ENER/FP7/609127/"READY"

Resource Efficient Cities Implementing Advanced Smart City Solutions - READY

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Scope of deliverable

This deliverable summarizes comprehensive strategies towards the development of smart sustainable districts for Aarhus (Denmark) and Växjö (Sweden) on the base of the activities and the results of the monitoring of the installations and buildings within READY. This deliverable reports on potential pathways to integrate the demonstration-projects into the ongoing city development planning process by valorising the envisioned strategies through a distinct set of performance indicators. This includes the transformation of strategies into performance indicators, establishing a baseline for a comprehensive evaluation, measuring demonstration activities against indicators, assessing the final impact, and investigating the replication and upscaling potential based on the impact assessment.

Context of deliverable

The report is based on the READY demonstration activities in Aarhus and Växjö.

Perspective of deliverable

The perspective of the deliverable is to present different scenarios to reach more sustainability and security in energy supply by using more Renewable Energy Sources (RES) and energy demand by increasing primary energy savings. This deliverable provides a supportive environment for policy makers by assessing the benefits of scaling up the envisioned measures developed under the READY project and provide a better understanding about their energy strategy development toward a sustainable development.

Involved partners

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Summary

This deliverable describes scenarios to integrate the demonstration-projects into the ongoing city development planning process on the base of the READY objectives for Aarhus (Denmark) and Växjö (Sweden). The READY objectives include energy efficiency gains of buildings and of the local district heating and cooling grids and the increase of the use renewable energy sources, for example PV, PVT and heat pumps. Moreover, the READY objectives include heat recovery systems, storages and the CO_2- neutrality of the district heating supply. In order to assess the overall impact of the achieved results relative to the baseline, environmental, energy, economic and national performance indicators are considered.

The conclusion of this deliverable is that READY objectives can be achieved in both cities. The different scenarios assessed for Aarhus and Växjö show that biomass has a big impact on the energy supply in the future and a transformation to a higher share in the energy mix of renewable energy sources is possible. Fossil fuel "Coal & Derived" can be completely substituted by renewable energy sources. Furthermore, CO_2- neutrality of the district heating supply in both cities by the substitution of fossil fuels mainly by biomass is possible. However, the district heating plants in Aarhus have the strategy in the future to continue using not bio-degradable waste, which is not CO_2-neutral. All the other fossil fuels of the district heating supply in Aarhus can be substituted by a large heat pump, which is already in Aarhus installed, and a higher share of biomass. In each sector (Residential, industry, service and transport sector) due to the implantation of energy measures the total energy demand will decrease in both cities in the future. The energy demand of the residential and the service sector in Aarhus and Växjö will be mainly covered by electricity and district heating. The share of E-vehicles in the transport sector are different in both cities. In the best-case scenario ("High scenario"), Växjö has a share of E-mobility of about 37% and Aarhus of about 27%. In addition, Växjö has the ambition to use more biofuel in the future to reduce gasoline consumption. In fact, in the High scenario, biofuel reach a share of 67% of the energy demand of the transport sector in this municipality.
Fuel switch in the energy supply of Aarhus and Växjö, generates a reduction of CO_2- emissions in all scenarios being lower than the current Status Quo (available data from 2018). In the High scenario of Aarhus, CO_2-emissions reduction in the service and residential sector are due the high share of electricity and district heating in the energy demand which is about 75% and 55% lower than the Status Quo. In Aarhus, total CO_2- emission- savings are in best case 38% compared to the Status Quo. In Växjö, in a similar way than in Aarhus a high CO_2- emissions reduction is possible in the service and residential sector. In the best-case scenario, the CO_2- emission-savings are lower in the residential sector about 95% and in the service sector 90% compared to the Status of quo. in parallel, switching fossil fuels to biofuel and electricity allows reductions, in the best case about 57% of CO_2- emissions in the transport sector. This gives that in total, Växjö can save 63% of the CO_2- emissions in best case. In an economical aspect, in all the scenarios of Aarhus and Växjö a lower "Energy per GDP" and "CO_2 per GDP" can be achieved compared to the Status Quo.

The most important **recommendations to local governments** are, that each city must adopt a strong governance towards energy efficiency and sustainability. Moreover, the inhabitants or rather the tenants should be convinced on the positive impacts of the installed technologies and of the retrofitting of buildings by the communication of their positive aspects (e.g.: higher living comfort). Low temperature district heating and waste heat utilization should be part of the energy supply and climate strategy by local authorities and should be integrated in urban development projects. In case of a higher share of E-mobility, it is important, that each city develops standards and promotes interoperability for drivers and charging network operators to achieve a market growth.

The **general recommendations** are to build well-insulated and robust buildings to minimize the need of energy consumption and to increase the economic feasibility of waste-water heat recovery systems. Moreover, in the transport sector it is important to convince drivers to switch from a fossil-fuel car to an electric vehicle and that the digital interfaces when charging an electric vehicle, must be intuitive. The most important general recommendation is to setup new collaborations between energy companies, consultants and government bodies including co-creating and design thinking involving end users and regulatory sand boxes.

Acknowledgment

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1 Introduction

The goal of this deliverable "**Report on the strategic development and possible policy measures related to Aarhus and Växjö and the assessment of the possible future impact of the demonstration projects**" is to outline a comprehensive strategy towards the development of smart sustainable districts for Aarhus and Växjö. It reports on potential pathways to integrate the demonstration-projects into the ongoing city development planning process by valorising the envisioned strategies through a distinct set of performance indicators. This includes the transformation of strategies into performance indicators, establishing a baseline for a comprehensive evaluation, measuring demonstration activities against indicators, assessing the final impact, and investigating the replication and upscaling potential based on the impact assessment. This is expected to provide a supportive environment for policy-makers by assisting them in understanding and assessing the benefits of envisioned measures and implementing them through strategic and coordinated actions toward sustainable development.

1.1 Method / Document Structure

The utilized method / structure of the document is as follows:

The current method applied in **READY** relates to unlocking the pathways and potentials for strategic integration of sustainable development principles directly into existing development urban planning processes. Besides the specific ways to carry out such modifications of the policy initiatives, the approach also reflects on the ways to allocate and adjust the financial resources towards the investments in the energy sector, more specifically, in frontline technologies and solutions for smart sustainable districts. In turn, this allows for unlocking the potential for replication and upscaling of such solutions on a European and global level. Maximizing these potentials further facilitates the development of specific business cases, especially based on innovative integration of new technologies and solutions demonstrated in READY study cases and related to energy efficiency and renewable energies.

In principle, the process of replication and upscaling of solutions in READY project leads to a large-scale **smart urban transformation** that **advances the resource-efficiency** of a city, **improve its functioning** and **increase the quality of urban life**. This will reduce dependence on energy imports and fossil fuels through integration of renewable energy, but also lead to reduction of related CO_2 emissions.

To reflect on the above-mentioned aspects, the document is structured as follows:

It starts with a reflection on the READY project objectives and the overall impact of the project results. It then looks at the status quo of the demonstrator areas to highlight the current challenges and future potentials. Following is the discussion of the overall strategy related to the Sustainable Energy Action Plan (SEAP). Finally, a summary of the document is offered.

2 READY Objectives

The following table lists the objective targets within READY for both demonstrator communities according to the DoW. The actual implemented systems with the actual installed capacities are monitored through the operation, which will be reported in in deliverable 7.3.

Table 1: READY Objectives

Main quantified objectives	Aarhus	Växjö
Energy efficiency gains of buildings	Savings on energy demand: DK1: 61,9% - 74 kWh/m²/y DK2: 59,8% - 78 kWh/m²/y DK3: 51,4% - 70 kWh/m²/y DK4: 51,5% - 94 kWh/m²/y	Savings on energy demand: SE1: 53% - 75 kWh/m²/y SE1.1: 53% - 75 kWh/m²/y SE2: 50,2% - 86 kWh/m²/y SE2.1: 50,2% - 86 kWh/m²/y SE3: 38% - 83 kWh/m²/y
Efficiency gains in local district heating and cooling grids	Approximately a reduction of 2-5% grid	Approximately a reduction to 12% grid loss
RES input (MW)	PVT_{heat}: 650 kW PVT_{elec}: 340 kW Heat pump: 1 MW	PVT_{heat}: 143 kW PVT_{elec}: 75 kW Cooling/heating plant: 100 kW
Waste heat recovery	Heat recovery in waste water: 0.043 GWh/y	Heat recovery in waste water: 3.6 GWh/y (industry and buildings)
Storage	Heat storage: 1 GWh Battery storage to de defined later	No additional heat storage, already 2.5 GWh
Local energy system	DH system: 100% CO_2 neutral DH supply by 2018	DH system CO_2 neutral by 2019

2.1 Overall Impact

In order to assess the overall impact of the achieved results relative to the baseline, the following list of performance indicators is considered:

- Environmental: CO_2 emissions
- Energy: Energy demand/m_2, energy production
- Economic indicators
- National indicators

Energy indicators, which are developed under D7.1., are used to assess both study cases. This Energy indicators are related to the energy production and consumption at city level. These indicators have been divided into three types due to its high number: **Global indicators**, which represent the aggregated values in terms of energy production and consumption, **heating and cooling indicators**, which are specific indicators for the heating and cooling demand and production, and **electric indicators**, which are specific indicators for the electricity demand and production. The **CO_2 emission indicators** quantify the emissions of the city. **Economic indicators** are focused on the relation between energy consumption and CO_2 emissions in terms of GDP. Finally, **national indicators** are the set of monitored indicators at national level to be used as a reference to compare the performing of the city level in terms of energy and CO_2 emissions.

2.2 Legislation

Heating and cooling accounts for around half of the energy consumed in the European Union (Heat Roadmap Europe). Despite significant and essential measures aimed at reducing demand – it is still expected to represent most of the demand in 2050. Delivering sustainable heating and cooling solutions to cover this demand is fundamental to achieve Europe's climate neutrality ambitions.

The EU produces more waste heat than the demand of its entire building stock as underlined in the landmark EU project Heat Roadmap Europe (www.heatroadmap.eu), as well as in the 2016 EU Heating and Cooling Strategy. Moreover, there is significant heat recovery potential from unconventional excess heat sources. Indeed, approximately 1.2 EJ (or 340 TWh) per year are possible to recover from data centres, metro stations, service sector buildings, and waste-water treatment plants, which corresponds to more than 10% of the EU's total energy demand for heat and hot water.

However, without adequate recovery solutions, including district heating, waste heat is released into the atmosphere and its potential lost.

Given the high stakes in play and the severity of the climate emergency, there is a clear and urgent need for a radical transformation of the energy system in the coming decades. The deployment of renewables and waste heat used in district heating networks is part of the solution.

Tapping into waste heat sources could displace a significant amount of primary energy demand for heating. It could form an essential component of a cost-effective energy transition to a smart integrated energy system, used alongside renewable energy solutions such as geothermal, large scale heat pumps, biomass or solar thermal in district heating networks.

The recovery of waste heat is not a new idea, especially in countries where district heating is well-developed. In Finland, industrial waste heat recovery represents 6% of the heat supplied in DH, while this share reaches 9% in Sweden. Concrete examples of projects all over Europe exist and show that this is a viable option. However, due to a multitude of barriers, waste heat recovery is far from reaching its full potential.

3 Status Quo Study Cases

This chapter provides an overview and status quo of the study cases. The status quo is used as reference to analyse the scenarios to assess the impact of the technologies and solutions developed under READY project.

3.1 READY Demonstrators

This chapter describes the current status of the demonstrators in the context of general description, existing reference national/local energy and other policies, city energy profile, emission sources.

3.2 Population Dynamics and Climate Change in Aarhus and Växjö

3.2.1 Aarhus, Denmark

Aarhus is the second-largest city in Denmark with a population of approximately 277,000 inhabitants. The city's vision is directed towards becoming a CO_2-neutral city by 2030. The details of this vision are provided in its climate strategy (Climate Plan 2016-2020).

Table 2 provides an overview of statistical data on population and daytime land surface temperature for the city of Aarhus, over a course of 20 years. The information is derived from different collections of remote sensing imagery (Terra MODIS products in case of land surface temperature, GPWv4 dataset in case of population count).

Table 2: Statistical information on population and land surface temperature for Aarhus, Denmark.

Years	Population count (number of persons)	Max Land Surface Temperature	Mean Land Surface Temperature	Min Land Surface Temperature
2000	212361.4	25.6	20.4	17.3
2005	223448.4	26.7	21.9	18.4
2010	236183.3	28.3	21.9	19.0
2015	250887.9	25.7	21.7	17.3
2019 / 2020	267991.0	27.5	23.1	19.7

The population number shows an increase of 26 % in 2020 (predicted), relative to the 2000 (Figure 2). The retrospective change of land surface temperature distribution reveals a warming trend over a course of 19 years (Figure 1). The maximal land surface temperature rose for around 2°C relative to the 2000. The minimal land surface temperature rose for around 2.5°C relative to the 2000. This points to the possible impeded cooling rate of the urban area. In 2019, a higher percentage of the city is affected by elevated land surface temperature, which might be connected with the observed population rise, especially noticeable in the city centre, and the resulting need for more living space in the city.

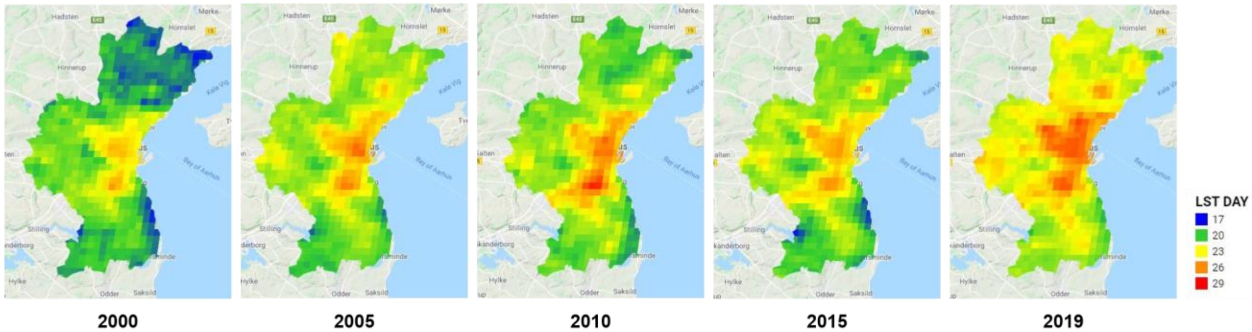

Figure 1: Spatial distribution of daytime land surface temperature for the city of Aarhus, Denmark (source: MODIS products: Terra Land Surface Temperature and Emissivity Daily Global 1 km).

