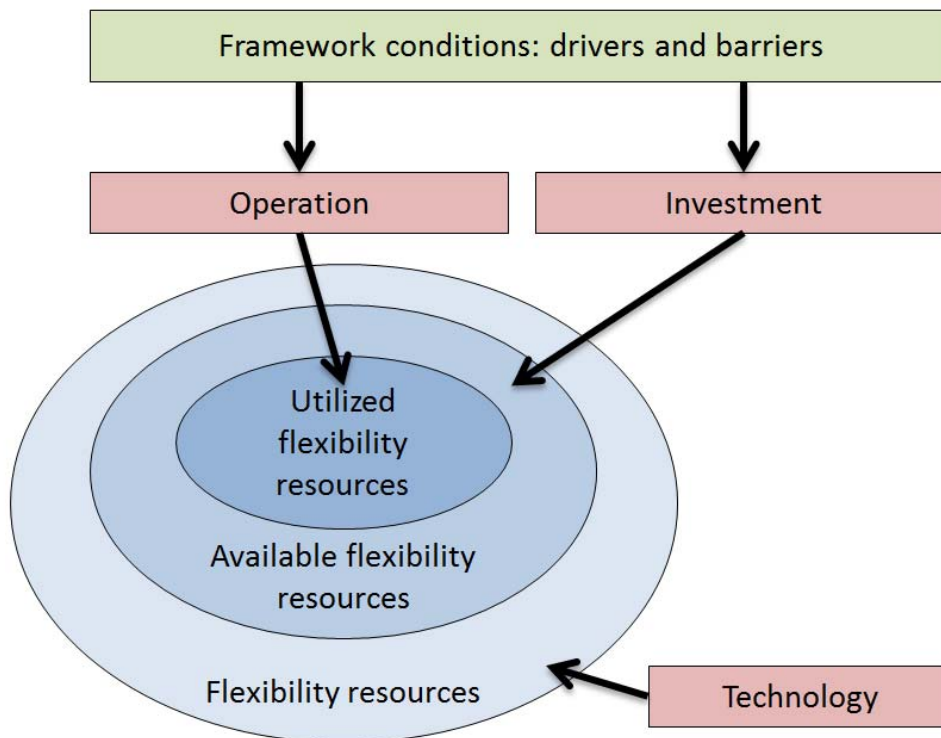


Figure 9 Framework conditions affecting flexibility

In this study the technical aspects of the flexibility resources are not analysed. This task is realized by Work Package 1 of the Flex4Res project. Instead, the focus lies on the framework conditions affecting the investment in flexibility resources and its flexible operation.

3.2. Survey

In order to collect information regarding country specific drivers and barriers to flexibility in the DH-electricity interface, a qualitative survey questionnaire was distributed to Flex4RES partners in the Nordic and Baltic countries (Denmark, Estonia, Finland, Latvia, Lithuania, Norway and Sweden).

Responses were received from late 2015 to early 2016. Due to the many differences in national deployment of district heating, the survey first covered general characteristics of the district heating sector. Then, questions regarding specific flexibility resources were asked. Broadly including all aspects of the DH sector, the survey aimed at capturing all potentially relevant aspects. In total, the following topics were included in the survey:

- General characteristics
 - Current role of DH
 - Regulation of DH in general
- Flexibility resources related to DH
 - Heat storage
 - Combined Heat and Power plants (CHP)
 - Electric boilers in DH
 - Large heat pumps (HP)
 - HO boilers in DH (as substitute to CHP)
 - Large solar heat panels
 - Flexible DH network operation
 - Consumers of DH as flexibility providers
 - Individual HO generation (as substitute to DH)
 - Feed-in to the DH grid from industry

In Denmark, Finland and Sweden, national DH-organisations have corroborated the survey responses. Furthermore, as an additional quality control measure, the structured interpretation of the surveys has been verified with the survey respondents, where possible.

The survey results indicated that CHP and P2H are considered the two most important flexibility resources, and the drivers and barriers related to the two technology groups were extracted from the survey answers of each country. Additionally, the surveys pointed at a number of other drivers and barriers that cannot be allocated to CHP and P2H specifically, but instead affect the general use of flexibility resources. As a result, the report focuses on the three resource categories *CHP*, *P2H* and *General resources*.

A list of framework conditions related to CHP, P2H and general resources was created on the basis of the survey results, and can be found in Section 4. While the list of conditions can never be exhaustive, it is intended to describe the key framework conditions.

The present study on the DH-electricity interface does not attempt a full ranking or quantification of the importance of the flexibility resources and framework conditions. Instead the identified barriers and drivers serve as input to the estimation and analysis of cost-curves of flexibility, which are a part of interrelated work packages in the Flex4RES project.

Section 5 summarises the survey results in the form of country profiles. In each of the country profiles a table presents the *absence* or *presence* of the framework conditions regarding CHP, P2H and general aspects, giving an overview of the conditions in the country. Section 6 then identifies the similarities and difference in framework conditions across the countries by comparing the country profiles.

4. Framework Conditions

Below is the list of the identified framework conditions that work as drivers or barriers for flexibility. As described in Section 3, the list draws on the survey results. The framework conditions are divided into the flexibility resources CHP, P2H and General resources, and are described in terms of their effect on the flexible operation of the resource, and investment in the resource.

Some of the framework conditions are presented in terms of their presence, while others are presented in terms of their absence. This way of phrasing the framework condition means that a confirmation of the sentence will always be a driver for *operational* flexibility, and correspondingly, a disconfirmation of the sentence will be a barrier for operational flexibility. The distinction between absence and presence allows for a visual representation of how the identified framework conditions affect operational flexibility, while both operation and investment is treated in the analysis. The visual representation can be found in Section 5 under each country profile.

Example: feed-in tariffs (FiT) for CHP may impede flexible operation, thus the absence of FiTs is a driver for flexible operation. The framework condition is therefore defined as *Absence of feed-in tariffs*.

4.1. Combined Heat and Power

4.1.1. *Absence of Mandatory Procurement of Electricity*

Mandatory procurement of electricity generated from CHP can be a way to incentivise production of electricity, and to provide a secure business case for investment.

Operation: Mandatory procurement reduces the incentive for flexible operation, since such schemes make it attractive to maintain production of the maximum amount of power, regardless of the system-needs.

Investment: Absence of mandatory procurement can reduce certainty regarding the ability to sell electricity from a CHP, which increases risk for investors.

4.1.2. *Absence of Feed-in Tariffs*

FiTs for electricity generated from CHP can be a way to incentivise production of electricity, and to provide a secure business case for investment.

Operation: FiTs reduce system flexibility, as they make power generation profitable even when market prices are low. Hence, the power generation is not adjusted to market conditions, but instead maximized for receiving maximum support.

Investment: Absence of fixed income can reduce certainty regarding the ability to sell electricity from a CHP, which increases risk for investors.

4.1.3. *Absence of Feed-in Premiums*

Feed-in premium (FiP) for electricity generated from CHP can be a way to incentivise production of electricity, and to provide a secure business case for investment.

Operation: Similarly to a FiT, a FiP may impede flexible operation in case its design increases the incentive for inflexible power generation by offering production-based support. Hence, the power generation is not necessarily adjusted to market conditions, but instead maximized for receiving maximum support.

Investment: Absence of stable income can reduce certainty regarding the ability to sell electricity from a CHP, which increases risk for investors.

4.1.4. Presence of Market Pricing for Electricity

In absence of direct signals for flexibility-needs, the electricity market is considered a useful proxy for such needs. CHP can be exposed to the power market by letting electricity production be traded under market conditions.

Operation: Market pricing improves flexible operation of CHP units as the power production is adjusted to market needs.

Investment: The level of incentive is positively correlated with market prices. High market prices provide incentives to invest in CHP technology while low market prices prevent profit opportunities

4.1.5. Presence of Power Capacity Payments

Power capacity payments are granted to CHP units for maintaining available capacity in response to system needs.

Operation: Assuming that capacity payments move the marginal price of production of heat and electricity from long-run marginal cost (LRMC, i.e. marginal cost including investment) down towards short-run marginal cost (SRMC), the CHP is more competitive and more able to participate in the power market and as a heat supplier.

Investment: Capacity payments can improve the investment case for new CHP, and maintain existing CHP if uncompetitive.

4.1.6. Presence of Other Subsidy to CHP

Other types of subsidies to CHP, which are not acting as a barrier for flexible production.

Operation: Assuming that the subsidy moves the marginal price of production of heat and electricity from LRMC down towards SRMC, the CHP is more competitive and more able to participate in the power market and as a heat supplier.

Investment: Subsidies can improve the investment case for new CHP, and maintain existing CHP if uncompetitive.

4.1.7. Presence of Tax Exemptions for Fuel to Electricity Production

Generally, fuels are taxed. However, exemption may be offered when the fuel is used for electricity production.

Operation: Tax exemptions generally move the marginal bidding price down, thereby making the CHP more competitive and more able to participate in the market.

Investment: Tax exemptions for fuel used for electricity production improves the business case towards investment in CHP capacity.

4.1.8. Presence of Energy, CO₂ or Other Tax Reductions

Reduction on energy tax, CO₂ tax and other tax for fuel or CHP electricity or heat production.

Operation: Tax reduction generally move the marginal bidding price down, thereby making the CHP more competitive and more able to participate in the market.

Investment: Tax reductions improves the business case towards investment in CHP capacity.

4.1.9. Presence of Grid Connection Discounts

The grid connecting cost for new CHP can be reduced. Grid connection discounts have been defined as framework conditions ex post the survey, hence related information are only available for some countries.

Operation: A one-time cost, which is assumed to affect bidding price, although only marginally.

Investment: Increases the investment incentives for CHP.

4.1.10. Absence of Tariffs Levied on CHP for Feeding Into Grid

Tariffs can be levied on the production of electricity from generators. Grid tariffs for feeding to grid have been defined as framework conditions ex post the survey, hence information regarding on these are only available for some countries.

Operation: Tariffs generally move the marginal bidding price up, thus the absence of these makes the CHP more competitive.