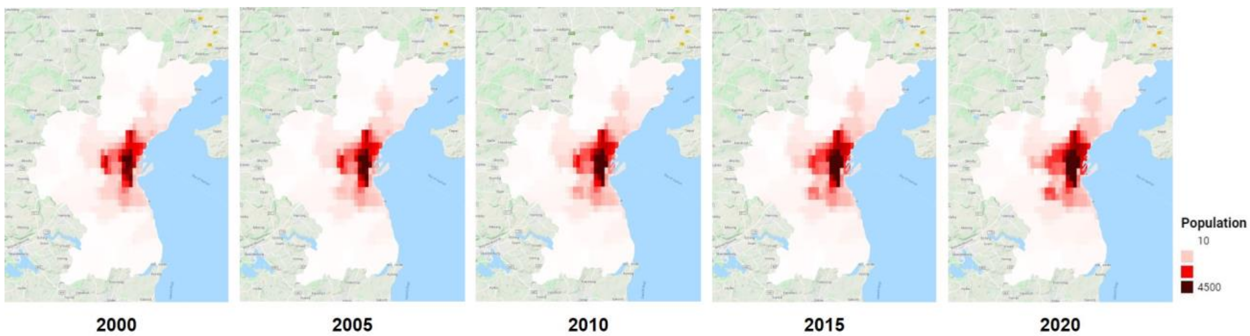

Figure 2: Population count of the city of Aarhus, Denmark (source: GPWv4: Gridded Population of the World Version 4, Population Count).

3.2.2 Växjö, Sweden

Växjö is a dynamic regional business and trading centre in the province of Småland in the south of Sweden with a population of approximately 92,000 inhabitants. The city is often described by the international media as "the Greenest City in Europe". The details of its environmental agenda are provided in the Environmental Program, with the main goal of becoming fossil free by 2030. A revised Energy Programme was adopted in 2016, pointing out concrete projects on how to reach the goals in the Environmental Programme.

Table 3 provides an overview of statistical data on population and daytime land surface temperature for the city of Växjö, over a course of 20 years. The information is derived from different collections of remote sensing imagery (Terra MODIS products in case of land surface temperature, GPWv4 dataset in case of population count).

Table 3: Statistical information on population and land surface temperature for Växjö, Sweden.

Years	Population count (number of persons)	Max Land Surface Temperature	Mean Land Surface Temperature	Min Land Surface Temperature
2000	73,901	25.6	20.5	17.3
2005	77,363	26.7	21.9	18.4
2010	83,005	28.3	21.9	19.0
2015	88,108	25.8	21.7	17.3
2019 / 2020	94,129	27.5	23.1	19.7

The population number shows an increase of 32% in 2020 (predicted), relative to the 2000 (Figure 4). As in the case of Aarhus, the retrospective change of land surface temperature distribution reveals a warming trend over a course of 19 years (Figure 3). The maximal land surface temperature rose for around 2 °C relative to the 2000. The minimal land surface temperature rose for around 2.5 °C relative to the 2000. This points to the possible impeded cooling rate of the urban area. However, in contrast to Aarhus, even with the observed population rise the percentage of the city affected by elevated land surface temperature seems to be the same as observed in 2000.

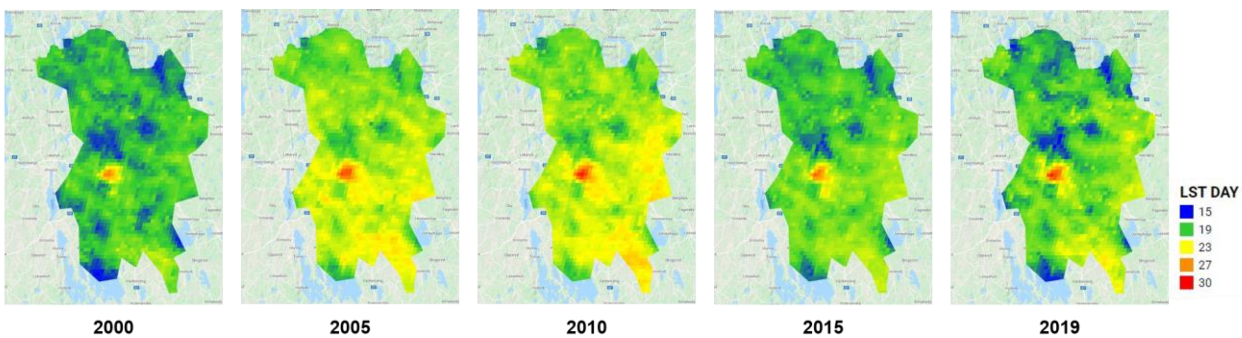

Figure 3: Spatial distribution of land surface temperature for the city of Växjö, Sweden (source: MODIS products: Terra Land Surface Temperature and Emissivity Daily Global 1km).

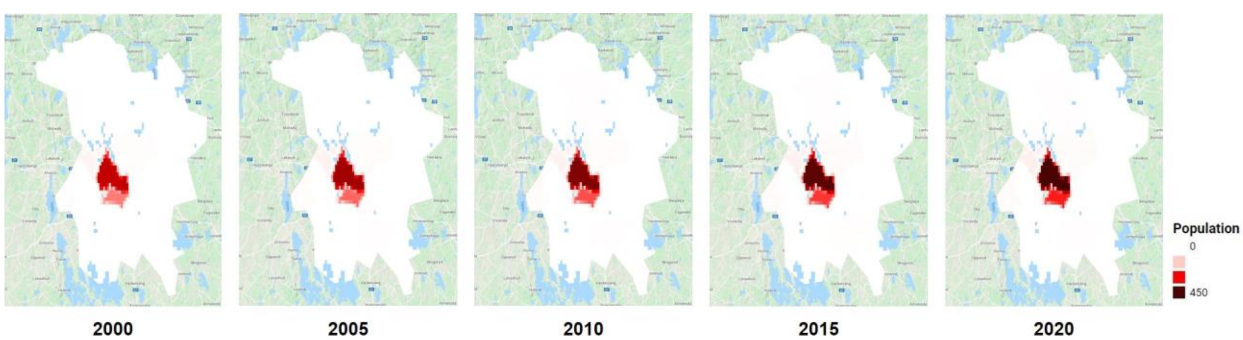

Figure 4: Population count of the city of Växjö, Sweden (source: GPWv4: Gridded Population of the World Version 4, Population Count).

3.3 Country description

3.3.1 Denmark- National Energy and Climate Plan [1]

In Denmark, the government promotes a sustainable policy with high ambitions concerning the climate, environment and nature and ensures that Denmark is following the Paris Agreement. In order to reach those targets, the Danish government made the "National Energy and Climate Plan", what includes a **climate policy** with a legally binding target **to reduce greenhouse gases by 70% by 2030** (relative to 1990 level), to reach **net zero emissions by 2050** at the latest, and **to limit Denmark's non-ETS greenhouse gas emissions in 2030** at least by **39%** (relative to 2005 level). When the effects of the implemented and adopted policies and measures are considered, the greenhouse gases emissions in 2030 will be 46 % below 1990. This implemented and adopted policies and measures are based on the RE- (renewable energy) and EE- (energy efficiency) policies. Furthermore, a range of initiatives will be implemented which will strengthen the effort for a better environment, create more nature and which is expected to reduce greenhouse gas emissions by approximately 0.5 million-ton CO_2- equivalents in the year 2030. Further policies and measures are in Denmark in a planning process.

Another point in the climate policy of Denmark is the **transition of the transport sector**, where a share of renewable energy of 19% is expected. As part of a green mobility plan, initiatives and measures are required to ensure an increase of the number of electric vehicles in the transport sector. One of the measures are a stop to sales of all new diesel and petrol cars and enhanced low emissions zones. Moreover, a Commission for Green Transition of passenger cars provide recommendations for policies and measures to ensure the green transition of the transport sector. All in all, more investments in the public transportation and cycling will be required. Furthermore, another point in the climate policy is to ensure, that the emissions do not exceed removals as accounted in the **LULUCF[2] (Land Use, Land Use Change and Forestry) sector**.

Moreover, the Danish **energy policy** focus on renewable energy, energy efficiency improvements, research, development and energy regulation. The government of Denmark has set the ambitious goal to cover **55% of the gross final consumption in 2030 with renewable energy**. This goal will also lead to a **RE** (renewable energy) **share in electricity above 100 % of consumption**, while ensuring that at least **90% of district heating consumption** is based on **energy sources except coal, oil or gas, by 2030**. Moreover, another objective is, that **in 2030** at least **80%** of the heating in the **district heating sector** will be based on **renewable energy**. For the **heating and cooling sector, the** share of **renewable energy** is expected to reach **60% in 2030.** To reach these goals, many key policies and measures are implemented. These are technology neutral RE (renewable energy) tenders, three new offshore wind farms of at least 800 MW each and the reduction of the electrical heating and the electricity tax. Furthermore, other measures are that geothermal energy should support the energy system and that the heating system should be analysed in course of modernisation.

[1] https://ec.europa.eu/energy/sites/ener/files/documents/dk_final_necp_main_en.pdf

[2] LULUCF, 2018/841 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0841&from=EN

Another key objective of the energy policy is to **phase out coal in electricity production until 2030**. The policies and measures to realise this objective are incentives for producing electricity and heat with other technologies and fuels than in coal fired power plants. Moreover, other measures are a good interconnection to neighbouring countries and market conditions (higher CO_2 price in the ETS System) and the deployment of large-scale wind power.

Furthermore, the government in Denmark also confirmed, that the **energy efficiency policy** in Denmark should be prioritised. Denmark has developed a great expertise in energy efficiency, which has made it possible to keep energy consumption largely unchanged in spite of significant economic growth over the last four decades. By a continuing economic growth, the Danish primary energy consumption is expected to increase in the period 2021-2030 by 1 Mtoe (=11.63 TWh). Moreover, the increase of the final energy consumption is expected in the period 2021-2030 by 0.5 Mtoe (=5.82 TWh). To reach these goals until 2030, Denmark plans some initiatives and measures to reduce its energy consumption and fulfil its energy saving obligation. One of these measures is a **subsidy scheme from 2021-2024** targeting private enterprises and buildings, where the **energy-saving potential** is estimated with **1.2 Mtoe** (=13.96 TWh). This measure is supported by other measures related to energy efficiency and renovation of public and private buildings. The **energy- saving potential** of this measure is estimated with **0.66 MToe** (=7.68 TWh). In the period 2021- 2024 the subsidy for private enterprises will be amounted to 300 million DKK per year and for buildings 200 million DKK per year. Furthermore, efficiency of existing buildings by other measures is increased through the requirements to the renovation of buildings. Another point of the subsidy scheme is to replace oil burners with heat pumps in buildings outside the district heating and gas grids. The subsidy will be amounted to 20 million DKK per year in 2021-2024.

3.3.2 Denmark- Construction sector[3]

The construction sector of Denmark has been experiencing a growth since 2010, in line with the overall improvement of the general economy. In the period of 2010- 2016, the number of companies in this sector increased by 10.9%. Moreover, in **2016** the **production in the construction of buildings grew by 17.2%** compared to the 2010 level (Figure 5).

[3]European Commission, June 2018, ECSO (European Construction Sector Observatory)- Country profile Denmark

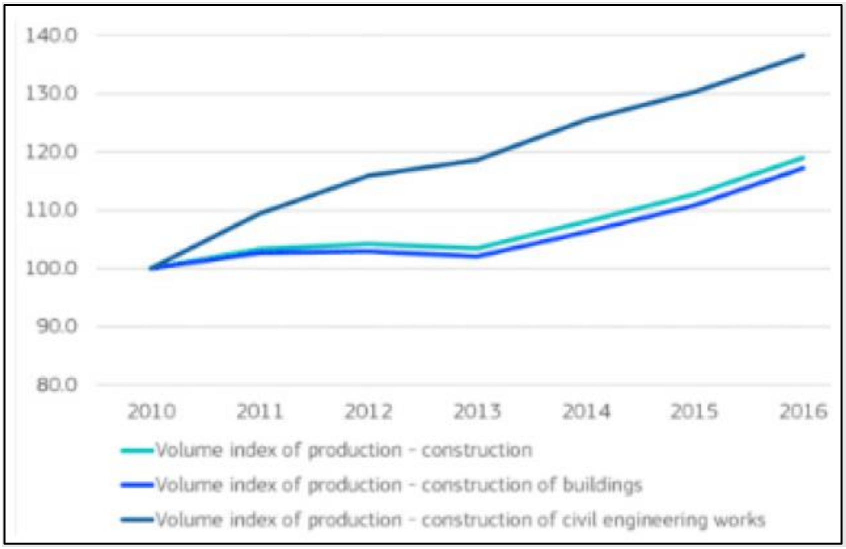

Figure 5: Volume index of production in the Danish construction sector over 2010-2016 (2010=100)[3]

In Figure 5 is illustrated, that the production in construction (total) and in the construction of buildings was between 2010 and 2013 nearly on the same level and increased since 2013 steadily. The production in construction of civil engineering works increased in the period 2010-2016 steadily, even there was the smallest increase in the year 2012. All in all, in 2016 the **production in the construction of civil engineering works grew by 36.6%** compared to the 2010 level

There are many **barriers in the construction sector**, for example money (credit, payment,) the building permits and licenses and the sector and sub-sector specific issues (Material efficiency, waste management, climate and energy policy,…). In general, **Denmark maintains a credit- friendly approach.** Because in 2016, on average **62.1% of domestic B2B sales** were transacted on **credit**, which is much higher than the whole Western Europe, who transacted only 42.6% of the domestic B2B sales on credit.

Other barriers in the construction sector are **the time and costs of obtaining building permits and licenses**. In Denmark, 7 administrative procedures and 64 days are needed to complete the administrative formalities to build a warehouse. This is shorter than the OECD-high-income-average, because they require 12.1 procedures and 152.1 days. The average cost of the warehouse value is with 1.8% a little bit higher than the OECD high-income average of 1.6%. In 2015, the Danish government decided to reduce the administrative burden and speed up the processing of applications for building permits. For a simple building, a maximum period of 40 days is granted to assess an application, while for complex buildings the authorities have 50-60 days to review an application.

Furthermore, **waste management is a further barrier in the construction sector** of Denmark. In 2013, over 2.89 million tonnes of construction and demolition (C&D) waste were generated in Denmark. That is an increase of 7.4% compared to the year 2012. Denmark has an overall recycling rate of 87%, which is the result of many measures and policies, including a weight-based landfill tax and the possibility of recycling C&D waste without a specific permit provided that the waste is sorted, unpolluted and processed. In addition, the government supports a host of initiatives to prevent waste in construction, notably the tightening of requirements for demolition of buildings. Moreover, since 1997 combustible waste must be incinerated in Denmark.

Another **barrier in the construction sector** are the emissions of the greenhouse gases (carbon monoxide and dioxide, methane,..) from activities in the construction and real estate sub-sectors. In the year 2014 the emissions of the construction sub-sector amounted to 1,712,432 tonnes and of the real estate sub-sector to 114,731 tonnes. The **Danish construction industry plays a major role** belonging to energy, as it is estimated that the Danish building stock is accountable for **40% of total energy consumption**.

The Danish policy strategy for the building sector "**Towards a stronger construction sector in Denmark**" aims to strengthen growth and increase productivity and employment in the building sector. The policy strategy seeks, inter alia, to improve the competitiveness of the construction sector, simplify building rules, streamline the technical aspects of construction permit applications and increase their effectiveness. The strategy also focuses on the sustainability of the construction sector, with the aim of reducing its greenhouse gas emissions, mitigating its overall environmental impact and ensuring its resource efficiency. Another key instrument of housing policy is the **National Building Fund**, which aims to support and develop public housing through various grant and loan schemes.

The main **Danish regulation and legislation in the construction sector are detailed in the Building Regulations 2015 (BR15)**. The BR15 dictate the rules for the construction of private and commercial buildings and provide the legally binding requirements (regarding e.g. building interiors, fire behaviour, energy consumption, installations,…) and guidelines to such requirements. The Building Act together with voluntary agreements shape construction activities. The Building Act sets the framework ensuring that buildings are designed and constructed in such a way that they provide health and safety standards and security against fire. The amendments to the Building Act describe a general requirement for the installation of heating based renewable energy in buildings.

The **outlook** for the construction sector of Denmark is positive, with a growth of 3.5% in 2017, 3.2% in 2018, 3.5% in 2019 and 2.4% in 2020. Despite the planned public investments in transport infrastructure in height of 13.5 billion € and a lot of planned large-scale infrastructure projects, more investments on construction and operation of roads is to be expected over the coming years. In the longer term, the generally positive outlook for the sector can be ascribed to the growing urbanisation and the implying additional construction. The dwellings will be needed, especially in the larger cities. In this context, improving transport but also digital infrastructure will be one of the key objectives in the construction sector.

3.3.3 Sweden- National Energy and Climate Plan [4]

The Swedish energy and climate policy are compatible with the ambitions of the EU and aims to combine ecological sustainability, competitiveness and security of supply. The energy policy must therefore create the conditions for effective and sustainable energy use and a cost-effective energy supply in Sweden, while minimising the damage to health, the environment and climate and facilitating the transition to a

[4] https://ec.europa.eu/energy/sites/ener/files/documents/se_final_necp_main_en.pdf

sustainable society. Sweden has the ambitious **aim to cut its net greenhouse gas emissions to zero by 2045** and **reduce the emissions from activities on Swedish territory to 15%** compared to the 1990 levels.

To reach this aim, the Swedish government implemented many other important objectives and milestones. For the EU-ETS sector, Sweden has the objective to **reduce its emissions to 20%** of their 2005 levels by **2030**. At the end of the year **2020**, **a reduction of 40% (base year 1990) in emissions from sectors outside the EU ETS** (Emission Trading System) should be reached entirely with **national measures**. A maximum of 13% can be achieved from additional measures. In **2030**, this target should be developed by a **reduction of 63% in emissions from sectors outside the EU ETS** compared to the 1990 level, where a maximum of 8% can come from additional measures. In **2040**, a **reduction of 75% (base year 1990) in emissions from sectors outside the EU ETS** should be reached, where a maximum of 2% can be achieved from additional measures. The additional measures include net removal by forests and land, verified emission reductions through investments in other countries and capture and storage of biogenic carbon dioxide (bio-CCS). Another target of the Swedish climate policy is to reduce **70% of the emissions** (base year 2010) in the **transport sector**, excluding national flights, **until 2030**.

The Swedish energy policy focus on the target, that **50% of the final energy consumption** should be covered by **renewable energy sources** at the end of the year 2020.

Another objectives are that in the year **2040**, **100% of the electricity generation** should be based on **renewable energy sources** and that in the year **2030**, an **improvement in energy efficiency of 50%** (base year 2005) should be achieved.

To achieve these objectives, many **policy areas and measures for renewable energy, energy efficiency and the reduction of greenhouse gas emissions** were in Sweden implemented. These key measures affect all the sectors of Sweden.

One of the important **climates and energy policies and measures** is the **Energy tax and Carbon tax**. The Swedish energy taxation system combines a carbon tax with a fuel tax and an electricity tax. The carbon tax was introduced in Sweden in 1991 to reduce carbon dioxide emissions and is based on the fossil content of fuel. In 2019 the carbon tax is 4.7- times higher compared to the 1990 level. The carbon and energy tax are not deducted on biofuels, but concerns fossil fuels like petrol and diesel. To take account of inflation and economic developments, energy and carbon taxes on fuel are also adjusted to reflect changes in the Consumer Prices Index (CPI) and Gross Domestic Product (GDP).

Furthermore, another important **measure in the energy policy** is the **electricity certificates system**. The aim of the electricity certificates system is to stimulate the growth of renewable electricity. Sweden has committed to generate 15.6 TWh electricity by renewable energy sources by the end of 2020. The Swedish government decided to extend the electricity certificate system until 2045 and to increase it by 18 TWh by 2030.

Moreover, to achieve the ambitious target to reduce 70% of the emissions in the **transport sector** in the period 2010-2030, many measures and policies are in Sweden in use. One of the important measures and policies is the "**Reduction obligation- switching fuels"**. This obligation was made to reduce petrol and diesel consumption and was introduced to promote the use of biofuels. All fuel suppliers must therefore reduce the greenhouse gas emissions of petrol and diesel over their entire lifecycle by a certain percentage every year by gradually increasing the amount of added biofuel. In the beginning of the year 2020, in course of this obligation 21% of Diesel and 4.2% of Petrol was reduced. This reduction obligation makes an important contribution to phasing out fossil fuels in transport and should be continued until 2030.

The **energy efficiency** is also a very important topic to reach Sweden's ambitious goals, especially the improvement in energy efficiency of 50% until 2030. This can be achieved by for example a long-term rennovation strategy to support the renovation of the national stock of residential and non-residential buildings. One requirement sets limits for primary energy consumption in buildings and is expressed as kWh per square metre per year. This requirement covers energy for heating, comfort cooling, domestic hot water and domestic energy and is given for normal use of the building. The primary energy requirement is currently 90 kWh/m^2 for buildings with one- or two-dwellings, 85 kWh/m^2 for multi-dwelling buildings and 80 kWh/m^2 for non-residential buildings.

3.3.4 Sweden- Construction sector[5]

The construction sector of Sweden has been experiencing a strong growth in the recent years. In the period of 2010- 2016, the number of companies in this sector increased by 21.4%. Moreover, in **2016** the **production in the construction of buildings grew by 192 %** and t**he construction in total increased by 16.3%** compared to the 2010 level (Figure 6).

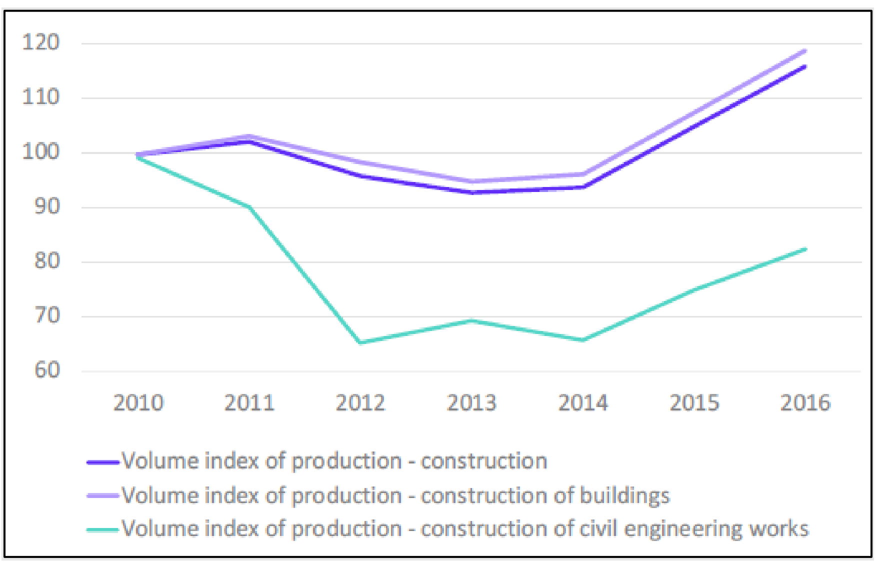

Figure 6: Volume index of production in the Swedish construction sector over 2010-2016 (2010=100)[5]

In Figure 6 is illustrated, that the production in construction (total) and in the construction of buildings was in decline between 2011 and 2013 but increased since 2014 again. The production in construction of civil engineering works decreased from 2010 to 2012 about 35%. Since 2014, the production in

[5]European Commission, June 2018, ECSO (European Construction Sector Observatory)- Country profile Sweden

construction of civil engineering works increased steadily but was **in the year 2016, 17.5% below the 2010 level**. Low interest rates and the easy access to mortgages coupled with population growth and immigration are leading to a higher demand for residential properties. In the period 2010-2016 the number of households increased about 8.2% and reached 4.8 million in 2016. In Sweden, there is an undersupply of dwellings and so it is requiring **600,000 new homes by 2025** compared to the 2017 level.

There are many **barriers in the construction sector**, for example money (credit, payment,) the building permits and licenses and the sector and sub-sector specific issues (Material efficiency, waste management, climate and energy policy,…). In general, **Sweden maintains a credit- friendly approach**, because in 2016, on average **52.1% of the sales to domestic B2B customers** were transacted on **credit**, while the share of sales **on credit to foreign B2B customers was 43.5%.** The whole Western Europe were transacted only 42.6% of the sales to domestic B2B customers and 35.1% of the sales to foreign customers on credit. **Other barriers** in the construction sector are **the time and costs of obtaining building permits and licenses**. In Sweden, 7 procedures and 116 days are needed to complete the administrative formalities to build a warehouse. This is shorter than the OECD-high-income-average, because they require 12.1 procedures and 152.1 days.

Furthermore, **waste management is a further barrier in the construction** sector of Sweden. In 2014, the Swedish construction sector generate **8.9 million tonnes of construction and demolition waste**, which is a share of **95%** of the whole Swedish construction and demolition waste. This kind of waste in Sweden is divided in hazardous (800,000 tonnes- 9%) and non- hazardous waste (8.6 million tonnes- 91%).). In Sweden, the waste treatment of the construction and demolition waste is different. The waste is mainly used as construction materials, refills and landfill coverage (4.2 million tonnes) and as landfill material (2.4 million tonnes). 1.2 million tonnes of the waste were dumped at sea and about a million tonnes went to pre-treatment / sorting. The Swedish waste management plan for 2012-2017 published the need for improved construction and demolition (C&D) waste management and the need of recycling. The Swedish Construction Federation updated in the following, guidelines to improve the management of resources and C&D waste during construction and demolition activities.

Another important fact of the construction sector is the **National & Regional Policy & Regulatory Framework**. The Swedish government introduced policy schemes, which aimed at addressing the structural undersupply of dwellings and the long-standing barriers to the efficient functioning of the housing market in Sweden. Moreover, in **2016** the Swedish government **introduced 22 measures to increase housing construction**. One of the measures foresees the sale of public land for residential construction. Furthermore, in **2017** the Swedish government presented a proposal aimed at further streamlining and simplifying the Planning and Building act and introduced a **state subsidy to municipalities** to increase housing construction in view of the increasing population and housing demand.

The main **regulations and legislation in the construction sector are detailed in the Boverket's Building Regulations (BBR)**. These cover mandatory requirements for accessibility, dwelling design, ceiling height and utility rooms, as well as general rules for buildings, mechanical resistance and stability, fire safety, hygiene, health and environment, noise protection and energy performance. The BBR set mandatory performance requirements for residential and non-residential buildings and cover requirements related to the thermal transmittance of the building envelope and encourage efficient design of the energy consuming systems including HVAC (heating, ventilation, air conditioning), hot water, lighting, auxiliary systems, as well as materials and products. After the construction of the buildings, the compliance with the requirements is verified through measuring the actual energy use and showing it to be less than or equal to the allowable energy frame predicted at the design stage. The building's energy consumption should be measured **over a continuous period of 12 months**, to be completed within 24 months after the building is put in use. Through these measurements, any gap between the designed and as-built performance of the building can be identified and corrected. The design regulations (BKR) cover areas such as load bearing structures, geo-structures, timber, masonry, concrete, steel, aluminium structures and fire resistance requirements.

The **outlook** for the construction sector is positive, with **3.9% annually for 2018-2022 and 2.6% over 2023-2027**. In the period **2018-2029**, the Swedish government wants to invest **65.8 billion € in infrastructure, improvement of mobility and in new residential buildings**. Schemes to support the energy efficiency and renovation of the housing stock are also available, including a 30% tax deduction (ROT) and an 82.2 million € programme for the energy efficient renovation of rental housing in socio-economically disadvantaged areas.

4 Status-Quo

4.1 Aarhus, Denmark

In the first quarter of 2018 the inhabitants of the municipality of Aarhus are counted with 340,312[6]. In **2018** the municipality of Aarhus accounts a total energy demand for electricity, heating and transportation of 4,846 GWh which represents around 14.2 MWh/Inh. 63% less compare to the EU gross energy demand per capita (38.7 MWh/Inh[7]) and a 62% less than in the Danish gross energy demand per capita (37.8 MWh/Ihn[7]). The energy supply of Aarhus, which includes also all the losses in energy conversion and distribution, is in total about 7,973 GWh. Of this, 51.0% comes from renewable sources.

In **2018,** 75% of the total energy consumption was produced locally and 46% come from renewable sources. Around 1,854 GWh of fossil fuels and 2,225 GWh of renewable fuels, mainly biomass with 2,216 GWh, are using to cover electricity and heat demand and the fossil fuels comes from the transport and industrial sector. From the economic point of view, the municipality of Aarhus an energy supply (primary energy demand) per GDP of 3,113 MWh/M€. At sector level, the residential sector accounted 2,153 GWh where electricity demand was around 18% and the remaining part was heat demand. For the Public & Service sector the energy demand was 1,363 GWh where the electricity demand was 47% of the total demand and the remaining part was heat demand. In the industrial sector the energy demand was 564 GWh where electricity and oil represent the 37% and 20% of the total demand. Additionally, 20% of this demand is covered by the district heating and the remaining part by biomass (includes biodegradable waste). Finally, the transport sectors accounts 767 GWh of the total energy demand where 40% is covered by diesel and the remaining part by fuel jet (32%), gasoline (24%), biofuel (3%) and electricity (1%).