Investment: Improves the business case towards investment in CHP capacity.

4.2. Power to Heat

4.2.1. Absence of PSO on Electricity (When Used for Heat Generation)

PSO (Public Service Obligation) is a tariff on electricity consumption, which is aimed at covering support costs for energy investment schemes, often for renewable energy. Similar tariffs, not necessarily called *PSO*, also fall into this category.

Operation: If applied on electricity when used for P2H, PSO and similar tariffs increase marginal operation costs, making the P2H-solution less competitive.

Investment: The operational barrier reduces incentive to invest.

4.2.2. *Absence of Grid Tariffs on Electricity (When Used for Heat Generation)*

Transmission, distribution and other tariffs applied when electricity is used for P2H in the DH system.

Operation: Grid tariffs increase marginal operation cost and hence decrease the competitive advantage.

Investment: The operational barrier reduces incentive to invest.

4.2.3. *Absence of Other Levies or Taxes on Electricity (When Used for Heat Generation)*

Electricity use is levied in various ways and to various degrees, but often with an energy/electricity tax or similar.

Operation: Levies increase marginal operation cost and hence decreases competitive advantage.

Investment: The operational barrier reduces incentive to invest.

4.2.4. *Presence of Reduced Electricity Tax on Electric Boilers*

In case electricity taxation is present, some degree of tax exemption or reduction can be applied for electric boilers.

Operation: If taxation on electricity is reduced for electric boilers in the DH system, it decreases marginal operation cost.

Investment: The operational driver increases incentive to invest.

4.2.5. *Presence of Reduced Electricity Tax on Heat Pumps*

In case electricity taxation is present, some degree of tax exemption or reduction can be applied for heat pumps.

Operation: If taxation on electricity is reduced for heat-pumps in the DH system, it decreases marginal operation cost.

Investment: The operational driver increases incentive to invest.

4.2.6. *Absence of Regulatory Priority to Heat from Waste, RES, Biomass or Geothermal*

Priority in terms of supplying heat to the system is given to waste incineration, heat produced by biomass, geothermal or other RES.

Operation: Special priorities may reduce the profitability of the P2H units, by displacing their production with other heat sources.

Investment: The operational barrier reduces incentive to invest.

4.2.7. *Presence of Subsidy for Heat pumps*

Subsidies to heat pumps, which are not acting as a barrier for flexible electricity consumption. An example is investment subsidy.

Operation: Assuming that the subsidy moves the marginal bidding price from LRMC to SRMC, the heat pump is more competitive and more able to participate in the electricity market.

Investment: Increases the investment incentives for heat pumps.

4.2.8. *Presence of Subsidy for Electric Boilers*

Subsidies to electric boilers, which are not acting as a barrier for flexible electricity consumption. An example is investment subsidy.

Operation: Assuming that the subsidy moves the marginal bidding price from LRMC to SRMC, the electric boiler is more competitive and more able to participate in the electricity market.

Investment: Increases the investment incentives for electric boilers.

4.3. General Resources

4.3.1. *Absence of Heat Price Regulation - Price Caps*

Heat price caps can be applied in cases where there is a regulatory priority for establishing a ceiling above which heat prices are not allowed to rise.

Operation: Price caps for DH can indirectly reduce flexibility, by limiting the feasibility of demand response programmes. Such a demand response programme could be based on hourly (or similar short-term) pricing, which maximises production from CHP and P2H.

Investment: Price caps can reduce the amount of operation on CHP and P2H, which in turn disincentivises investment.

4.3.2. *Absence of Heat Price Regulation - Flat Tariff Structures*

Flat tariffs imply that the heat provider receives a fixed payment for its output, no matter the immediate need for flexibility.

Operation: Flat tariffs for DH can indirectly reduce flexibility, in case they limit the possibility to incentivise the provision of flexible heat demand, through e.g. hourly (or similar short-term) metering, which maximises production from CHP and P2H.

Investment: Flat tariffs can reduce the amount of operation on CHP and P2H, which in turn disincentivises investment.

4.3.3. *Absence of Heat Price Regulation – Profit Caps in Commercially Owned DH*

Profit caps can reduce the incentive for commercial operators to make long term investments in flexible heat production units.

Operation: Not directly affected.

Investment: Investments with high capital costs (e.g. CHP and heat pumps) can be unattractive to investors, and they may instead prefer investments with lower capital costs incurring less risk (e.g. HO).

4.3.4. Absence of Operational Practice of Generation Following Demand

Assuming that operation on HO, CHP and P2H is happening without any application of storage, and not dictated by electricity prices.

Operation: If heat generation follows heat demand, instead of utilising heat storages, potentially flexible units are bounded by heat demand and not by flexibility needs. Hence, flexible operation is limited.

Investment: Operation on P2H and CHP is assumed to be higher than with flexible generation, and the investment risk is reduced, due to certainty regarding operation.

4.3.5. Absence of Tax Exemption for RES Fuels

CHP and HO operating with RES fuels will gain lower marginal costs. Experience shows that HO might benefit relatively more than CHP, particularly with low electricity prices, making HO more attractive. From the perspective of the entire energy system, HO is not a good flexibility provider, as it does not interact with the electricity system.

Operation: Lower marginal production prices for RES-based HO and CHP. Overall assumed to be a barrier due to the relatively higher advantage for HO.

Investment: Tax exemption for biomass may create incentives for investment in HO, more so than in CHP. Experience shows relatively higher benefit for HO, due to the lower competitiveness of especially small-scale CHP.

4.3.6. Absence of Subsidies for HO Boilers

Subsidies directly targeted HO on either production or investment.

Operation: Subsidies for HO will leave P2H and CHP indirectly negatively affected, if HO has lower marginal costs. This leads to relatively more operating hours of HO.

Investment: Subsidy for HO may make it more attractive than P2H and therefore impede investment.

Framework Categories for the Country Surveys

Table 1, Table 2 and Table 3 summarise all framework conditions described in this section.

Table 1 Summary table of the framework conditions for CHP. All elements presented are provided under the condition of *all things being equal*.

Framework conditions for CHP	Effect on flexible operation	Effect on investment
Absence of mandatory procurement of electricity	Driver	Barrier
Absence of feed-in tariffs	Driver	Barrier
Absence of feed-in premiums	Driver	Barrier
Presence of market pricing for electricity	Driver	N/A
Presence of power capacity payments	Driver	Driver
Presence of other subsidy to CHP	Driver	Driver
Presence of tax exemptions for fuel to electricity production	Driver	Driver
Presence of energy, CO ₂ or other tax reductions	Driver	Driver
Presence of grid connection discounts	Driver	Driver
Absence of tariffs levied on CHP for feeding into grid	Driver	Driver

Table 2 Summary table of the framework conditions for P2H.

Framework conditions for P2H	Effect on flexible operation	Effect on investment
Absence of PSO on electricity (when used for heat generation)	Driver	Driver
Absence of grid tariffs on electricity (when used for heat generation)	Driver	Driver
Absence of other levies or taxes on electricity (when used for heat generation)	Driver	Driver
Presence of reduced electricity tax on electric boilers	Driver	Driver
Presence of reduced electricity tax on heat pumps	Driver	Driver
Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Driver	Driver
Presence of subsidy for heat pumps	Driver	Driver
Presence of subsidy for electric boilers	Driver	Driver

Table 3 Summary table of the framework conditions for general resources (elements that do not exclusively affect CHP or P2H).

Framework condition for general resources	Effect on flexible operation	Effect on investment
Absence of heat price regulation - price caps	Driver	Driver
Absence of heat price regulation - flat tariff structures	Driver	Driver
Absence of heat price regulation – profit caps in commercially owned DH	N/A	Driver
Absence of operational practice of generation following demand	Driver	Barrier
Absence of tax exemption for RES fuels	Driver	Driver
Absence of subsidies for HO boilers	Driver	Driver

In the country profiles, an overview of the defined framework conditions will be presented in a table as in Table 4.

Table 4 Template for the tables used in the country profile overview of framework conditions.

COUNTRY									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5. Results: Drivers and Barriers for Flexibility in the District Heating-Electricity Interface

This section is organized as nation-specific evaluations of those framework conditions affecting flexibility in the DH-electricity interface. Each national profile includes a part on the present situation, as well as a part on the future prospects, following the below structure:

- Summary of the profile
- Country profile overviews identical to Table 4 in Section 4, colour-coded to provide a systematic overview and easy comparison
- General overview of the DH-electricity interface in the country
- Section on current and future CHP framework conditions
- Section on current and future P2H framework conditions
- Section on general resources on issues beyond the specific focus in the first two parts

Regarding the colour-coded table, the characteristics are summarised and colour-coded, according to presence of selected features that affects flexibility. The legend below explains each of the applied colour-codes. For easy visual overview, blue will always indicate an *operational flexibility driver*, while red is a barrier. Absence of colour means that data has not been available at the deadline of the study.

Legend - summary tables		
Yes	No	In some cases/to some degree

5.1. Country Profile: Denmark

5.1.1. Main Drivers and Barriers

The future of the large capacity of CHP with heat storages, which has been able to provide flexibility in the power system, is uncertain due to low electricity prices, out-phasing of support payments and tax exemptions for biomass. At the same time, high taxes and tariffs on electricity use reduce incentives for investment in P2H technologies. For CHP plants the electricity production is exempted from taxes, while the CHP heat is subject to taxes.

Table 5: Framework conditions for flexibility in the DH-electricity interface in Denmark

DENMARK									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.1.2. Flexibility Options in the Danish DH System

CHP has since long been encouraged in Denmark by legal means. In Denmark DH covers around half of the total heat consumption of industries and households (Energistyrelsen 2015). In 2014 approximately two thirds of DH were produced by CHP units mainly based on waste incineration, coal, wood pellets, and natural gas. Electric boilers and heat pumps were the source of 0.4% of the DH. By introducing time varying electricity tariffs (and later market pricing), heat storage tanks have been installed in connection to many CHP plants. The heat storages contribute to flexibility by making the CHP plants able to postpone the delivery of heat, which allows for optimization of electricity generation according to demand.