In **2018**, the heating demand of the municipality of Aarhus is around 2,841 GWh which represents around 8.3 MWh/Inh. The 85% of this demand is covered by district heating and 8% comes from renewable sources. By sectors, the residential sector accounts 1,759 GWh of the heat demand with 720 MWh/HDD. Additionally, 89% of this demand is covered by the district heating. The total heat demand for the public & Service sector is 726 GWh with 297 MWh/HDD, where the district heating covers completely (100%) the heat demand. In the industrial sector the heat demand is 352 GWh where 32% is covered by district heating. The rest of the heat demand can be categorized in the transport sector with 3 GWh.

In the district heating fuel mix of the municipality of Aarhus the three main sources are biomass (includes biodegradable waste), not biodegradable waste and coal. Biomass is the main one, generating 83% of the heat production, followed by not biodegradable waste with 11% and coal with 5%. The remaining part is covered by fuel oil (1%).

In **2018**, the electricity demand of Aarhus is around 1,250 GWh which represents around 3.7 MWh/Inh. The public & service sector is the biggest consumer with 51% of the total electricity demand, followed by

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[6]https://ledelsesinformation.aarhuskommune.dk/aarhus-i-tal/default.aspx?doc=vfs://Global/Befolkning-antal.xview)

[7] Eurostat (Simplified energy balances); Eurostat (population)

the residential sector with 31%, the industrial sector with 17% and the transport sector with 1%. The local electricity production accounts 1,018 GWh which represents an electricity production of 3.0 MWh/Inh. The local electricity production from renewables is 832 GWh, which represents 82% of the local production and 2.4 MWh/Inh. Biomass with 95% is the main renewable source followed by wind with 2% and PV with 3%.

In **2018**, the municipality of Aarhus accounts 1,239,707 ton of CO_2 emissions due to the energy consumption from electricity, heating and transportation. This represents an average of 3.6 ton/Inh and a CO_2 emissions intensity of 255.8 ton/GWh. 49% less compare to EU CO_2 emissions per capita (7.0 ton/Inh[8]) and a 45% less than in the Danish CO_2 emissions per capita (6.5 ton /Inh[8]). From the economic point of view, the municipality of Aarhus has CO_2 emissions per GDP of 484 ton/M€. At sector level the transport sector has the highest CO_2 emissions with 56% of the total, followed by the residential and public & commercial sectors with respectively the 19% and 17% of the total. The remaining 8% is allocated to the industrial sector.

The CO_2 emissions from the electricity demand are 268,987 ton. This represents a CO_2 emission per capita for the electricity consumption of 0.79 ton/Inh with a CO_2 emissions intensity of 215.2 ton/GWh. The Public & Service sector accounts 51% of the total electric CO_2 emissions followed by the residential sector with 31% of the total and the industrial sector with 17%. The remaining part (1%) is due to the electric consumption from within the transport sector.

The CO_2 emissions to cover the heat demand are 274,419 ton which represents 0.81 ton/Ihn and heating CO_2 emission intensity of 96.6 ton/GWh. District heating covers 82% of the CO_2 emissions of the heat demand having a total CO_2 emission of 225,566 ton and making that CO_2 emissions intensity for the district heating of 93.7 ton/GWh. At sector level, the residential sector is the main source with 57% of the total CO_2 emissions with CO_2 emissions per heating degree day of 63.9 ton/HDD. The Public & Service sector accounts 25% of the total CO_2 emissions with 27.8 ton/HDD. The industrial sector accounts 18% of the total CO_2 emissions for heating.

4.2 Växjö, Sweden

In **2018**, the inhabitants of the municipality of Växjö are counted with 92,567. In **2018**, Växjö accounts total energy demand for electricity, heating and transportation of 2,200 GWh which represents around 23.8 MWh/Inh. 39% less compare to the EU gross energy demand per capita (38.7 MWh/Inh[9]) and 60% less than in the Swedish gross energy demand per capita (59.8 MWh/Inh[9]). The energy supply of Växjö, which includes also all the losses in energy conversion and distribution, is in total about 2,362 GWh. Of this, 70% comes from renewable sources.

[8] Eurostat (Greenhouse gas emissions by source sector); Eurostat (population)
[9]Eurostat (Simplified energy balances); Eurostat (population)

In **2018** around 266 GWh of fossil fuels and 1,195 GWh of renewable energy sources, mainly biomass with 803 GWh, are using to cover electric and heat demand. From the economic point of view, the city of Växjö has an energy supply (primary energy demand) per GDP of 609 MWh/M€. At sector level (2018), the residential sector accounted a primary energy demand (including losses) of 899 GWh, which is mostly covered by bought electricity (226 GWh), district heating (500 GWh), heat pumps (111 GWh) and biomass (60 GWh). In the Public & Commercial sector the primary energy demand (including losses) was 608 GWh, which is mostly covered by bought electricity (316 GWh), district heating (256 GWh), district cooling (17 GWh), biomass (9 GWh) and heat pumps (6 GWh). The primary energy demand of the industrial sector (including energy use in agriculture buildings) was 196 GWh, which is mostly covered by bought electricity (126 GWh), district heating (23 GWh), LPG (Liquefied Petroleum Gas- 10 GWh), biomass (9 GWh), fossil oil (6 GWh) and heat pumps (6 GWh). Finally, the transport sectors including machinery, accounts 726 GWh of total energy demand where about 70 % (506 GWh) was covered by diesel and gasoline, about 25% (182 GWh) by biofuels, about 5% by jet fuel for airplanes (33 GWh) and electricity (5 GWh) mainly for trains.

In **2018**, the heating demand of Växjö is around 790 GWh which represents around 8.5 MWh/Inh. 70% of this demand is covered by district heating and about 93% come from renewable sources. Notice that efficiency measures in the district heating production can reduce the share, even if the demand itself in fact is the same, or even bigger. By sectors, residential sector accounts the 526 GWh of the heat demand with 154 MWh/HDD. Additionally, 67% of this demand is covered by the district heating. The total heat demand for the public & Service sector is 200 GWh with 59 MWh/HDD, where the district heating covers 90% of the heat demand. In the industrial sector the heat demand is 64 GWh where 25% is covered by district heating. In the district heating fuel mix of Växjö, biomass is the main source covering 94% of the energy needs for heat production.

In **2018**, the electricity demand of Växjö is around 671 GWh. The public & service sector is the biggest consumer with the 47% of the total electricity demand followed by the residential sector with the 34% and the industrial sector with the 19%. Additionally, 1% of the electricity in the city of Växjö is consumed in the transport sector. The local electricity production accounted 236 GWh which represents an electricity production of 2.6 MWh/Inh. The local electricity production from renewables is 222 GWh, which represents 94% of the local production and 2.4 MWh/Inh. Biomass with 89% is the main renewable source but there are also small contributions from wind, hydro, PV and biogas.

In **2018**, Växjö accounts 147,975 ton of CO_2 emissions due to the energy consumption from electricity, heating and transportation. This represents an average of 1.6 ton/Inh and a CO_2 emissions intensity (per energy demand) of 67.3 ton/GWh. 77% less compare to EU CO_2 emissions per capita (7.0 ton/Inh[10]) and 63% less than in the Swedish CO_2 emissions per capita (4.4 ton/Inh[10]). From the economic point of view, the city of Växjö has CO_2 emissions per GDP of 38 ton/M€. At sector level the transport sector has the highest CO_2 emissions with 78% of the total, followed by the residential and public & commercial sectors with respectively 10% and 8% of the total. This low emissions rate is because most of the building are

[10] Eurostat (Greenhouse gas emissions by source sector); Eurostat (population)

connected to the district heating network which uses mainly biomass to generate the heat. The remaining part (4%) is allocated to the industrial sector.

The CO_2 emissions from the electricity demand are 8,756 ton. This represents a CO_2 emission per capita for the electricity consumption of 0.09 ton/Inh with a CO_2 emissions intensity of 13.0 ton/GWh. The Public & Service sector accounts 47% of the total electric CO_2 emissions followed by the residential sector with the 34 % of the total and the industrial sector with 19%. The remaining part is due to the electric consumption from within the transport sector.

The CO_2 emissions to cover the heat demand are 23,304 ton which represents 0.25 ton/Ihn and heating CO_2 emission intensity of 29.5 ton/GWh. District heating covers 76 % of the CO_2 emissions of the heat demand having a total CO_2 emission of 17,614 ton and making that CO_2 emissions intensity for the district heating of 22.6 ton/GWh. The low values of CO_2 emissions intensity to cover the heat demand are because biomass is the main source for heating in the municipality of Växjö. At sector level, the residential sector is the main source with the 50% of the total CO_2 emissions with CO_2 emissions per heating degree day of 3.5 ton/HDD. The Public & Service sector accounts the 31% of the total CO_2 emissions with 2.1 ton/HDD. The industrial sector accounts 19% of the total CO_2 emissions for heating. The low values of CO_2 emissions intensity and CO_2 emission per HDD to cover the heat demand are because biomass is the main source for heating in the municipality of Växjö.

5 Overall Strategy Related to the Sustainable Energy Action Plan (SEAP)

Aarhus and Växjö have for years been frontrunners and have very ambitious climate and smart-city policies and corresponding plans for developing of smart sustainable districts. The following section outline the essential aspects of such policies.

5.1 Aarhus, Denmark

The main focus of the Denmark's climate strategy is to be a low-emission nation by 2050 which is communicated in the Climate Plan (2016-2020). As the Denmark's society was majorly dependent on the use of fossil fuels in almost every sector (transport, industry, residential and public services), a total transformation of the system was needed to reach this goal. This is mainly reflected through implementation of new technologies, better use of resources, new business models and active involvement from its citizens. The main milestones of the Climate Plan 2016-2020 are: *(i)* CO_2 emissions per resident 2.3 tons p.a. (7.5 tons p.a. in 2008); *(ii)* Energy consumption per resident of 19 MWh (21 MWh in 2008). 70% CO_2 reduction target from 1990 to 2030, and 100% by 2050 for heating, electricity and transport.

In this regard, Aarhus Municipality is very dedicated to advancing this development by setting up its own target of CO_2-neutrality by 2030. One of the driving forces behind this change is to alter the way energy is generated (moving towards fossil freedom and wind energy) and to reach an overall reduction in energy consumption. The following subsections outline envisioned and implemented modifications related to different focus areas linked to the climate strategy.

5.1.1 Energy

Main milestones for 2020 in accordance with the climate plan for the city of Aarhus are: *(i)* long-term and strategic plans for the energy infrastructure; (ii) recycling of 4.500 tons of refuse more per year. To achieve this, the city has done the following measures:

A major transition to biomass from coal used for district heating, carried out in 2016, lead to 90% of Aarhus residents having the access to green heat with lower CO_2 emissions. The expected total annual CO_2 reduction from this measure is approx. **1.3 million tons**. As a large proportion of electricity in Aarhus is produced in combination with district heating, this also allowed the city to be almost self-sufficient in green electricity. Accordingly, the boilers at the Studstrup power station were converted to be able to burn sustainable wood pellets. This is also done in the new power station Lisbjerg. The Lisbjerg plant uses both the biomass and waste in energy production carried out with an advanced waste-to-power incinerator, whereby 100% heat input comes from straw and approx. 50% from wood chips. The plant is also equipped with an advance system for flue gas cleaning with a heat recovery system. To allow for the most optimal use of waste, the plant is established next to the Waste Centre Lisbjerg.

Due to a large amount of daily generated refuse, a smarter way of disposing of refuse through recycling is currently under way via the 'Refuse plan for Aarhus' that advocates the Aarhus without refuse. This could lead to reduction of **7.000 tons** of CO_2 per year.

5.1.2 Transport

Due to the fact that the transport section will be the biggest source of CO_2 emissions in Aarhus by 2030, a major switch to new technologies powered by green energy is needed. This will be mainly done through electrification of the public transport. In accordance to the main milestones for 2020 set by the climate plan, Aarhus is however still above the national average: *(i)* the number of electric cars above the national average (4 out of 1000 in Aarhus, compared to 3 out of 1000 on national bases); (ii) active promotion with successful shift to alternative ways of transportation (biking, walking, use of public transport). The latter is achieved through initiatives such as Smart Mobility (changing transport habits and behaviour patterns in the favour of car-sharing) and Bike City Aarhus (promotion of cycling).

In addition, the City Council is introducing Intelligent Traffic Management and upgrading streetlights with LED, leading to significant energy consumption reductions in the transport sector.

5.1.3 Buildings

Energy consumption in buildings is an essential factor affecting the overall consumption. Therefore, smart energy optimization for the buildings with more severe energy criteria for renovation and new-built projects is the key theme for the upcoming years. The corresponding milestones for 2020 relate to: *(i)* continued reduction in building energy consumption; (ii) enhanced collaboration for green building in the local building industry.

More than 900 homes are foreseen for energy optimization measures, while for commercial and industrial buildings a pilot project is oriented towards the potential of intelligent building management and programmed consumption for reducing or eliminating peak demand. Furthermore, green transition is also integrated into construction industry through sustainable urban development and circular economy (construction using recycled materials).

5.1.4 Industry

Due to the fact that Aarhus is the biggest industrial city in Denmark, the potential of acting in this sphere is vast. The main focus is set on reduction of energy consumption and the use of fossil fuels. The milestones for 2020 that are reached in this regard relate to the reduced use of oil in industrial processes.

An active change of technology in industry requires a joint initiative and collaboration between environmental authorities, energy consultants and industry itself. To make this happen, an Industry Task Force was set up, that will oversee the process in phasing in sustainable energy sources.

Additionally, new methods of utilising surplus heat from industry processes are being identified. The potentials relate to utilisation of surplus heat at DNU (new University Hospital) and green district heating for the light railway via mobile heat pumps. Likewise, recycled materials and refuse are being regarded as valuable resources within industry, thus developing new circular business models.

5.1.5 Summary of the main targets

The main targets of the city of Aarhus may be summarized as following:

Climate and Energy target for the city of Aarhus in 2020

- 50% of the electricity consume by citizens and businesses comes from renewable energy sources and waste by 2020;
- District heating will be primary based on renewable energy sources by 2020;
- 40% of the gross energy consumption comes from renewable energy sources and waste by 2020;
- 35% of CO_2 emission reduction in the period 2009-2020.