5.1.3. Framework Conditions for CHP in Denmark

Current Aspects

Co-generation of heat and power in Denmark is divided into central and decentral plants. Decentral CHPs are usually locally owned back-pressure plants, while central CHPs are large extraction-

based plants. Both types are considered flexible with the back-pressure plants able to ramp and cycle production within short timeframes, and the extraction plants' large degree of freedom in the share between heat and electricity output. CHP has historically been a political priority in Denmark and plays a significant role in the Danish DH and power systems. However, decreasing market prices for electricity have resulted in fewer operating hours of the CHP units. Therefore, the installed capacity of centralised CHP plants has been decreasing throughout the last decade (from 6,877 MW electrical capacity in 2005 to 4,852 MW in 2014 (Energistyrelsen 2015)). Biogas-based CHP is only deployed to a limited extent and receive FiP on electricity produced, while other decentralised CHP receive production independent capacity payments, based on their electricity production capacity (the so called *grundbeløb*). This is set according to average spot power prices, and is a subsidy that maintains the capacity on the market, while not affecting its flexible operation. The share of fuel for electricity production is taxed less than fuel for heat production. CHP pay a grid use tariff for feeding into the grid.

Future Aspects

The capacity payment received by decentral CHP is to be phased out in 2018. Decentral DH companies with CHP have raised concerns that after the discontinuation of the capacity-based support scheme, electric capacity cannot be maintained.

Biomass is currently exempted from taxation which makes it an attractive input for heat production. It is seen that decentral CHP prefer a business case for new capacity with biomass-based HO boilers. Where it is allowed, these are currently installed in order to supplement the current capacity.

If no further incentives for maintaining CHP capacity are provided, this tendency is expected to persist in the future. Some central CHP plants are shifting fuel to biomass and/or are being taken over by municipalities in order to secure heat supply. The fuel shift does not necessarily affect the flexibility of the plant. This counter-tendency is working for the life extension of CHPs, but depends on the technology choices of the new owners.

5.1.4. Framework Conditions for P2H in Denmark

Current Aspects

Electric boilers have been installed from early 2000s due to good market conditions at the regulating power market (a balance market in the power exchange Nord Pool). This setup allows the DH-plants with electric boilers to balance short-term fluctuations in the electricity system by turning on and off the electric boiler and, to a lesser extent, to utilise very low electricity prices.

By 2014, the total capacity of electric boilers was around 400 MW_{EL}. However, compared to other countries the taxation imposed on electricity use is very high in Denmark, which results in P2H technologies generally being unfeasible for producing heat at a low cost. This result remains despite the adoption of the Electric Heater Scheme in 2005 (The Danish Ministry of Taxation 2005), which was an initiative for improving the conditions for electric boilers by shifting the taxation on electricity consumed to the heat produced (Sørensen et al. 2013). The act did not improve the conditions of heat pumps with coefficient of performance (COP, i.e. efficiency) greater than 3. A tariff for financing public service obligations (PSO), is levied on heat pumps, but not electric boilers. Grid use tariffs are levied equally on both heat pumps and electric boilers. Another issue related to the framework

conditions of heat pumps in Denmark is the taxation on utilization of excess heat from industries. Heat pumps' efficiency increases with the temperature of the heat source, thus sources based on excess heat from industries are more attractive than colder alternatives. However, in order to secure incentives for investments in energy efficiency, taxation on the utilization of excess heat has been imposed. Priority for waste-based heat is applied.

Future Aspects

Since 2012, energy taxes have been under review to adapt them to the new and changing conditions. Part of this review is expected to cover the future aspects on electrification of the heat supply, which could play an important role for demand-side flexibility.

5.1.5. *Framework Conditions for General Resources*

In Denmark the DH consumer price is a flat two-part tariff, consisting of a fixed and variable part. The prices are set by the DH-companies according to a zero-profit benchmark (a *break-even principle*), which means that the DH companies are entitled to have all their necessary costs covered by the consumers, but not to make a profit. This is monitored and benchmarked by a national regulator. The zero-profit approach is currently under review by state authorities. DH companies are furthermore prohibited from making investments that would lead to higher heat prices.

5.2. Country Profile: Estonia

5.2.1. Main Drivers and Barriers

Main barriers for flexibility are baseload operation of CHPs due to FiT, operational custom of generation following demand, lack of heat storages to balance daily load and limited incentives and deployment for P2H technologies due to taxation on electricity consumption when used for heating.

Table 6: Framework conditions for flexibility in the DH-electricity interface in Estonia

ESTONIA									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.2.2. Flexibility Options in the DH System

DH in Estonia accounts for approximately 44% of the total heat consumption. The heat is produced by HO boilers and CHP units with a share of 62% and 38% respectively. The main fuel types are natural gas and biomass. Estonia has the World's largest oil-based power plants, supplying the majority of electricity produced in Estonia (Eesti Energia n.d.).

5.2.3. Framework Conditions for CHP in Estonia

Current Aspects

Co-generation of heat and power is politically prioritized due to efficiency. CHP installations qualify for a FiT, which means that there is no incentive for operating flexibly with respect to the power market conditions and market prices. For the same reason, CHP is used for electricity base load, which in turn reduces the incentive for investing in heat storages.

Future Aspects

While remunerated under the FiT scheme the CHP installations are not used as flexibility option, however, the support scheme provides incentives for investment in CHP capacity. The contract period is limited to a certain amount of years, and after it expires the CHP installations can enter the power markets and contribute to the flexibility of the system. In other words, the incentive scheme may counteract the flexibility at the moment, but it helps to secure that flexibility through CHP capacity is available in the future. For improved flexibility the CHP installations would need to be supplemented with heat storages.

5.2.4. Framework Conditions for P2H in Estonia

Current Aspects

P2H technologies are currently not utilized in the Estonian DH system and no special regulation regarding electric heating has been adopted. Low heat prices and high electricity cost are considered reasons for the lack of investment incentives. Furthermore, due to high installation costs, heat pumps are considered baseload units, however, baseloads are presently covered by CHP.

Future Aspects

If P2H technologies are to be promoted, relevant legislation should be implemented.

5.2.5. Framework Conditions for General Resources

Operational practice in DH-systems is primarily to match demand with supply through production units, and not through storage. Heat storages are uncommon. Seasonal storages are not deployed. HO boilers are not subsidised, but are widely deployed. Heat tariffs are subject to approval by the national competition authority, and must be flat, consumption-based and determined according to the cost of supply. Hence, they provide no incentive for flexibility. The heat suppliers are allowed a capital return of about 5-6% on top of their costs to supply heat power to the customers. DH systems are ageing, since many were established in the Soviet-era, and have large transmission losses.

5.3. Country Profile: Finland

5.3.1. Main Drivers and Barriers

CHP, heat storages and – to a very small extent – heat pumps, are all present in Finland. Investment subsidies are generally available for non-fossil-based units. Biomass is generally untaxed, which, all things being equal, increases the comparative advantage of fuel-based units compared to P2H. Coal is discussed to be phased out within an unknown timeframe, potentially affecting large CHPs.

Table 7: Framework conditions for flexibility in the DH-electricity interface in Finland

FINLAND									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.3.2. Flexibility Options in the DH system

In 2014, DH supplied 46% of all heat in Finland. 72.4% of this came from CHP-plants, while the remaining 27.6% was supplied by HO technologies such as boilers. Fuel diversity is rather high, as seen in the following distribution: bioenergy 31%, coal 24.6%, natural gas 22.3%, peat 14%, heat pumps & industrial reaction heat 2.5%, oil 2.1%, other 3.4%. Information regarding grid connection has not been identified.

5.3.3. Framework Conditions for CHP

Current Aspects

CHPs are operating on the power market. Biomass-based CHPs are subsidised with a heat premium, in addition to their revenue on the power market. Investment subsidy is generally provided to RE-based technologies, under which CHPs smaller than 10 MW_{FUEL} input can receive 10-15% investment-support, when they are based on biomass. Biomass for CHP-based energy production is not taxed, while the heat share of the energy produced by fossil fuels is taxed. Compared to other

types of energy production, the CO₂-tax is halved from 54 EUR/ton to 27 EUR/ton on CHP-based production.

Future Aspects

The government is considering prohibiting use of coal, which would affect several large CHPs. It is pointed out that the ramping rates of these CHPs are poor, and hence not very flexible. As Finland is building much new nuclear power towards 2020, the competitiveness of CHP may decrease after this point.

5.3.4. *Framework Conditions for P2H*

Current Aspects

A *strategic stockpile tax* and an excise duty are levied on the consumption of electricity. Subsidies for investments in heat pumps can be up to 15% of investment. According to dialogue with the Finnish Tax Authorities, electricity consumption in heat pumps and electric boilers is exempt from tax in plants with CHP, but not for HO-plants.

Future Aspects

Due to construction of several nuclear power plants and wind power simultaneously, P2H may become important after 2020, but would also influence CHP plants at the same time.

5.3.5. *Framework Conditions for General Resources*

In case coal-based CHPs are prohibited, the survey points out that HO boilers can be a relevant alternative to these, posing a potential competition to CHP. Storages are widely applied for heat, and also for cold. Biomass boilers can receive 10-15% investment subsidy. The prices and profits of DH are defined by the local provider, and are subject to control from the competition authorities. Heat tariffs are typically based on a fixed fee, supplemented with a consumption-based fee. In some cases, summer and winter fees are applied. Use of RE-based fuels is not taxed, and biomass-based boilers can receive 10-15% of investments in subsidy.

5.4. Country Profile: Latvia

5.4.1. Main Drivers and Barriers

Main barriers for flexibility are baseload operation of CHPs due to FIT, operational custom of generation following demand, lack of heat storages to balance daily load and limited incentives and deployment for P2H-technologies.

Table 8: Framework conditions for flexibility in the DH-electricity interface in Latvia

LATVIA									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.4.2. Flexibility Options in the District Heating System

In 2014, there were 175 CHP plants in Latvia with total installed capacity of 1,265 MW_{EL}. They produced 58% of total electricity generation and 73% of total heat generation. There are four larger CHP plants with installed capacity above 20 MW_{EL}. These plants make up 83% of total electrical capacity installed among CHPs and produces 60% of total CHP-based electricity. Heat storages are used for daily balancing by some companies, but are generally deployed to a limited extent.

The major fuel used in CHP plants in Latvia is natural gas. In 2014, 78% of electricity produced was from the 1,140 MW_{EL} natural gas-based CHP plants. Large-scale electric boilers are not deployed. Heat pumps to a limited extent with a best-case example of a 2 MW_{TH} heat pump installed in Riga. HO boilers accounted for 23% of heat production in 2014; a share that has steadily decreased from about 50% in 2002. This development is interpreted as a consequence of increased energy efficiency in DH production and consumption, leading to decreased demand for HO boilers. The extent of grid tariffs has not been identified for Latvia.

5.4.3. Framework Conditions for CHP in Latvia

Current Aspects

CHPs smaller than 4 MW_{EL} are incentivised to operate as baseload, and do so, due to mandatory procurement of electricity from those, along with FiT for this production. Those plants are usually biogas-based plants. Larger CHPs receive a capacity-based payment in form of a guaranteed fee corresponding to the electric capacity installed. Contrary to the capacity payment seen in Denmark, the Latvian capacity payment does not facilitate flexible operation, since the large CHPs operate as baseload. This happens due to operational practice, and to replace the baseload historically received from the Ignalina nuclear power plant in Lithuania and shale-oil-based electricity from Estonia.

Future Aspects

The current financing of subsidies for CHP and renewable energy in general is valid until 2017. What happens thereafter remains uncertain. Since the European Commission has ruled that the Danish PSO-based subsidy, similar to the one applied in Latvia, must be changed before 2018, it is likely that the current approach to financing will have to change at some point.

5.4.4. Framework Conditions for P2H

Current Aspects

A PSO-like *obligatory purchase component tariff* is levied on end-users of electricity, to finance the support for CHP and RE-based production. Thereby, P2H-technologies pay the same for electricity as other types of electricity consumption. Subsidies are provided for heat pump installation in households, public buildings and commercial buildings (national level support scheme), as well as European Economic Area-grants for green innovations and Cohesion Fund programmes. Despite this, the deployment is limited. In the survey, it is pointed out that electricity prices on the market are too high to provide an incentive for investment in electric boilers, which also does not receive any subsidies or special regulation.

Future Aspects

As described in 5.4.3, the potential consequence of European Commission ruling can mean that levies will change on electricity use. This can in turn make P2H-technologies more profitable, by lowering their marginal production costs.

5.4.5. Framework Conditions for General Resources

Operational practice in DH-systems is primarily to match demand with supply through production units, and not through storage. Heat storages are present, but uncommon. Seasonal storages are not deployed. There are no direct subsidies for heat storages, apart from cases where they are part of new renewable energy installations. HO boilers, based on biomass, are not subsidised other than by special EU grants, but are widely deployed. Heat tariffs are flat and settled in each individual DH



Results: Drivers and Barriers for Flexibility in the District Heating-Electricity Interface

system, based on production costs, distribution costs and a sales cost. Tariffs are regulated and approved by the Public Utilities Commission.



5.5. Country Profile: Lithuania

5.5.1. Main Drivers and Barriers

Main barriers for flexibility are FiT for CHP and mandatory procurement of CHP-based heat, operational custom of generation following demand, lack of heat storages to balance daily load and limited incentives and deployment for P2H-technologies due to taxation on electricity consumption when used for heating. Support for heat pumps and biomass-based CHP can potentially increase flexibility.

Table 9: Framework conditions for flexibility in the DH-electricity interface in Lithuania

LITHUANIA									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.5.2. Flexibility Options in the DH System

In 2014, DH supplied 57% of Lithuanian households. Sales (10.24 TWh in 1996) and heat input to grid (15.20 TWh in 1996) have decreased to respectively 6.99 and 8.57 TWh in 2014, partly explained by energy efficiency measures. Until 2014 natural gas was the dominant fuel in DH-supply, where it was marginally overtaken by biomass and waste, which have both seen a significant increase since especially the mid-2000s. This is explained partly by the EU 2020 goal for Lithuania of 23% RES in gross final energy consumption, but also by a strong focus on security of supply and fuel-diversification. In 2014, 68% of DH was CHP-based, while the remaining 32% came from boilers. Tariffs for feeding to grid from CHP have not been identified.

5.5.3. *Framework Conditions for CHP in Lithuania*

Current Aspects

Two biomass-based CHPs have been built in 2012. 23% of fuels in CHP were from renewables in 2014. Contrary to the biomass-based CHPs, the natural gas-based plants are not considered economically feasible due to comparatively higher natural gas costs. Neither the larger natural gas-based CHPs nor the smaller biomass-based CHPs are considered flexible today. Mandatory procurement of electricity from biomass-based CHPs is practiced, as well as centrally defined quotas and purchase prices for larger DH-systems. In addition, FiT is applied to CHP. Electricity produced from renewable resources is exempt from tax. CHPs on biomass and waste receive a 40% discount on grid connection when being established.

Future Aspects

Power generation from renewable sources is prioritised in the energy policy. This is exemplified in the target of 355 MW_{EL} biomass-based plants by 2020. At the same time, it is pointed out that it can become a challenge to preserve the current volume of CHPs and to further develop CHP, since it poses a financial challenge, given current unfavourable energy market conditions which have increased the requested CHP support intensity. Planned support for construction and renovation of biomass-based CHP and boiler plants from EU Structural Funds amounts to 304 MEUR in the period 2014-2020.

5.5.4. *Framework Conditions for P2H*

Current Aspects

Electric boilers are not installed, explained with the lack of sufficiently low electricity prices. Apart from 35 MW_{TH} absorption heat pumps utilising geothermal heat, heat pumps are not deployed. PSO and grid tariffs are levied on the consumers, where also P2H is assumed to be included. A notable exemption from tariffs is pumped-storage hydro power (where energy is stored by pumping it into a reservoir, and energy is regained by releasing it through turbines) and in case P2H is a preferred option, a similar exemption could be applied here. Heat pumps can receive investment support or reduced electricity tax, but not both, since they are mutually exclusive. A regulatory priority to take heat from RE-based sources is present.

Future Aspects

Future aspects for HO-boilers are affected by the 2020 targets for RE. In 2020 60% of DH will be supplied with RE, mainly through biomass. Boilers are expected to become one of the most common technologies, hence displacing potential supply from P2H-technologies.

5.5.5. *Framework Conditions for General Resources*

Operational practice in DH-systems is to match demand with supply through production units, and not through storage. Seasonal storages are not applied, while heat storages for balancing daily load are present, but uncommon. There are no direct subsidies for heat storages, apart from cases where

they are part of new renewable energy installations. Heat tariffs are flat and settled in each individual DH-system. While there is no profit cap for DH-companies, tariffs are approved by the National Control Commission for Prices and Energy. In some occasions, HO-boilers are supported. This can happen through EU projects or grants, or through the directed subsidy towards conversion to liquid biomass for heating.

5.6. Country Profile: Norway

5.6.1. Main Drivers and Barriers

Norway has a high share of reservoir-based hydropower production, and the need for short-term flexibility in the energy system is currently limited. The Norwegian heat supply is heavily dependent on individual electricity technologies, and the DH sector is very small. The extent of storage systems and CHP is very limited, but electric boilers made up 13% of the DH production in 2014.

Table 10: Framework conditions for flexibility in the DH-electricity interface in Norway

NORWAY									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.6.2. Flexibility Options in the DH System

Only 15 of 93 DH companies in Norway were coproducing electricity and heat in 2012. 11 of these 15 are waste incinerators. These companies are however quite large in the DH sector, and their total heat production constituted of around 40% of the total gross district heat production. These companies are nevertheless very small in the electricity market. Their power production constituted of around 0.3% of the total electricity production in Norway in 2012 and around 12% of the total production of thermal power.

Electric boilers contributed to 13% of the total heat production in 2014, and heat pumps 9% (Statistics Norway 2016b). The total net production of district heat was around 5 TWh. Only a few DH producers have invested in heat storages. Seasonal storages are non-existent in Norwegian DH.

5.6.3. *Framework Conditions for CHP*

Current Aspects

New CHP plants based on waste or bio fuel are eligible for green certificates on the renewable share of their produced electricity, or they can choose to apply for an investment grant from Enova (governed by the Norwegian energy ministry). This subsidy is a financial support of up to 45% of the investment costs in a DH plant based on renewables.

Future Aspects

Norwegian DH is characterised by densification of current DH-grids, rather than by establishment of new DH-systems. There are thus few investments in new facilities. CHP plants based on biomass may become profitable with a sufficiently high green certificate price, but currently CHP is not competitive to small-scale hydropower or onshore wind power.

5.6.4. *Framework Conditions for P2H*

Current Aspects

DH producers have a lower energy tax charge on electricity than residential consumers. The largest DH companies have a flexible network tariff, which means that the network company can deactivate their electric boiler on short notice. In compensation, the DH producers get a discount on the load demand component in the network tariff. The tariff structure however varies greatly among the different utility companies, and is in many cases a barrier for flexible use of electric boilers in the DH sector.

Future Aspect

Due to general low electricity prices, there has been an observed increase in the use of electricity for heat production since 1999. The use of electric boilers however drops in cold and dry years with high electricity prices. Due to advanced metering, the tariff structure is under evaluation.

5.6.5. *Framework Conditions for General Resources*

Heat storages are rarely applied, but an oversized pipe system makes storage within the DH network theoretically possible. There are no subsidies for flexible solutions alone, unless specified in the Enova investment support scheme for entire systems, based on renewable energy, or the green certificate scheme for variable renewable electricity. Third party access and supply of district heat has been introduced in the Energy Act.

Heat tariffs follow the electricity price, and are not allowed to exceed these. There is a trend towards an extended use of load demand tariffs in the DH price, and so far, one company charges a tariff based on the water volume to induce efficiency. An energy charge according to the current season is common.