Climate and Energy target for the city of Aarhus in 2030

- The city of Aarhus will have fulfilled its vision to be CO_2-neutral by 2030.

5.2 Växjö, Sweden

The main environmental targets of the City of Växjö can be found in its Environmental Programme, a steering document that is revised for each mandate period. These targets relate to three core areas: Living Life, Our Nature and Fossil Fuel Free Växjö. Measurable targets of Living Life relate to the food consumption (a toxin-free society), waste (turning waste into a resource) and environmental inspections (carrying out inspections on all environmentally hazardous activities). Measurable targets of Our Nature relate to water (the reduction in phosphates for good water quality and bathable lakes), nature (free access to parks and nature areas), and air and noise (clean air throughout the municipality, reduction of noise-related health risks). Measurable targets of Fossil Fuel Free Växjö relate to climate (reduction of direct and indirect climate impact), energy (sustainable energy future), and traffic (reduction of the environmental impact of motor vehicles).

The City of Växjö has signed the Covenant of Mayors and by doing so, adopted a Sustainable Energy Action Plan (SEAP) with the main focus on reductions in energy consumption and CO_2 emissions. The core target for the City of Växjö is to become a fossil fuel free city. These efforts relate, in part, to the measures required to achieve the goals set by the Environmental Programme. The City of Växjö is committed to achieve energy and climate targets set up in their Energy Plan, that go beyond the targets of the EU, starting from the reduction of fossil carbon dioxide emissions by 65% per capita in 2020 relative to 1993.

The Energy Plan for the City of Växjö outlines visions, strategies and actions in relation to five focus areas.

Focus Area 1: Renewable energy

The primary source of energy (electricity and heat) is from the renewables. District heating is biomass based and is available in most parts of the city. There are several strategies related to the production of energy:

- Strategy A concerns the increase of overall share of renewable energy, but especially coming from local small-scale production (production of electricity from local systems). This is, among other things, directed to construction of “positive energy buildings” that generate more energy than they use, but also small-scale wind turbines or PVs.
- Strategy B concerns the opportunities for business sector and related developments in the area of renewable energy production, which is expected to advance the readiness to invest in solutions that can further renewable energy production.

- Strategy C relates to the expansion of the network of central district heating and cooling, with potentials for development of smaller local district heating plants.
- Strategy D relates to the establishment of wind power. The wind power plan contains potential areas designated for the placement of wind turbines.
- Strategy E relates to the elimination of peat as an energy source, towards the complete phasing out of this material by 2020.

Focus Area 2: Energy efficiency

The citizens live energy efficient smart buildings and act accordingly. The main aspiration is to reach a status of the greenest business and industry sector in Europe. There are several strategies related to the energy efficiency:

- Strategy A relates to the large-scale renovation projects of existing building stock towards a more energy efficient operation. The goal is to reach the following energy levels: dwellings - 75 kWh/m^2 and year (40 kWh/m^2 for electricity heated dwellings); premises - 701 kWh/m^2 and year (40 kWh/m^2 for electricity heated premises). The City of Växjö supports local citizens, companies, real estate owners, organisations and associations with professional energy and climate counselling and advice when they want to undertake energy efficiency measures.
- Strategy B relates to the energy efficiency of new building stock. The allowed energy levels for new buildings should be lower than 55 kWh/m^2 and year (30 kWh/m^2 for electricity heated dwellings) and 50 kWh/m^2 and year (30 kWh/m^2 for electricity heated premises). Life cycle cost should also be considered.
- Strategy C takes citizen behaviour into account, especially regarding the water and energy consumption, towards the low-consumption society.
- Strategy D concerns the optimization of energy use. A pilot residential area uses smart grid solutions - in the electric grid and/or central district heating grid.

Focus Area 3: Renewable vehicle fuel and energy efficient vehicles

The vehicles run on renewable fuels. By 2020, the construction of local production unit for renewable vehicle fuels is already under its way. There are several strategies related to the energy efficient vehicles:

- Strategy A relates to the free access to renewable energy fuel, whereby both the production and distribution of renewable energy fuels is notably increased. Biogas market within the region is advanced through active involvement of the City of Växjö in relevant initiatives and projects. Additionally, the City of Växjö shows a great effort to improve infrastructure by offering charging possibilities for electric vehicles.
- Strategy B prioritises the increase of the share of environmentally friendly vehicles in the city. Within multiple local initiatives, citizens are encouraged to take on electric vehicles. The renewables are also integrated into the transport industry, targeting heavy vehicles, machinery and public transportation.

Focus Area 4: Reliable and sufficient energy supply

The supply of renewable vehicle fuels, electricity, and heat produced from renewable energy sources is sufficient to meet the demand of local population. There are several strategies related to the sufficient energy supply:

- Strategy A relates to the adequate production and delivery of heat, cooling, electricity, and vehicle fuels from renewable energy sources, and meeting up with the competitors.
- Strategy B relates to the reliable delivery of energy. To further support this, the risk and vulnerability analysis is carried out, to account for any potential issues.

Focus Area 5: Other energy and climate aspects

These strategies fall under other focus areas than the ones described above:

- Strategy A supports the development and advancement of the greenest industry and business sector. The City of Växjö keeps track of energy intensive companies and guides them through their transition towards the energy efficient future. A promising climate network with diverse set of stakeholders is established to discuss all the relevant topics and issues related to the energy and climate.
- Strategy B prioritizes the operation of local administrations as fossil fuel free ambassadors. #
- Strategy C supports new future initiatives and projects aimed at reaching the energy and climate goals.
- Strategy D prioritizes the education of citizens, employees, students and politicians in the context of energy and climate protection.

Summary of the main targets

The main targets of the City of Växjö may be summarized as following:

Targets for Fossil Fuel Free Växjö 2020

Climate targets

- Fossil carbon dioxide emissions per person in the City of Växjö will decrease by 65% in the period 1993-2020;
- The municipal organisation will be fossil fuel free by 2020;
- In the City of Växjö a minimum of 50% of new municipal buildings will be wood-based by 2020

Energy targets

- Energy consumption per person in the City of Växjö will decrease by 20% in the period 2008-2020;
- The total energy consumption per square metre in municipal properties will decrease by 20% in the period 2010-2020;
- Municipal solar, wind and hydro power production will supply a minimum of 4,500 MWh by 2020.

Targets for Fossil Fuel Free Växjö 2030

Climate targets

- The city of Växjö shall be fossil fuel free by 2030.

6 Replication and upscaling of the measures at city level

6.1 Replication and upscaling for city of Aarhus

6.1.1 Scenario description

In the scenarios Low, Medium and High, there are measures implemented to reach the READY- objectives (chapter 2). Each scenario has different impacts to reach the objectives, the High scenario (Best case scenario) has the biggest one with more measures compared to the Low and Medium scenarios. In Aarhus (Denmark), the main focus is in the renovation of the buildings, an increase of LTDH (Low-temperature-district-heating) and the capacity of PV and PVT. In the High scenario the share of renovated buildings should be 60%, the share of LTDH in the energy supply 30% and the total capacity of PV and PVT about 450 MW.

Moreover, the increase of the share of air heat pumps with waste-heat-recovery and of E-mobility is included in the scenarios. In the High scenario the share of heat pumps with waste-heat-recovery should reach 20% and the share of E-mobility 27%.

Furthermore, in all scenarios the district heating in Aarhus should be, except of using non-biodegradable waste and a few peak hours of using oil boilers, CO_2-neutral. Large heat pumps should be part of the heat production in the district heating (Table 4).

Table 4: Measures of the scenarios Low/Medium/High of Aarhus

Measures	High	Medium	Low
Share of renovated buildings [%]	60%	30%	15%
Service [%]	20%	10%	5%
Share of energy provide by LTDH [%]	30.0%	15.0%	7.5%
Installed capacity PVT panels [MW]	40.5	33.7	27.0
Installed capacity PV panels [MW]	407.3	339.4	271.6
Large HP for DH [MW]	12.0	12.0	12.0
Share Air HP with WHR [%]	20%	15%	5%
DH CO_2 neutral	100%	100%	100%
Share of E-vehicles [%]	27%	18%	14%

6.1.2 Results and discussion- Aarhus

The scenario calculation in Aarhus shows, that energy efficiency and the switch of the energy carrier to renewable energies have a big impact on the energy demand, energy supply and CO_2-emissions.

In 2018, the primary energy supply of Aarhus is about 7,973 GWh. In the scenarios, the total primary energy supply is because of the lower energy demand lower than the status quo of 2018 (Table 5).

Table 5: Total primary energy supply of Aarhus (2018/ scenarios Low/Medium/High)

Status qou (2018)	Scenario High	Scenario Medium	Scenario Low
7,973 GWh	7,090 GWh	7,289 GWh	7,340 GWh

In Aarhus, the total primary energy supply to cover the energy demand for electricity, heating, cooling and transport in 2018 is mostly based on biomass (47%), diesel (15%), gasoline (9%), fuel jet (9%) and not-biodegradable waste. In the scenarios, the imported non-renewable and renewable electricity was substituted by local electricity generation. Furthermore, coal & derived gets substituted by biomass in all scenarios (Figure 7).

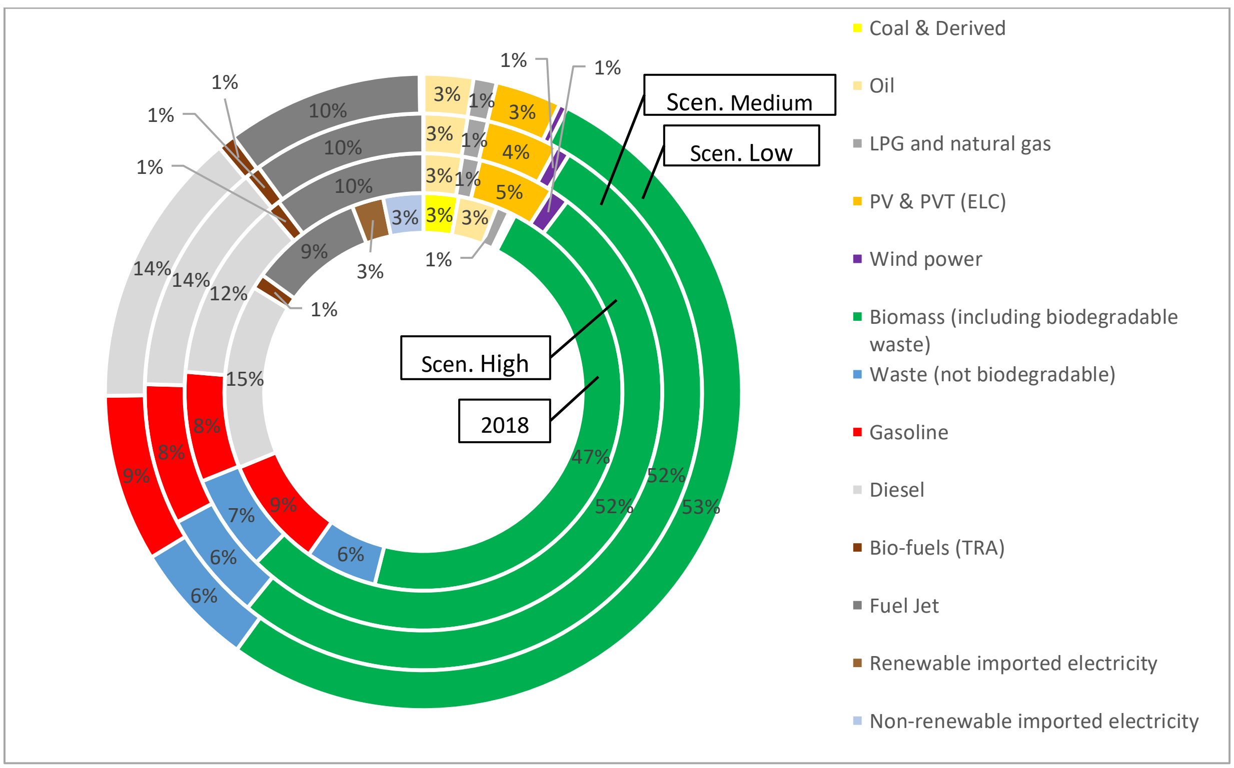


Figure 7: Total primary energy supply by fuel- Status quo (2018)/ scenario Low/Medium/High in Aarhus

Moreover in Figure 7 is shown, that the share of PV and PVT in the total energy supply is in the status quo (2018) small, but the electricity generation of these increases in the scenarios. In Aarhus, solar heating does not play a role in energy production (Figure 8).