5.7. Country Profile: Sweden

5.7.1. Main Drivers and Barriers

Swedish DH is largely market-based regarding both heat and electricity. Renewable electricity production is additionally eligible for green certificates. The producers of DH are facing a full electricity tax charge on electricity procured as input to the district heat production, which may reduce the extent of electricity to heat as a flexibility option. Heat pumps, electric boilers, seasonal and daily storage and CHPs are all present in Swedish DH.

Table 11: Framework conditions for flexibility in the DH-electricity interface in Sweden

SWEDEN									
Framework conditions for CHP									
Absence of mandatory procurement of electricity	Absence of feed-in tariffs	Absence of feed-in premiums	Presence of market pricing for electricity	Presence of power capacity payments	Presence of other subsidy to CHP	Presence of tax exemptions for fuel to electricity production	Presence of energy, CO ₂ or other tax reductions	Presence of grid connection discounts	Absence of tariffs levied on CHP for feeding into grid
Framework conditions for P2H									
Absence of PSO on electricity (when used for heat generation)	Absence of Grid tariffs on electricity (when used for heat generation)	Absence of other levies or taxes on electricity (when used for heat generation)	Presence of reduced electricity tax on electric boilers	Presence of reduced electricity tax on heat pumps	Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Presence of subsidy for heat pumps	Presence of subsidy for electric boilers		
Framework conditions for general resources									
Absence of heat price regulation - price caps	Absence of heat price regulation - flat tariff structures	Absence of heat price regulation – profit caps in commercially owned DH	Absence of operational practice of generation following demand	Absence of tax exemption for RES fuels	Absence of subsidies for HO boilers				

5.7.2. Flexibility Options in the DH System

The CHP share in the heat production was around 50% in 2014. The CHP share of the total electricity production was however only 5%. Hydropower and nuclear power dominated the electricity production in Sweden, and constituted of about 40% each. Biomass dominates in the Swedish DH sector, and contributed to nearly 60% of the fuel use in the electricity production in CHP plants, and 40% of the fuel use in the heat production in 2014. The use of biomass has increased steadily since the 1970's. Waste is the second most used fuel and constituted of 21% of the heat production and 24% of the electricity production in CHP plants in 2014. Heat pumps are more common than electric boilers, and contributed to respectively 8 and 0.5% of the total delivered heat.

5.7.3. *Framework Conditions for CHP*

Current Aspects

Electricity is taxed on the consumption side while DH is taxed on the production side. This implies that for CHP plants the electricity production is exempted from taxes, while the CHP heat is subject to taxes. CHP is promoted through tax reductions and green certificates.

Future Aspects

Stable low electricity prices, also during winter, may be a threat to CHP, because it makes heat pumps more profitable.

5.7.4. *Framework Conditions for P2H*

Current Aspects

DH producers pay full energy tax charge on electricity, and the share of delivered heat that comes from electric boilers has been less than one percent the last decade. There has not been an observed increase in the use of heat pumps since the early 1980's.

Future Aspect

Low electricity prices may make P2H more attractive.

5.7.5. *Framework Conditions for General Resources*

Daily heat storages (water tanks) are common. The pipes and connected buildings may potentially also be used as storage. The DH consumers are often faced with variable DH prices, for instance according to the outside temperature. A load demand tariff is becoming more common. The Swedish Energy Market Inspectorate must monitor that the DH companies provide transparent price information, and that the prices are according normal competition regulation. Legal framework conditions are in place for third party access in Sweden. The building codes are considered a barrier for the Swedish DH sector and the system efficiency as a whole, because it equates electricity and heat, regardless of the production efficiency of these energy products.

6. Comparative Analysis of Identified Drivers and Barriers for Flexibility

In this section, the research questions are synthesised, so that the identified framework conditions for flexibility in the DH-electricity interface and the condition of those in each country is compared to identify patterns and differences among the countries. Solutions are proposed for selected barriers. The analysis follows the same structure as Section 5 (i.e. CHP, P2H and general resources), and applies the same colour coding, as also indicated below.

Legend - summary tables		
Yes	No	In some cases/to some degree

6.1.1. Framework Conditions for Combined Heat and Power Plants

CHP is generally encouraged by energy policy, not because of flexibility but to increase energy efficiency. This priority means that CHP in all countries receive some sort of investment and/or operational support, and that CHP in no cases are fully market-exposed.

Market exposure is considered one of the most important framework conditions for flexibility, since market pricing for electricity is considered the best proxy for flexibility needs. As this project deals with flexibility down to the hourly level, this section refers specifically to the day-ahead electricity market. Market exposure is highest in the Nordic countries, while the Baltic countries see less direct exposure of CHP to power market prices. In the Baltic countries, operation of CHP is encouraged through FiT, which improves the investment-case, but counteracts flexible operation. Latvia and Lithuania (supporting CHP to substitute baseload production from especially the Ignalina nuclear power plant after its closure), practice mandatory purchasing of electricity from some CHP plants, a practice which does not provide an incentive to operate flexible.

Whereas Latvia and Lithuania have CHP as an important part of their energy policy, it is more limited in Estonia. The reason is likely to be the reliance on the large capacity of the existing Estonian oil-based power plants. In Estonia, the old Soviet-era DH systems are inefficient, and much effort remains in renewing them. The process should be conducted simultaneously with considerations on CHP or P2H production capacity, since changes in heat demands will impact the feasibility of heat production capacity.

Tax exemptions and reductions for CHP are applied in Denmark, Finland, Sweden and Estonia, where the fuel used for power production is generally not subject to energy tax. The fuel used in CHP is allocated to heat and power production according to formulas decided by the national policy makers, and the distribution affect the degree of advantage CHP has compared to HO in terms of fuel tax. In combination with market pricing for electricity, fuel tax reduction for electricity production improves the ability of CHP to compete on both the power and heat markets.

The presence of grid connection discounts and grid tariffs varies, but as their share of impact on the flexibility potential is estimated to be quite small, they are not considered a key barrier.

In Denmark and Finland large coal-fired power plants have provided a large share of CHP generation of heat for DH. This kind of plant is increasingly being challenged – in Denmark because of low power prices, in Finland because of potential future restrictions on coal. In Denmark this can be considered a challenge to flexibility, as these extraction power plants can operate flexibly by varying the steam outlet for heat, and because they have developed very fast ramping rates. In Finland, on the contrary, the closure of large coal-fired CHP can be a benefit for flexibility as they have rather slow ramping rates.

Table 12: Framework conditions for CHP in the Nordic and Baltic countries.

Framework conditions for CHP	DK	ES	FI	LA	LI	NO	SE
Absence of mandatory procurement of electricity	Blue	Blue	Blue	Orange	Orange	Blue	Blue
Absence of feed-in tariffs	Blue	Red	Blue	Red	Red	Blue	Blue
Absence of feed-in premiums	Orange	Blue	Orange	Blue	Blue	Blue	Blue
Presence of market pricing for electricity	Blue	Orange	Blue	Orange	Red	Blue	Blue
Presence of power capacity payments	Blue	Red	Red	Blue	Red	Red	Red
Presence of other subsidy to electricity production	Red	Blue	Blue	Red	Red	Orange	Orange
Presence of tax exemptions for fuel to electricity production	Blue	Blue	Blue	Red	Red	Red	Blue
Presence of energy, CO ₂ or other tax reductions	Orange	Red	Blue	Red	Orange	Red	Blue
Presence of grid connection discounts	White	Red	White	Red	Orange	Red	Red
Absence of tariffs levied on CHP for feeding into grid	Red	Blue	White	White	White	Blue	Blue

Mitigation of Barriers – CHP

Figure 10 displays a simple count of the number of barriers present in each country. When the barrier only is present to some extent, it is counted as a half. The sum of these are held in relation to the total number of barriers. It is the same data, but illustrated differently, as seen in the tables in this chapter. It should be noted, that the figures above do not evaluate the importance of each barrier. The same conditions apply for the corresponding figures, Figure 11 and Figure 12, in the subsequent sections.

The lack of market pricing for electricity produced by CHP constitutes a barrier to flexible operation in the Baltic countries. While it can be difficult to address electricity prices through regulation, participation of the CHPs on the power market can be regulated. This would require changes in the support schemes for CHP, for instance offering CHP an investment grant or sliding FiP instead of FiT. Estonia is practising this to some extent, since the FiT is gradually phased out in favour of market-exposure. This need for regulatory change is also indicated by the fact that the Baltic countries presents most barriers - closely followed by Norway.

Common for all countries is the priority for CHP, and additionally that the power market alone is not sufficient for providing a feasible investment-case for CHP. At the same time, subsidies should only be necessary to the extent that the energy system cannot ensure the type of production facilities that society prefers. A solution can be re-regulation on a national level to remove the current barriers, concretely by replacing flexibility-reducing subsidy schemes with flexibility inducing taxation. It remains to context-specific feasibility studies, to show whether additional support is needed to maintain and invest in flexibly operated CHP. Also, since the process of reforming taxation can be lengthy, it might be relevant to consider subsidies on the short term.

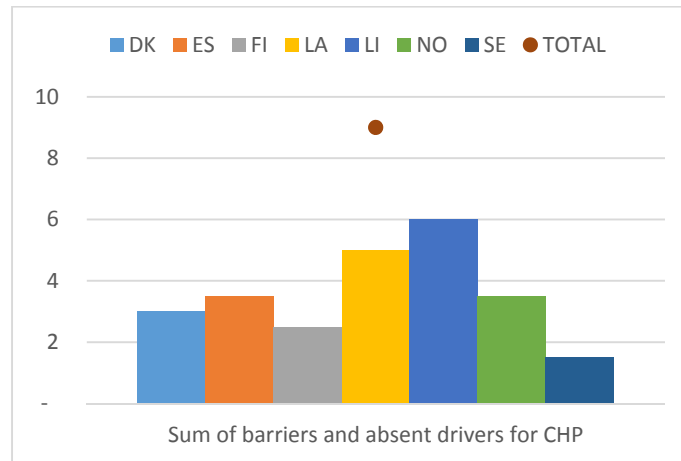


Figure 10 Distribution of barriers for flexibility in CHP operation. Total indicates the sum of all barriers for CHP, not counting the less relevant category Grid connection discounts.

6.1.2. Framework Conditions for Power-to-Heat Technologies

P2H has very limited deployment in all surveyed countries. Denmark, Finland, Norway and Sweden use heat pumps and electric boilers to varying, but generally to small extent, while the Baltic countries use almost no electricity for heat generation. In the latter case, it is likely to be explained by the electricity production, which is less characterised by low-cost renewable electricity than the Nordic countries.

All countries apply some sort of levy on the use of electricity for heating purposes. Tariffs on P2H for using electricity, decrease the comparative advantage against other heat producers. In the Nordic countries levies and taxes are reduced to a varying degree, while in the Baltic countries the electricity used for heat production is taxed and levied in the same way as any other electricity consumption.

As with tariffs, presence of reduced energy taxation improves the competitive power of P2H. This effect is particularly present in Denmark and Norway, and for Finland specifically for P2H combined with CHP. For Lithuania, the exception regarding heat pumps is valid if the heat pump has not received investment subsidy. In Sweden and Finland, P2H is exempt from taxes in CHP-plants, but not in HO-plants. This appears to be a regulatory artefact from the time when CHPs were positively discriminated to increase deployment, but can be a barrier for P2H on the longer term.

Regulatory priority is applied for waste-based heat in Denmark, where waste heat plants are present in the larger cities. This could limit the operational time of other production facilities, including heat pumps, resulting in a competitive advantage of waste. For Norway and Lithuania, the priority is linked to investment subsidy and reduced electricity tax for electricity produced by waste.

In Finland subsidies for heat pumps are limited to certain new types of heat pumps, and in Norway it is included as part of subsidy for a whole DH plant. In Latvia and Lithuania some degree of support for heat pumps can be obtained as part of the general RE-support schemes. Subsidy for electric boilers is almost absent, apart from Norway where electric boilers are subsidised under the same conditions as for heat pumps.

Lack of sufficiently low electricity prices is mentioned specifically for the Baltic countries as a disincentive for investment in P2H. For the Nordic countries, tariffs and electricity taxes appear to be the barrier.

Table 13: Framework conditions for P2H in the Nordic and Baltic countries.

Framework conditions for power to heat	DK	ES	FI	LA	LI	NO	SE
Absence of PSO on electricity (when used for heat generation)	Red	Red	Blue	Red	Red	Orange	Blue
Absence of grid tariffs on electricity (when used for heat generation)	Red	Red	Blue	White	Red	Orange	Blue
Absence of other levies or taxes on electricity (when used for heat generation)	Red	Red	Red	Blue	Blue	Orange	Red
Presence of reduced electricity tax on electric boilers	Blue	Red	Orange	Red	Red	Blue	Red
Presence of reduced electricity tax on heat pumps	Blue	Red	Orange	Red	Blue	Blue	Red
Absence of regulatory priority to heat from waste, RES, biomass or geothermal	Orange	Blue	Blue	Blue	Red	Red	Blue
Presence of subsidy for heat pumps	Red	Red	Orange	Orange	Blue	Orange	Red
Presence of subsidy for electric boilers	Red	Red	Red	Red	Red	Orange	Red

Mitigation of Barriers – Power-to-Heat

In the case of P2H, all framework conditions that provide barriers are related to regulation. Tariffs and levies should receive special regulatory attention in the Baltic countries and Denmark, and for all countries, dynamic tariffs could be a flexibility-improving option.

Similarly, it could be considered to introduce dynamic taxation, in case fiscal or other concerns are prohibiting a general reduction in electricity taxes.

Regulatory priority for non-flexible heat generators happens as a result of a priority for securing use of certain technologies. In order to address the issue of regulatory priority, it is hence necessary to consider the larger system context. For Denmark, this would be the interplay between waste and P2H, where heat storages might be able to mitigate the problem on the short term, and consideration on choice of heat supply on the longer term. For Norway and Lithuania, the short term solution might be heat storages as well. As with Denmark, changing conditions in the energy system on the longer

term, would make it relevant to consider whether the regulatory priority is still the socio-economically preferred option.

As indicated in the section on CHP, it might be most relevant to address tariffs and taxes before turning to subsidies. In the design of tariffs, taxation and subsidies, it should be considered that heat pumps and electric boilers operate in different places in the electricity-price spectrum: Electric boilers are usually operating during very low electricity prices, or if there are high gains from ancillary services, since other, cheaper heat production options will often be available. Heat pumps, on the contrary, will need to recover relatively large capital costs and are less sensitive to electricity prices than electric boilers due to higher efficiency per amount of electricity used. Hence, heat pumps are likely to operate as mid- to baseload, and will probably mainly contribute to flexibility by stopping production. Common for tariffs and taxes on both is that they should reflect real costs, including the need for flexibility.

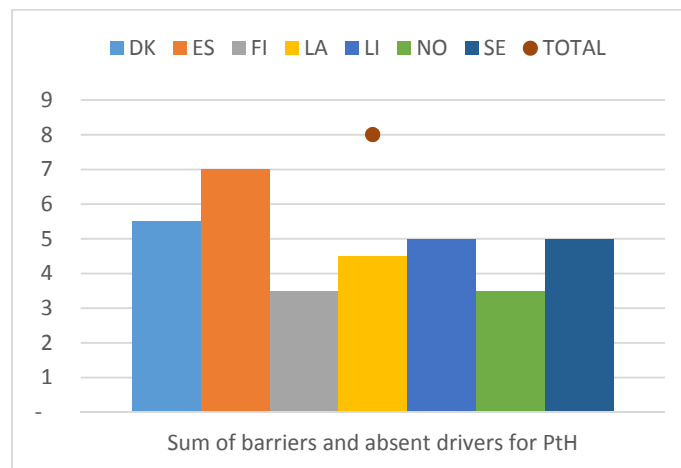


Figure 11 Distribution of barriers for flexibility in P2H operation, sorted by framework categories and political level. Total indicates the sum of all barriers for P2H.

6.1.3. Framework Conditions for General Resources

Heat generation following demand is present in the Baltic countries, Norway and to some degree in Sweden. In the case of Sweden and Norway, it can be explained with the ability of hydro power to supply the needed flexibility, while details on the Baltic countries has been covered in Section 6.1.1. The subject of heat generation following demand relates especially to the application of heat storages, since these can detach electricity consumption and production from the heat demand. Flexibility for CHP is often achieved by combining the plant with a heat storage (mostly a steel tank). Such storages are common in Denmark, Finland and Sweden but not so much in the three Baltic countries. Neither of the countries have restrictions on investing in storages nor are there special public policies (e.g. subsidies) to encourage their use. In Sweden, which has a very high amount of hydro power, this incentive is generally lower than in Denmark and Finland. In the three Baltic countries heat storages are considered to have a great potential, but are not widely deployed, partly due to CHP being operated as baseload. Heat storages are equally relevant in combination with P2H, since this also enables flexible production. The present barriers are mainly economic as there are no restrictions on this technology. In Latvia and Lithuania heat storages are encouraged by energy policy when they are included in new plants using renewable energy.

A much favoured piece of regulation for promotion of renewable energy is tax exemption for biomass. This is taking place in all countries, but Estonia, by different policy means. Such exemptions can have dubious effects on CHP and P2H, since it reduces the comparative advantage of these technologies towards HO boilers. The barriers here are both regulatory and technological, as small scale CHP using solid biomass is currently not an economically attractive alternative to other types of heat production. Traditionally, there has been plenty of biomass in all countries, which in many cases have provided an economically attractive fuel for DH production.

Subsidies and additional support for biomass-based boilers are generally not applied. The exceptions are Finland, where wood-based heat plants are supported, and Norway where biomass-based boilers are supported as part of general DH-plant subsidy. Furthermore, support can in some cases be provided in Latvia and Lithuania, as part of EU projects.

Price regulation is generally impacting flexibility in all countries. Price caps are present in Norway and the Baltic countries, but prices are generally monitored by regulators. Flat tariff structures are present in all countries. Profit caps are not directly impacting operational flexibility, but can reduce incentive for commercial operators of DH to make long term investments in flexible production units, due to potentially higher capital costs and payback times of flexible units, compared to e.g. HO boilers. Since the profit cap is only present in Denmark and Lithuania, which both have a significant share of public ownership in DH, the barrier might not be significant here.

Table 14: Additional framework conditions for DH in the Nordic and Baltic countries.

Framework conditions for general resources	DK	ES	FI	LA	LI	NO	SE
Absence of heat price regulation – price caps	Blue	Red	Blue	Red	Red	Red	Blue
Absence of heat price regulation – flat tariff structures	Red	Red	Red	Red	Red	Red	Red
Absence of heat price regulation – profit caps in commercially owned DH	Red	Red	Blue	Blue	Blue	Blue	Blue
Absence of operational practice of generation following demand	Blue	Red	Blue	Red	Red	Red	Orange
Absence of tax exemption for RES fuels	Red	Blue	Red	Red	Red	Red	Red
Absence of subsidies for HO boilers	Blue	Blue	Red	Orange	Orange	Orange	Blue

Mitigation of Barriers – Framework Conditions for General Resources

The framework condition *Absence of operational practice of generation following demand* is considered the most important, since it is the direct opposite of flexible operation. As described in the previous section, heat storage is a prerequisite for utilising the full flexibility of CHP and P2H. Secondly, CHP and P2H should be market-exposed, to allow them to operate flexibly, and should be a first, and often not significantly expensive, investment when moving towards flexible production. For the Baltic countries, security of supply is a concern and an argument for establishing the conditions for CHP that results in generation following demand. It is likely, that increased market

exposure, and thereby flexible operation, can make them subject to competition to a degree where they are economically unattractive. For CHP as well as P2H, transition to market-exposure can be somewhat similar to the Danish transition of CHPs from fixed tariffs to the power market in the mid-2000s. Here, electricity market revenue is supplemented with production independent subsidy. Additionally, it should for Sweden as well as the Baltic countries, be considered whether there is sufficient local awareness on the business opportunities for providing flexibility.