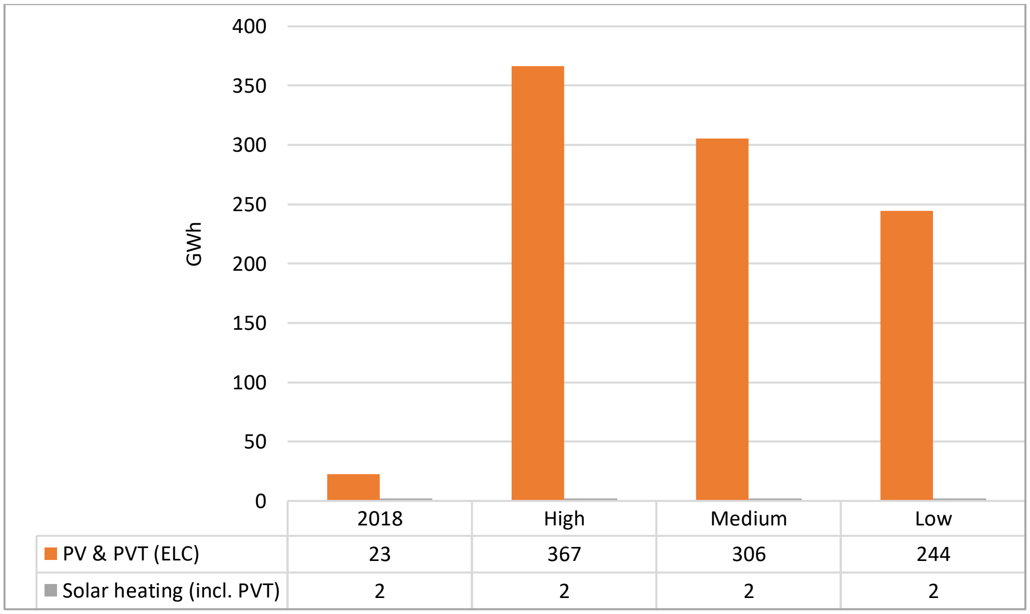
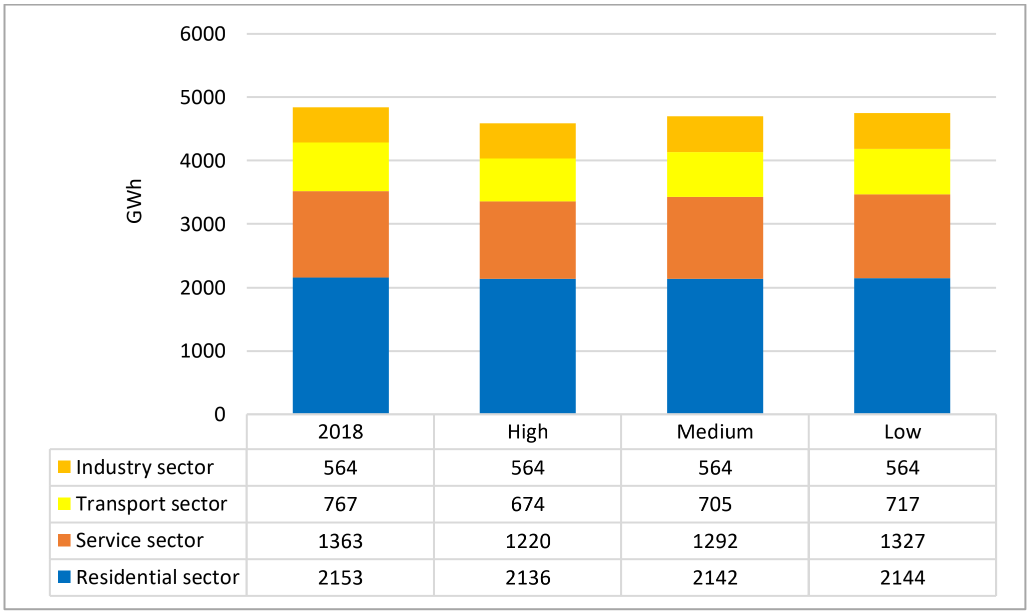


Figure 8: Capacity of solar heating, PV & PVT in the status quo (2018) and in the scenarios Low/Medium/High

The Figure 8 illustrates, that the total electricity generation of PV & PVT increases in the scenarios, compared to the status quo (2018). In the High- scenario, the total amount of electricity generation of PV & PVT is more than 16- times higher compared to the status quo. This shows the high importance of solar energy in the energy supply of Aarhus.

The energy demand for electricity, heating and transportation is in 2018 about 4,846 GWh and decreases in the scenarios because of the higher share of renovated buildings and the energy efficiency measures in the heating and electricity system of the service and residential buildings (Figure 9).

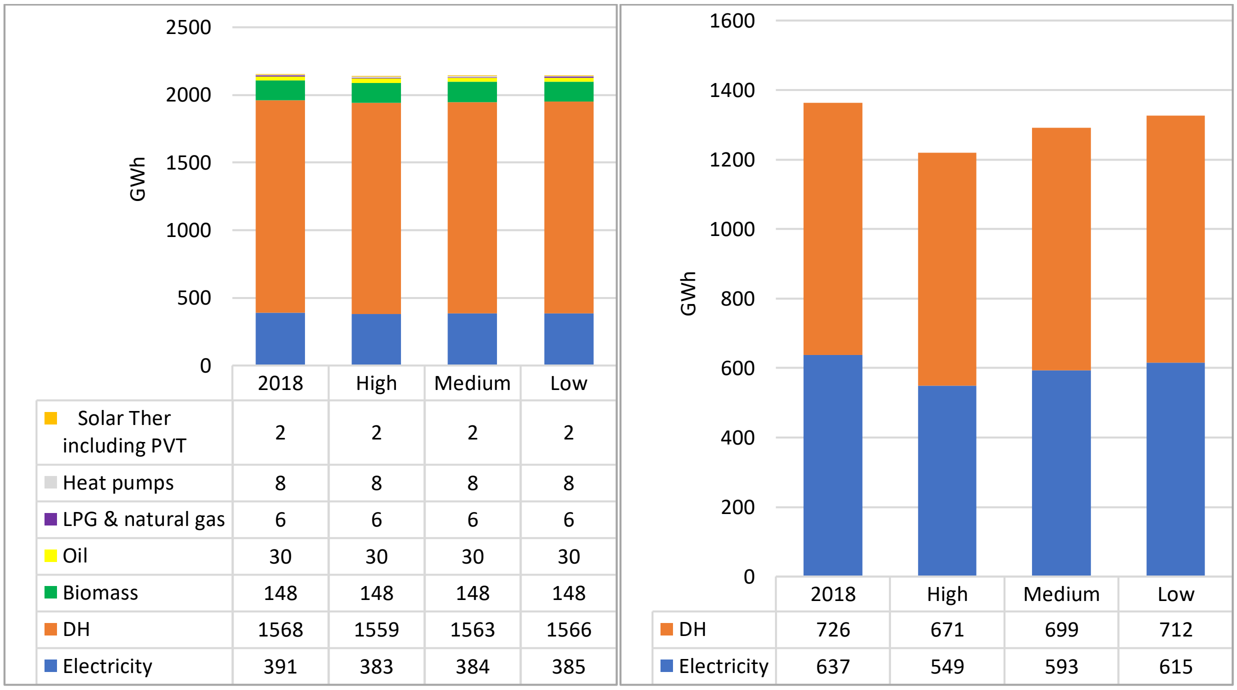


	2018	High	Medium	Low
Industry sector	564	564	564	564
Transport sector	767	674	705	717
Service sector	1363	1220	1292	1327
Residential sector	2153	2136	2142	2144

Figure 9: Total energy demand by sector in Aarhus

Moreover Figure 9 shows, that in addition to energy efficiency measures for buildings in the residential and service sector, the transport sector also has a high energy efficiency potential due to the target of a high share of e-mobility. The industry sector has in all scenarios the same amount.

In the residential sector of Aarhus, most of the energy demand (2,153 GWh) is the heating demand (2018: 82%), which is mostly covered by district heating (2018: 73%), by biomass (2018: 7%) and oil (2018: 2%). The biomass in Aarhus considers wood, straw and biodegradable waste. The remaining used fuels in the residential sector are solar thermal energy (including PVT- 2 GWh), LPG & natural gas (6 GWh) and heat pumps (8 GWh). In the scenarios the amount of the heating and electricity demand decreases because of energy efficiency measures of the residential buildings. In the scenarios the amount of district heating decreases and the amount of biomass, oil and the other heat fuels (e.g. heat pumps, solar heating,..) are still constant (Figure 10-left).



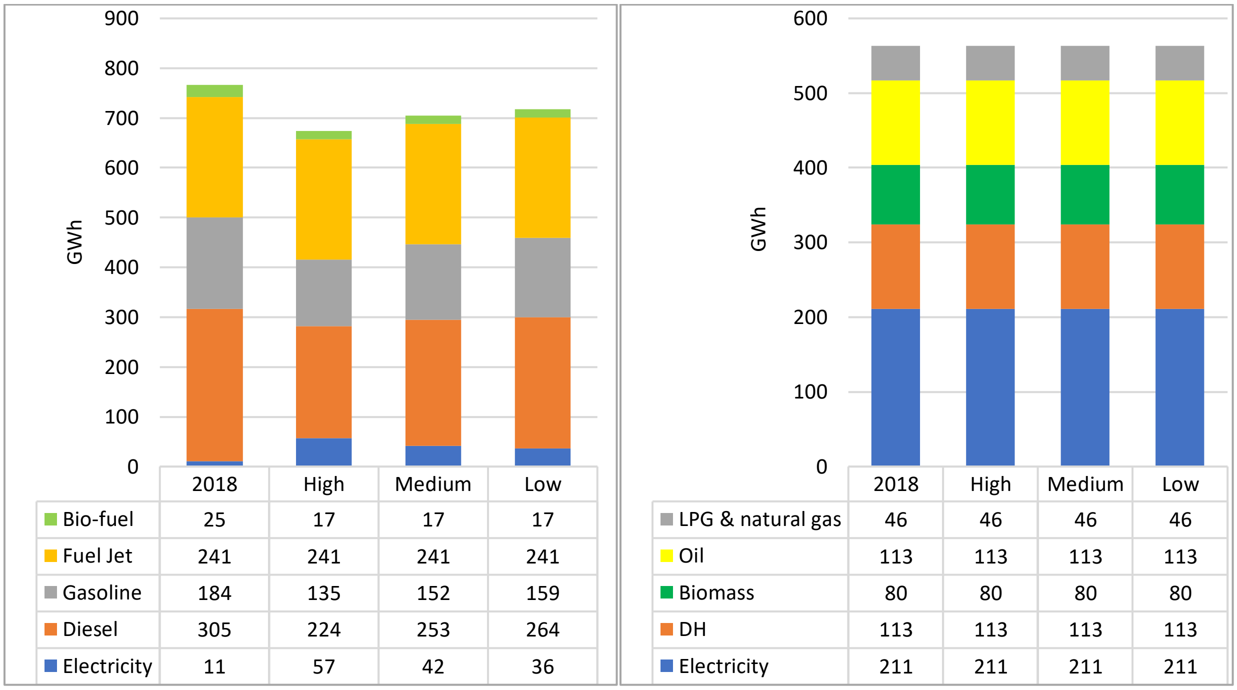
	2018	High	Medium	Low
Solar Ther including PVT	2	2	2	2
Heat pumps	8	8	8	8
LPG & natural gas	6	6	6	6
Oil	30	30	30	30
Biomass	148	148	148	148
DH	1568	1559	1563	1566
Electricity	391	383	384	385

	2018	High	Medium	Low
DH	726	671	699	712
Electricity	637	549	593	615

Figure 10: Share of energy demand for the residential (left figure) and service sector (right figure) in Aarhus

In the right figure of Figure 10, there is the energy demand of the service sector of Aarhus illustrated. In 2018, the final energy demand of the service sector is about 1,363 GWh. The highest amount of the energy demand is the heating demand (2018: 53%). The heating demand of the service sector in Aarhus is completely covered by district heating. The remaining energy demand in Aarhus is the electricity demand, which is lower than the heating demand (2018: 47%). Because of the energy measures of the service buildings, the amount of electricity and heating is in the scenarios lower than the status quo (2018).

The transport sector of Aarhus has an energy demand of 767 GWh. In 2018, the transport sector is mostly covered by diesel (40%), fuel jet (32%), gasoline (24%), biofuel (3%) and electricity (1%). Aarhus has the target to reach a higher energy security and sustainability and a switch of fuels also should happen in the transport sector. In the scenarios, gasoline and diesel was partially substituted by electricity. In the High-Scenario, electricity has a total share of 8%. In this High-scenario, gasoline and diesel decreases by about 27% compared to the status quo (Figure 11-left figure).



	2018	High	Medium	Low
Bio-fuel	25	17	17	17
Fuel Jet	241	241	241	241
Gasoline	184	135	152	159
Diesel	305	224	253	264
Electricity	11	57	42	36

	2018	High	Medium	Low
LPG & natural gas	46	46	46	46
Oil	113	113	113	113
Biomass	80	80	80	80
DH	113	113	113	113
Electricity	211	211	211	211

Figure 11: Share of energy demand for the transport (left figure) and industry sector (right figure) in Aarhus

In Figure 11 (right figure) is shown the final energy demand of the industry sector of Aarhus (564 GWh). The energy demand of the status quo is mainly based on the heating demand (2018: 63%), which is covered by district heating (2018: 20%), fossil oil (2018: 20%), biomass (2018: 14%) and LPG & natural gas (2018: 8%). The remaining energy demand is the electricity demand of the industry sector. In the scenarios the amount of all used fuels is the same as the status quo (2018).

In Aarhus, the energy of the **heating demand** is mainly consumed by the residential sector (1,759 GWh) and by the service sector (726 GWh). A heating demand of 352 GWh is consumed by the industry sector and the remaining heating demand (3 GWh) is consumed by the transport sector (Figure 12- left figure). Because of a high share of renovated buildings (60%- High scenario/30%- Medium scenario/15%- Low scenario), the heating demand decreases, especially in the residential and service sector. In the High scenario, the heating demand of the service sector or rather of the residential sector is compared with the heating demand of the status quo (2018), reduced by 8% or rather by 1%. The total heating demand of the High- scenario is about 2% lower than the status quo (2018).

The total heating demand (2018) of the status quo of Aarhus is mainly covered by district heating (2,407 GWh/85%), biomass (228 GWh/8%), fuel oil (143 GWh/5%), LPG & natural gas (53 GWh/2%), heat pumps (8 GWh) and solar thermal systems (including PVT- 2 GWh). In the scenarios, the share of all fuels is the same as in the status quo (Figure 12- right figure).

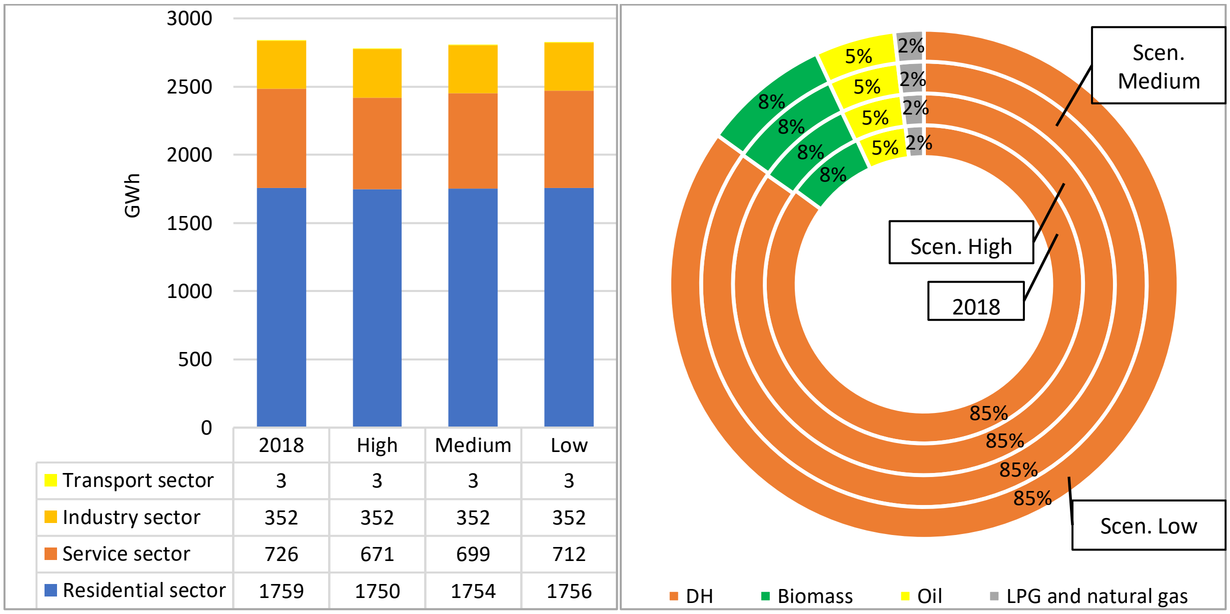


Figure 12: Heating demand by sectors (left figure) and heating demand by fuel (right figure) in Aarhus

In Aarhus, an amount of about 7.7 GWh of heat is generated by heat pumps, based on ground heat pumps (1.3 GWh) and air heat pumps (6.4 GWh). This heat pumps are part of decentralised heating systems. Aarhus has the target to use more heat pumps with waste-heat recovery, which is the scenarios considered (Figure 13). In the High-Scenario, the total share of heat pumps with waste-heat-recovery from the heat production with heat pumps is about 17% (1.3 GWh).