Access to relatively cheap biomass can make the business case for CHP and P2H. Taxation of biomass, or equivalently reduced taxation on energy for CHP and P2H can be an approach for a level playing field. It is a regulatory matter on the national level, and should be dealt with as part of a consideration on the priority for the future heat production. Biomass-based CHP is competitive in large scale plants, particularly due local access to relatively inexpensive fuel, tax exemptions and direct support. At the smaller scale, biomass-based CHP is not as competitive, when compared to biomass-based HO-boilers. A technical solution that can change this situation, can be more economic gasification technologies, which have been in development for many years. The dichotomy of inflexible use of locally available biomass against flexible heat supply (using and producing electricity across borders), will firstly require a socio-economic analysis of the two options, and secondly, if flexibility turns out to be attractive, be a trade-off between political concerns over security of (self-)supply and socio-economic gains of flexibility.

All surveyed countries are currently using a *flat tariff structure*, which should be dealt with locally by screening this against alternatives. Most likely, large heat storages are more business economically attractive and easier to implement. Thus, this framework condition is not considered a key barrier.

As illustrated in Figure 12, Latvia, Lithuania and Norway stands out, since they have the most barriers present (profit caps is the only barrier not present). It calls for a general regulatory overview, in case conditions for DH-based flexibility need to be improved. In the case of Norway, the abundance of highly flexible hydropower might displace most needs for flexibility from other sources in the near term. Increased interconnection or local transmission constraints could change this picture.

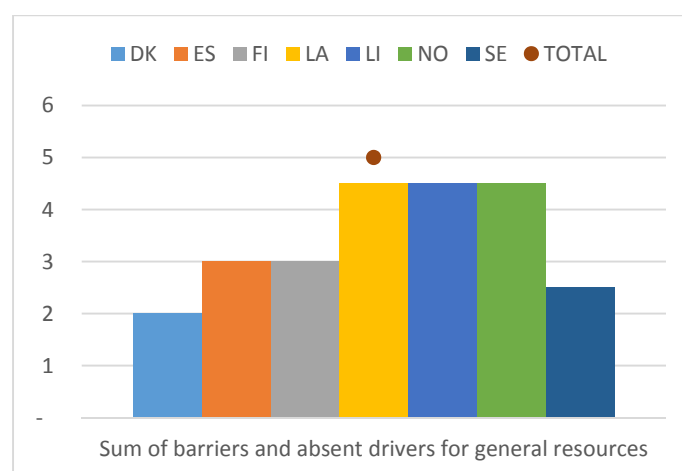


Figure 12 Distribution of other barriers for flexibility in DH, sorted by framework categories and political levels. Total indicates the sum of all barriers for general resources, not counting the framework condition *Absence of heat price regulation – profit caps in commercially owned DH*, since this pertains to investment only.

7. Conclusion

This study has been conducted with the purpose of addressing three elements:

1. Identifying framework conditions for flexibility in the DH-electricity interface
2. Determining the impact of these framework conditions in the Nordic and Baltic countries
3. Suggest solutions to address the barriers identified for the framework conditions in the countries

Based on the literature review and the survey, framework conditions for flexibility in the DH-electricity interface was identified. The regulatory impact of these framework conditions was identified in profiles for each of the Nordic and Baltic countries, followed by an analysis wherein solutions were proposed for the key barriers. The following concludes on this work.

None of the countries included in this study have policies designed to specifically increase flexibility, so today flexibility is mainly driven by the electricity markets. The framework conditions identified and analysed in this study, are therefore the result of policies with other aims. The typical regulatory aim is to reduce CO₂ emissions, increase energy efficiency or reduce the dependency of electricity as a heating source. Some of these framework conditions may even act as barriers for flexibility.

The technology mix and the regulations of DH vary between the studied countries, which makes the framework conditions for utilizing DH for providing flexibility to the electricity system a very complex phenomenon. Nonetheless, the literature study generally confirmed the benefits of coupling the DH-electricity interface to improve flexibility in the energy system.

CHP is the technology that today provides by far the largest contribution from DH to flexibility, particularly when heat storage (mostly a water tank) is added. This is the case for Denmark, Finland and Sweden but very little in the Baltic countries where DH is not providing much flexibility. CHP is less relevant for Norway today due to hydropower.

All countries support CHP, but in different ways that are not always beneficial for flexibility. In the Baltic countries, electricity produced by CHP is supported by feed-in tariffs. This stimulates incentives to invest in CHP and produce electricity, but does not stimulate flexible operation of such plants. Tax breaks for CHP, as Sweden, Denmark, Finland and partly Estonia are practicing, increases the competitiveness of CHP facilities without impeding the capability of operating flexible. Heat storages have a very large coverage in Denmark and are also common in Finland and Sweden. In the Baltic countries there are very few.

Heat storage capacities in DH systems are generally not supported, nor hindered by regulation or taxes. The feasibility of investments in heat storages within CHP plants and/or plants with installed electric boilers increases with fluctuating electricity prices.

Support for biomass (e.g. by tax exemptions) may hinder flexibility options as it is often more economically feasible to install HO boilers that are uncoupled to the electricity market. In Denmark this policy provides strong economic incentives for DH-utilities to supplement, and perhaps on a longer term, substitute gas-fired CHP with biomass-fired boilers. This tendency is to some extent also seen in Sweden.

Large central CHP power stations are under pressure, primarily from an increasing number of hours with low spot prices for electricity, which makes it uneconomic to continue operations and thereby

also to invest in new plants. In Denmark this tendency can to some extent be counteracted by substituting coal by tax-free biomass. In the Danish case, this kind of plant is flexible, as it has high ramping rates and the generation mix of heat and power can be changed. In Finland a ban on coal as fuel is being assessed. This may contrary to Denmark improve the system flexibility, because these Finnish plants are old and have low ramping rates. The outcome will, however, depend on the technology the plants are substituted with.

P2H technologies that are coupled to the electricity market by using electricity as an input for heat production have a large potential for providing flexibility. However, the deployment of P2H is very limited in the Nordic and Baltic countries today. The different P2H technologies cover different loads. Large heat pumps are most economic as base-load whereas electric boilers are better fitted for peak-load. The investment costs of large heat pumps for DH are high, but due to their high conversion efficiency they have low marginal generation cost when electricity prices are low. Electric boilers are attractive for following the electricity load, as costs are very low for adapting their output. Today these technologies are only of some importance in Norway, where DH is very limited, and to a lesser extent in Sweden. In Denmark they are much discussed but high electricity taxes make them uneconomic for utilities to invest in. These technologies cannot compete with HO biomass boilers under the present tax-regime.

Tariffs, taxes and levies on electricity used for DH production increase the marginal costs of P2H technologies and restrict the flexibility such technologies have to offer. All countries included in the study tax electricity but with large variations in magnitude.

Today flexibility is mainly provided by market incentives and very little by energy policy. This means that power market-exposure of P2H and CHP technologies is presently the best measure for flexible operation. Revenue from balancing markets in addition to the spot market can be a further incentive, but both the literature review and survey indicates that it in itself is not sufficient for providing sufficient incentive for investment. Partly due to electricity prices being too low for CHP and too high for P2H, and partly due to uncertain investment conditions such as revenue from green certificates. This means that regulation for increased market exposure should be conducted with the recognition that power markets alone are currently unlikely to provide the best business economic case for the DH company.

Flexibility should not be pursued for flexibility's sake, and this is not the purpose of this study. Rather, the purpose is to provide due diligence guidance on the regulatory bottlenecks which can limit the provision of flexibility. When energy policies are formed, it is thus advantageous to take the entire energy system into consideration (e.g. low-carbon AND flexibility), and not certain actors and effects isolated, in order to avoid adverse effects of policy measures.

8. References

- Blarke, M.B., 2012. Towards an intermittency-friendly energy system: Comparing electric boilers and heat pumps in distributed cogeneration. *Applied Energy*, 91(1), pp.349–365. Available at: <http://dx.doi.org/10.1016/j.apenergy.2011.09.038>.
- Blarke, M.B. & Lund, H., 2008. The effectiveness of storage and relocation options in renewable energy systems. *Renewable Energy*, 33(7), pp.1499–1507.
- Blumberga, D. et al., 2014. Evaluation of RES-E support policies in the Baltic States. , (May).
- Connolly, D., 2015. *Finding and Inputting Data into the EnergyPLAN Tool*, Aalborg.
- Difs, K., 2010. National energy policies: Obstructing the reduction of global CO2 emissions? An analysis of Swedish energy policies for the district heating sector. *Energy Policy*, 38(12), pp.7775–7782.
- Eesti Energia, Power Production - Eesti Energia. Available at: <https://www.energia.ee/en/polevkivist-elektri-tootmine> [Accessed June 13, 2016].
- EMD International, 2016. energyPRO. Available at: www.emd.dk/energypro/.
- Energistyrelsen, 2015. Energistatistik 2014.
- Euroheat, 2015. District Heating and Cooling Statistics 2015 - Country by country.
- Eurostat, 2016. Supply , transformation and consumption of electricity - annual data (nrg_105a).
- Frederiksen, S. & Werner, S., 2013. *District Heating and Cooling* 1st ed., Lund: Studentlitteratur.
- Gebremedhin, A. & De Oliveira Granheim, J., 2012. Is there a space for additional renewable energy in the Norwegian power system? Potential for reduced global emission? *Renewable and Sustainable Energy Reviews*, 16(3), pp.1611–1615.
- Grim, J. et al., 2015. Demand-Orientated Power Production from Biogas: Modeling and Simulations under Swedish Conditions. *Energy and Fuels*, 29(7), pp.4066–4075.
- Gustavsson, L. & Truong, N. Le, 2011. Coproduction of district heat and electricity or biomotor fuels. *Energy*, 36(10), pp.6263–6277.
- Hagos, D.A., Gebremedhin, A. & Zethraeus, B., 2014. Towards a flexible energy system – A case study for Inland Norway. *Applied Energy*, 130, pp.41–50.
- Hvelplund, F., 2006. Renewable energy and the need for local energy markets. *Energy*, 31(13), pp.1957–1966.
- IEA, 2014a. *Technology Roadmap : Solar Photovoltaic Energy*,
- IEA, 2014b. *The power of transformation*,
- Jacobsson, S., 2008. The emergence and troubled growth of a “biopower” innovation system in Sweden. *Energy Policy*, 36(4), pp.1491–1508.
- Johansson, P., Nylander, A. & Johnsson, F., 2006. Electricity dependency and CO2 emissions from heating in the Swedish building sector-Current trends in conflict with governmental policy? *Energy Policy*, 34(17), pp.3049–3064.
- Kempegowda, R.S., Skreiberg, Ø. & Tran, K.Q., 2012. Techno-economic evaluations of various