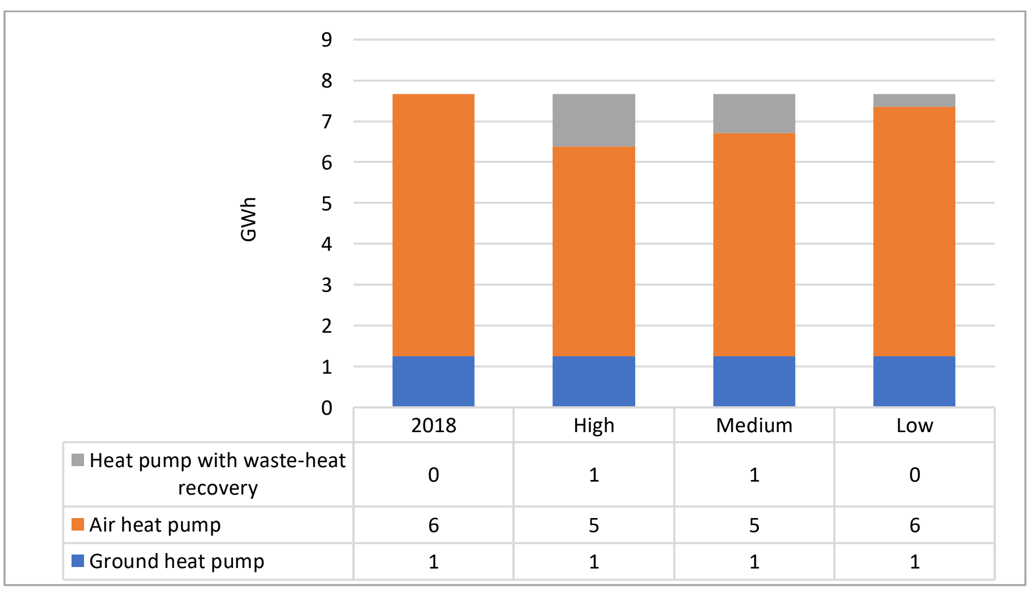


Figure 13: Heat production from heat pumps in Aarhus- decentralised heating systems

The heating demand is mainly covered by district heating (Figure 12), which uses in the status quo (2018) biomass (2,410 GWh/83%), not-biodegradable waste (323 GWh/11%), coal & derived (158 GWh/5%) and fuel oil (28 GWh/1%) to generate heat. In the scenarios the amount of not-biodegradable waste is constant. Moreover, in the scenarios the fossil fuels coal & derived and fuel oil gets substituted by heat pumps (41 GWh) and biomass (Figure 14- right figure). This substitution of fossil fuels in the heat production of district heating is necessary, because Aarhus has the target to reach CO_2- neutrality by 2018 in the district heating supply (see chapter 2). The calculation of CO_2- neutrality exclude the incineration of non- biodegradable waste.

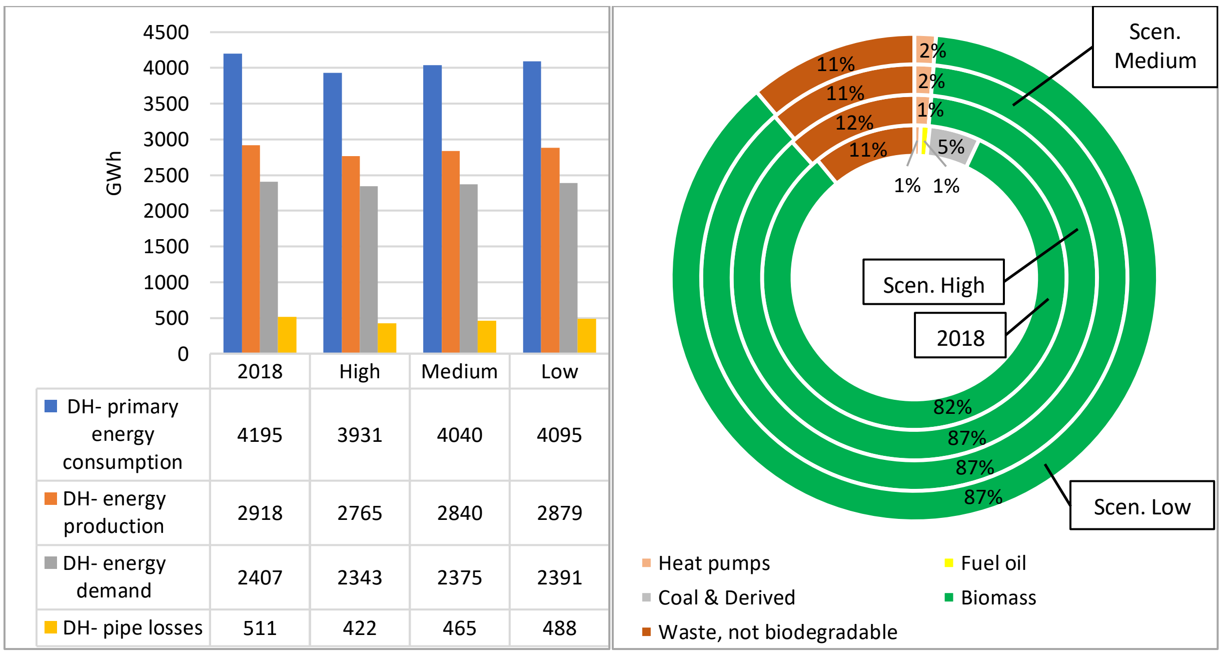


Figure 14: District heating (DH)- primary energy consumption/production/demand/pipe losses (left figure) and DH by fuel (right figure)

In the left figure of Figure 14 is shown, that in the status quo (2018) the primary energy consumption of the district heating accounts 4,195 GWh. The energy production of the district heating is a value, which considers the process efficiency in the heating plant (transformation from fuel to heat) and accounts in Aarhus 2,918 GWh in 2018. By considering also the pipe losses from the district heating network, an energy demand of 2,407 GWh is calculated for the status quo (2018) in Aarhus. In the left figure of Figure 14 is illustrated, that in the scenarios the primary energy consumption, energy production and the energy demand decreases compared to the status quo (2018). This is the result of a higher share of renovated buildings and energy efficiency measures. Furthermore, in the scenarios there is also a higher efficiency of the district network considered, which means lower pipe losses compared to the status quo.

The **electricity demand** in Aarhus (2018) is 1,250 GWh and is covered by local electricity production from renewable energies (loc. elc. renew.- 66%), electricity imports (Elc. imp.- 19%) and local electricity production from non-renewable fuels (loc. elc. non-renew.- 15%). In the scenarios, the share of local electricity production increases. In the High scenario and in the Medium scenario, the electricity demand is completely covered by the local electricity production from renewable energies. In all the scenarios, the non-renewable fuels in the local electricity production gets substituted by renewable sources (Figure 15- right figure). The switch to generate electricity locally from renewable sources is necessary to reach energy security and sustainability in Aarhus.

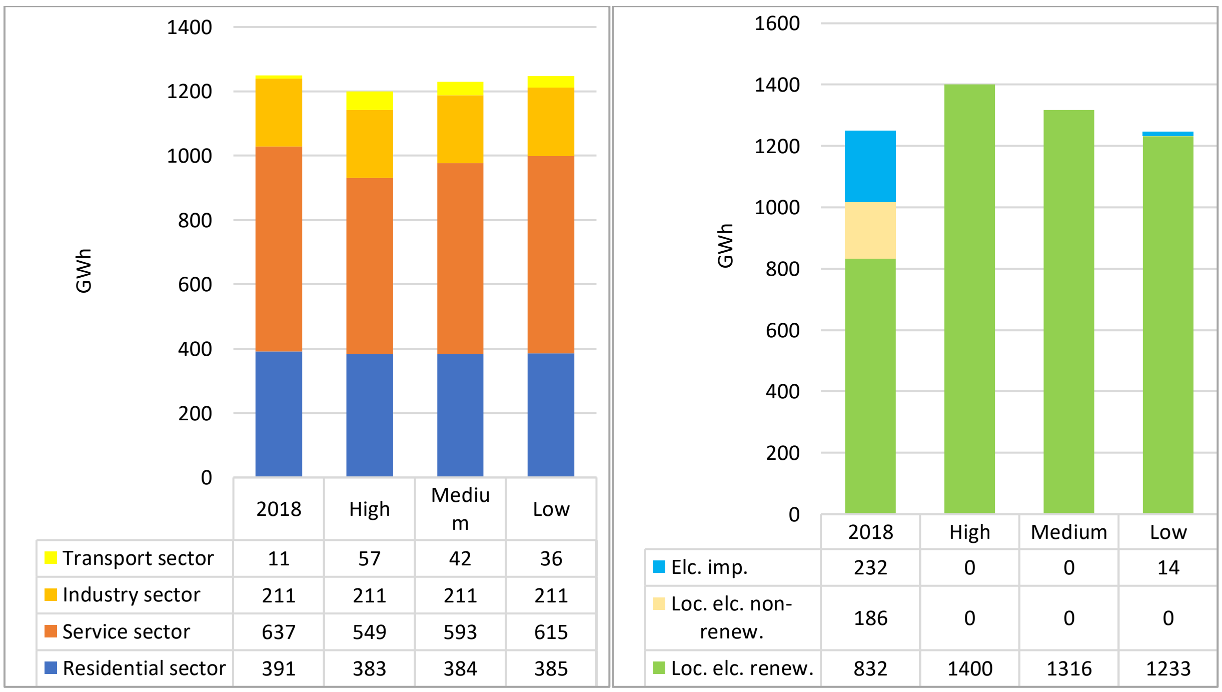


Figure 15: Total electricity demand by sector (left figure); Electricity- imports and local production (right figure)

In the left figure of Figure 15 is illustrated, that in Aarhus the biggest consumers of electricity are the service sector (637 GWh) and the residential sector (391 GWh). In the status quo (2018), the transport sector has a very low amount (11 GWh) on the electricity demand. The scenarios show, that on one hand, the energy efficiency measures of the buildings reduce the electricity consumption of the residential and service sector, but on the other hand the high share of e-mobility increases the electricity demand in total.

The total electricity production in Aarhus is mainly based on biomass (78%), not-biodegradable waste (10%), coal (6%), fuel oil (3%), wind (2%) and PV (2%). In the scenarios, there is a high increase of wind energy and PV included. The High scenario considers a share of 6% wind energy and 24% PV, which causes a total substitution of fossil fuels (coal and fuel oil) and a decrease of biomass (62%) in the total electricity production (Figure 16- left figure).

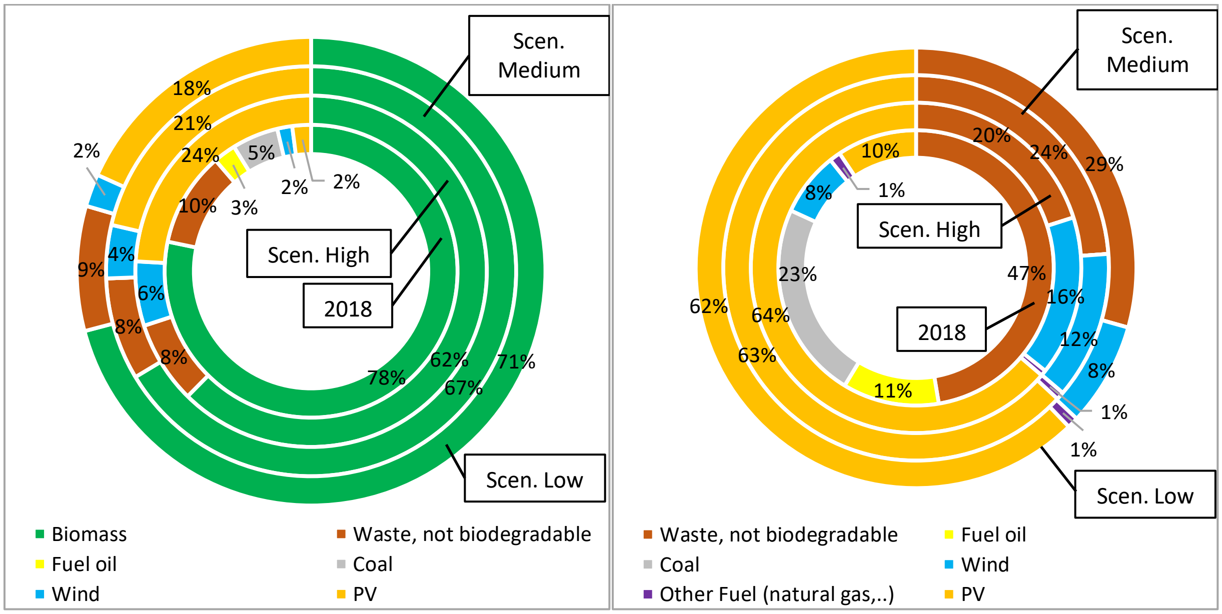
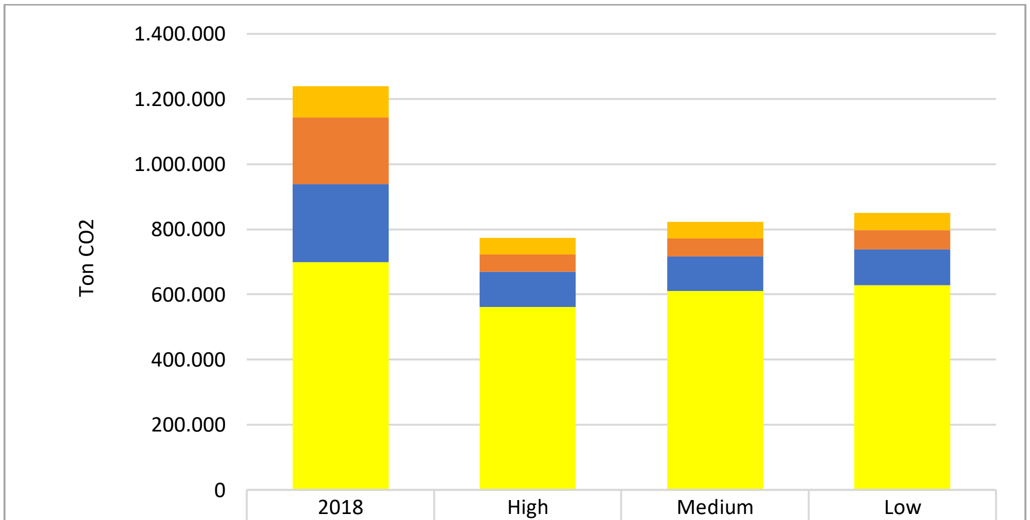


Figure 16: Total electricity production by fuel (left figure) and by fuel without biomass (right figure) in Aarhus

The right figure of Figure 16 shows, that in the status quo (2018) the main energy sources, excluding biomass, are coal, fuel oil, not- biodegradable waste, PV, wind and other fuels (e.g. natural gas). In the scenarios, the share of wind and PV increases and the share of not- biodegradable waste decreases. In the scenarios, coal and fuel oil is not used in the electricity production anymore.