- biomass CHP technologies and policy measures under Norwegian conditions. *Energy Procedia*, 20(1876), pp.1–10.
- Keppo, I. & Savola, T., 2007. Economic appraisal of small biofuel fired CHP plants. *Energy Conversion and Management*, 48(4), pp.1212–1221.
- Kirkerud, J.G. et al., 2014. Modeling the Power Market Impacts of Different Scenarios for the Long Term Development of the Heat Sector. *Energy Procedia*, 58(1876), pp.145–151. Available at: <http://dx.doi.org/10.1016/j.egypro.2014.10.421>.
- Kirkerud, J.G., Trømborg, E. & Bolkesjø, T.F., 2016. Impacts of electricity grid tariffs on flexible use of electricity to heat generation. *Energy*, pp.1–9. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0360544216309367>.
- Kiviluoma, J. & Meibom, P., 2010. Influence of wind power, plug-in electric vehicles, and heat storages on power system investments. *Energy*, 35(3), pp.1244–1255.
- Klinge Jacobsen, H. & Zvingilaite, E., 2010. Reducing the market impact of large shares of intermittent energy in Denmark. *Energy Policy*, 38(7), pp.3403–3413.
- Lislebø, O., Havskjold, M. & Langseth, B., 2011. *Fleksibilitet i fremtidens kraftsystem: Kan varmemarkedet bidra?*,
- Lund, H. et al., 2012. From electricity smart grids to smart energy systems – A market operation based approach and understanding. *Energy*, 42(1), pp.96–102. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0360544212002836> [Accessed December 20, 2013].
- Lund, H., 2007. Renewable energy strategies for sustainable development. *Energy*, 32(6), pp.912–919.
- Lund, H. & Clark, W.W., 2002. Management of fluctuations in wind power and CHP comparing two possible Danish strategies. *Energy*, 27(5), pp.471–483.
- Lund, H. & Münster, E., 2003. Management of surplus electricity-production from a fluctuating renewable-energy source. *Applied Energy*, 76(1–3), pp.65–74.
- Lund, P.D. et al., 2015. Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renewable and Sustainable Energy Reviews*, 45, pp.785–807. Available at: <http://dx.doi.org/10.1016/j.rser.2015.01.057>.
- Magnusson, D., 2012. Swedish district heating-A system in stagnation: Current and future trends in the district heating sector. *Energy Policy*, 48, pp.449–459.
- Miskinis, V., Slihta, G. & Rudi, Y., 2006. Bio-energy in the Baltic States: Current policy and future development. *Energy Policy*, 34(18), pp.3953–3964.
- Møller, U., 2016. Personal correspondence with EnergiNorge.
- R.Kuhi-Thalfeldt & Valtin, J., 2009. Combined Heat and Power Plants Balancing Wind Power. *Oil Shale*, 26(3), pp.294–308.
- Rolfman, B., 2004. Combined heat-and-power plants and district heating in a deregulated electricity market. *Applied Energy*, 78(1), pp.37–52.
- Roos, I. et al., 2012. Greenhouse gas emission reduction perspectives in the Baltic States in frames of EU energy and climate policy. *Renewable and Sustainable Energy Reviews*, 16(4), pp.2133–

2146.

- Salomón, M. et al., 2011. Small-scale biomass CHP plants in Sweden and Finland. *Renewable and Sustainable Energy Reviews*, 15(9), pp.4451–4465.
- Schulz, K., Schacht, M. & Werners, B., 2013. Influence of Fluctuating Electricity Prices due to Renewable Energies on Heat Storage Investments. *Operations Research Proceedings*, pp.421–427.
- Skov, A. & Petersen, J., 2007. *Dansk fjernvarme i 50 år: 1957-2007*, Kolding, Denmark: Dansk Fjernvarme.
- Sorknæs, P., Lund, H. & Andersen, A.N., 2015. Future power market and sustainable energy solutions - The treatment of uncertainties in the daily operation of combined heat and power plants. *Applied Energy*, 144, pp.129–138.
- Sovacool, B.K., 2013. Energy policymaking in Denmark: Implications for global energy security and sustainability. *Energy Policy*, 61, pp.829–839.
- Statistics Norway, 2016a. District heating statics.
- Statistics Norway, 2016b. Fjernvarme - Tabeller - SSB. Available at: <http://www.ssb.no/energi-og-industri/statistikker/fjernvarme/aar/2015-10-02?fane=tabell&sort=nummer&tabell=241269> [Accessed May 24, 2016].
- Stupak, I. et al., 2007. Sustainable utilisation of forest biomass for energy-Possibilities and problems: Policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. *Biomass and Bioenergy*, 31(10), pp.666–684.
- Svensk Fjärrvärme, 2015. Tillförd energi till fjärrvärme och kraftvärme.
- Sørensen, P.A. et al., 2013. Udredning vedrørende varmelagrings teknologier og store varmepumper til brug i fjernvarmesystemet.
- The Danish Ministry of Taxation, 2005. *Lov nr 1417 af 21/12/2005 - Lov om ændring af forskellige miljø- og energilovgivning*, Copenhagen: The Danish Ministry of Taxation. Available at: <https://www.retsinformation.dk/Forms/R0710.aspx?id=17158&newwindow=true>.
- Zakeri, B., Rinne, S. & Syri, S., 2015. Wind integration into energy systems with a high share of nuclear power-what are the compromises? *Energies*, 8(4), pp.2493–2527.
- Østergaard, P.A., 2012. Comparing electricity , heat and biogas storages ' impacts on renewable energy integration. *Energy*, 37(1), pp.255–262. Available at: <http://dx.doi.org/10.1016/j.energy.2011.11.039>.
- Østergaard, P.A., 2010. Regulation strategies of cogeneration of heat and power (CHP) plants and electricity transit in Denmark. *Energy*, 35(5), pp.2194–2202.
- Åberg, M., Widén, J. & Henning, D., 2012. Sensitivity of district heating system operation to heat demand reductions and electricity price variations: A Swedish example. *Energy*, 41(1), pp.525–540.

Appendix

Literature on Flexibility Options

The focus of this study is, as mentioned, framework conditions affecting the terms for P2H, CHP and heat storage technologies. The purpose is not a full review of flexibility measures, as this has been provided by others already, e.g. Lund et al. (Lund et al. 2015). Instead, this section deals with a description of selected flexibility options identified from previous studies of the Nordic and Baltic countries.

Heat Pumps along with Flexible Cogeneration and Heat Storages

As indicated in the introduction, an increasing share of variable renewable energy supply increases the need for flexibility in the energy system. There is a great potential for additional power system flexibility in the production and use of heat, greater than for electric vehicles and electric storage options (Kiviluoma & Meibom 2010). Studies however show that the most effective flexibility option within the DH sector is a combination of several flexibility options, where distributed cogeneration with a thermal storage and an electricity to heat option seems to be the most efficient solution (Lund & Münster 2003). Blarke & Lund (2008) shows that a combination of CHP, heat pumps and cold storage is the most efficient flexibility option. Hvelplund (2006) suggests heat pumps along with flexible cogeneration a better option than increased transmission capacity in Denmark. Hagos et al. (2014) argues that heat pumps together with an increased bio share in heating, as a replacement for direct electric heating, is an economical feasible option to increase flexibility in the Norwegian energy system rather than increasing bio-heating deployment alone.

Finland and Sweden have a high share of nuclear power. Zakeri et al. (2015) shows that a high share of nuclear energy limits the integration of electricity from wind, and that there is a need for additional flexibility in such systems. He shows that large heat pumps in connection with a thermal storage, CHP and DH systems offer the highest efficiency in balancing excess power from VRE. However, P2H options offer a limited capability for absorbing excess power, as oversupply arises mainly in the periods with relatively low demand for heat. This calls for longer-term energy storage and/or other flexibility options to achieve a higher renewable share (Zakeri et al. 2015).

Storage Capacity

Energy can both be stored as electricity and as heat. Battery storages for electricity are very flexible, but are also the most expensive storage option. This advocates for less costly heat storages in the DH sector (Østergaard 2012). Schulz et al. (2013) shows that the benefits of heat storage investments increases with fluctuating electricity prices. Rolfsman (2004) argues that heat storages can contribute to maximizing the electricity generation of CHP plants during peak-price periods, and shows that the investment potential in heat storage tanks increases along with fluctuating electricity prices. Seasonal storages, however, requires sufficient space due to large volume; something which is not always available due to dense population or other geographic limitations. Spatial distribution can mitigate this problem.

Small Scale Operation

There is a decreased transmission need with scattered load balancing (with heat pump and storage) (Østergaard 2010). Lund et al. (2012) emphasizes the potential role of small, distributed CHP plants with storage and electric boilers for stabilization of the electric grid. R.Kuhi-Thalfeldt & Valtin (2009) also shows that it is possible to balance the wind power locally with small-scale cogeneration plants, and that small storages will improve the operation of CHP plants. They however conclude that the electricity price needs to increase to realize investments in such plants.

Power to Heat

DH producers can take advantage of low electricity prices and simultaneously relieve the electrical system by using electric boilers or heat pumps during periods low electricity prices due to large amount of wind or precipitation. Electricity to heat options however cover different loads. Kiviluoma & Meibom (2010) show that heat pumps are most cost efficient in base load scenarios, while electric boilers prove to be most cost efficient in variable power scenarios.



www.Flex4RES.org