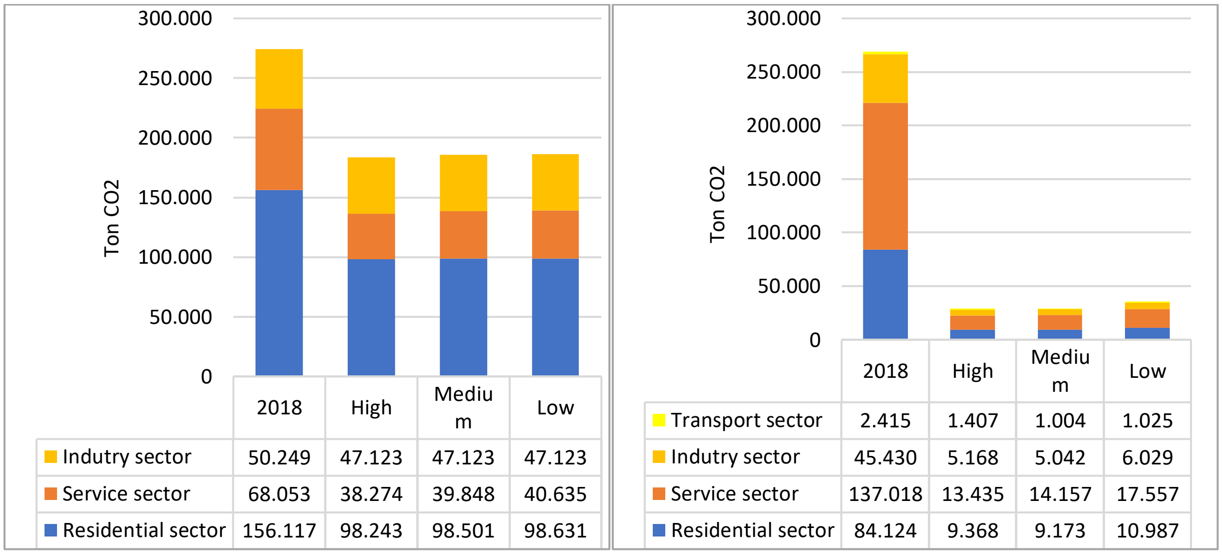
Most of the CO_2- emission in the status quo (2018) is assigned to the transport sector (56%), the residential sector (19%) and the service sector (17%). Because of the switch of the fuels in the transport sector (higher share of electricity), the amount of the CO_2- emissions of the transport sector in the High scenario can be reduced by 20% compared to the status quo (2018). Because of the high amount of the switch of fossil fuels (especially coal and fossil oil) to renewable sources and the high share of renovated buildings, the CO_2- emissions of the service and residential sector in all the scenarios decrease compared to the status quo (Figure 17).



	2018	High	Medium	Low
Indutry sector	95.679	52.291	52.165	53.153
Service sector	205.070	51.708	54.005	58.191
Residential sector	240.241	107.610	107.674	109.617
Transport sector	698.716	562.464	609.983	629.172

Figure 17: Share of the total CO_2- emissions by sector in Aarhus

In the status quo (2018) of Aarhus, the CO_2- emissions for heating is higher than the CO_2- emissions for electricity (Figure 18). This is the result of the use of not-biodegradable waste (11%), coal & derived (5%) and fuel oil (1%) in the district heating and the use of fuel oil (5%) and LPG & natural gas (2%) to cover the heating demand. Because of the use of fossil -free-fuels, except the use of biodegradable waste, in the electricity production in all scenarios, the CO_2- emissions for electricity are in the scenarios Low/Medium/High lower than the CO_2- emissions for heating. Especially the CO_2-emissions for heating and electricity in the residential and the service sector have a big decline in all scenarios compared to the status quo (2018).

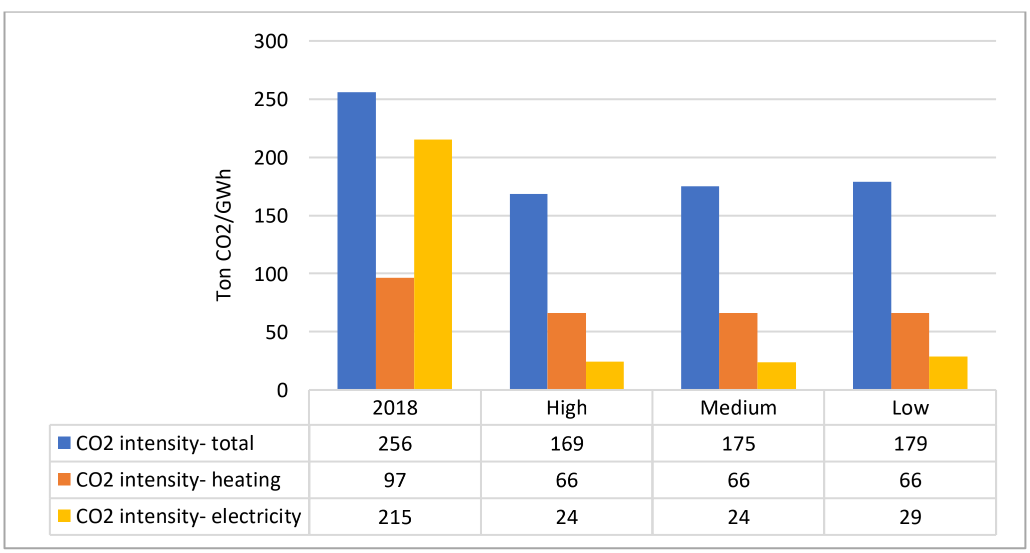


	2018	High	Medium	Low
Indutry sector	50.249	47.123	47.123	47.123
Service sector	68.053	38.274	39.848	40.635
Residential sector	156.117	98.243	98.501	98.631

	2018	High	Medium	Low
Transport sector	2.415	1.407	1.004	1.025
Indutry sector	45.430	5.168	5.042	6.029
Service sector	137.018	13.435	14.157	17.557
Residential sector	84.124	9.368	9.173	10.987

Figure 18: CO_2- emissions for heating by sector (left figure) and for electricity by sector (right figure) in Aarhus

By comparing the CO_2- intensity for heating and electricity, in the status quo of Aarhus, the CO_2- intensity for electricity is higher than for heating (Figure 19). The reason is the 2.3- times higher heating production compared to electricity production, even the CO_2-emissions for heating is 2% higher than the CO_2-emissions for electricity. In the scenarios, the CO_2-intensity for electricity are lower as the CO_2-intensity for heating. The reason is the switch of the fossil fuels (coal and fuel oil) to renewable energy sources in the electricity production. Furthermore, the difference between the total CO_2-intensity and the CO_2-intensity for heating and electricity in the scenarios shows, that a high CO_2- intensity is also assigned to the transport sector.



	2018	High	Medium	Low
CO2 intensity- total	256	169	175	179
CO2 intensity- heating	97	66	66	66
CO2 intensity- electricity	215	24	24	29

Figure 19: CO_2- intensity of Aarhus in total, for heating and for electricity

In Figure 20 are shown the economic indicators (Energy per GDP/ CO_2 per GDP) of Aarhus. The indicator Energy per GDP is calculated by the division of the final energy demand and the GDP of Aarhus. Because of lower final energy consumption, the indicator Energy per GDP decreases in the scenarios compared to the status quo (2018). In the High scenario, the energy per GDP is about 5% lower than the status quo (Figure 20- left figure).

The comparison of the economic indicator CO_2 per GDP shows, that because of the high decrease of the CO_2- emissions in the scenarios (Figure 17), the decline of the CO_2 per GDP in the scenarios compared to the status quo is much higher than of the Energy per GDP. In the High scenario, the CO_2 per GDP is about 38% lower than the status quo (Figure 20- right figure).

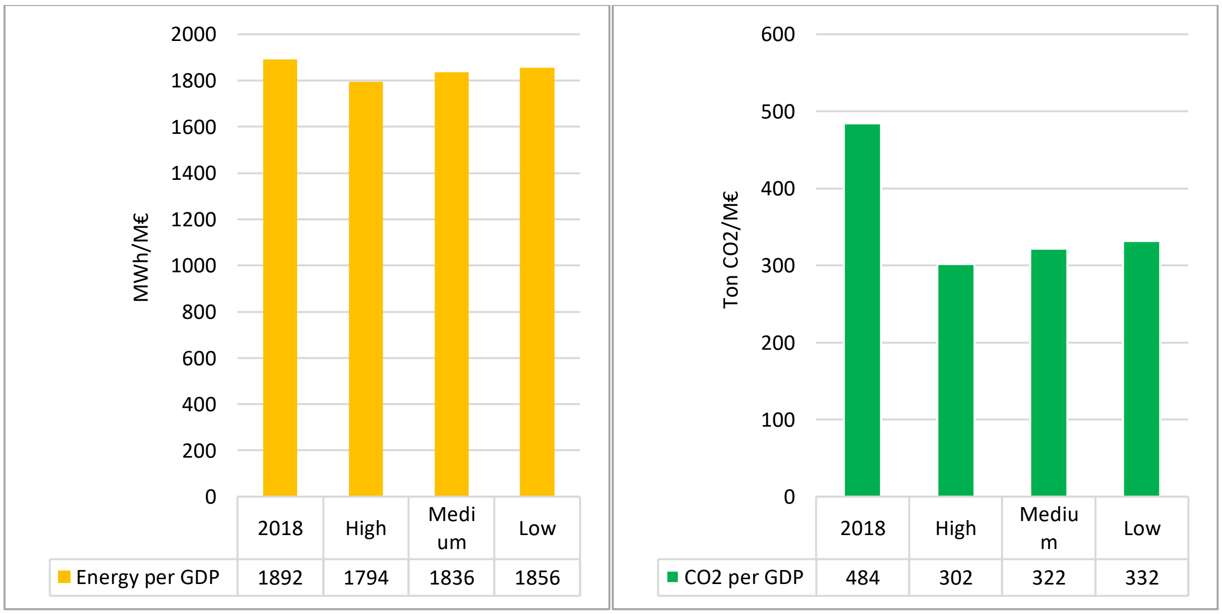


Figure 20: Economic indicators of Aarhus- Energy per GDP (left figure) and CO_2 per GDP (right figure)

6.2 Replication and upscaling for city of Växjö

6.2.1 Scenario description

In Växjö (Sweden), the main focus is in the renovation of the buildings, an increase of LTDH (Low-temperature-district-heating) and a high share of E-mobility to reach more sustainability and energy security. In the High scenario the share of renovated buildings should be 40%, the share of LTDH in the energy supply 20% and the share of E-mobility 37%.

Moreover, the increase of the share of air heat pumps with waste-heat-recovery and the capacity of PV and PVT is included in the scenarios. In the High scenario the share of heat pumps with waste-heat-recovery should reach 30% and the total capacity of PV and PVT about 33 MW.

Furthermore, in all scenarios the district heating in Aarhus should be CO_2-neutral. Large heat pumps should not be part of the heat production in the district heating (Table 4).

Table 6: Measures of the scenarios Low/Medium/High of Växjö

Measures	High	Medium	Low
Share of renovated building [%]	40%	20%	10%
Service [%]	20%	10%	5%
Share of energy provide by LTDH [%]	20.0%	10.0%	5.0%
Installed capacity PVT pannels [MW]	3.0	2.0	1.4
Installed capacity PV pannels [MW]	30.0	20.0	14.0
Large HP for DH [MW]	n.a	n.a	n.a
Share Air HP with WHR [%]	30%	20%	5%
DH CO2 neutral	100%	100%	100%
Share of E-vehicles [%]	37%	31%	25%

The comparison of the measures of the cities Växjö (Table 6) and Aarhus (Table 4) shows, that each city has different concepts to reach the READY- objectives. In Aarhus, the renovation of buildings to make them more energy-efficient, the high share of LTDH in the energy supply and the big increase of PV and PVT is in the focus. Moreover, large heat pumps should support the district heating. Växjö is focussed on the strategy to renovate buildings, increase the share of LTDH and the share of E-mobility. PV and PVT and the share of air heat pumps with waste-heat-recovery should also be increased like in Aarhus, but without high ambitions. Furthermore, in the district heating system of Växjö, large heat pumps should not be installed.

6.2.2 Results and discussion- Växjö

The scenario calculation in Växjö shows, that energy efficiency and the switch of the energy carrier to renewable energies have a big impact on the energy demand, energy supply and CO_2- emissions.

In 2018, the primary energy supply of Växjö is about 2,362 GWh. In the scenarios, the total primary energy supply is because of the lower energy demand lower than the status quo of 2018 (Table 7).

Table 7: Total primary energy supply of Växjö (2018/ scenarios Low/Medium/High)

Status qou (2018)	Scenario High	Scenario Medium	Scenario Low
2,362 GWh	2,217 GWh	2,279 GWh	2,319 GWh

In Växjö, the total primary energy supply to cover the energy demand for electricity, heating, cooling and transport in 2018 is mostly based on biomass (45%), gasoline (13%), biofuels (12%), renewable (10%) and non-renewable imported electricity (8%). In the scenarios, a high amount of gasoline and diesel from the transport sector was transformed in biofuels. In the scenario High, the share of biofuels of the total primary energy supply was about 21% (Figure 21).

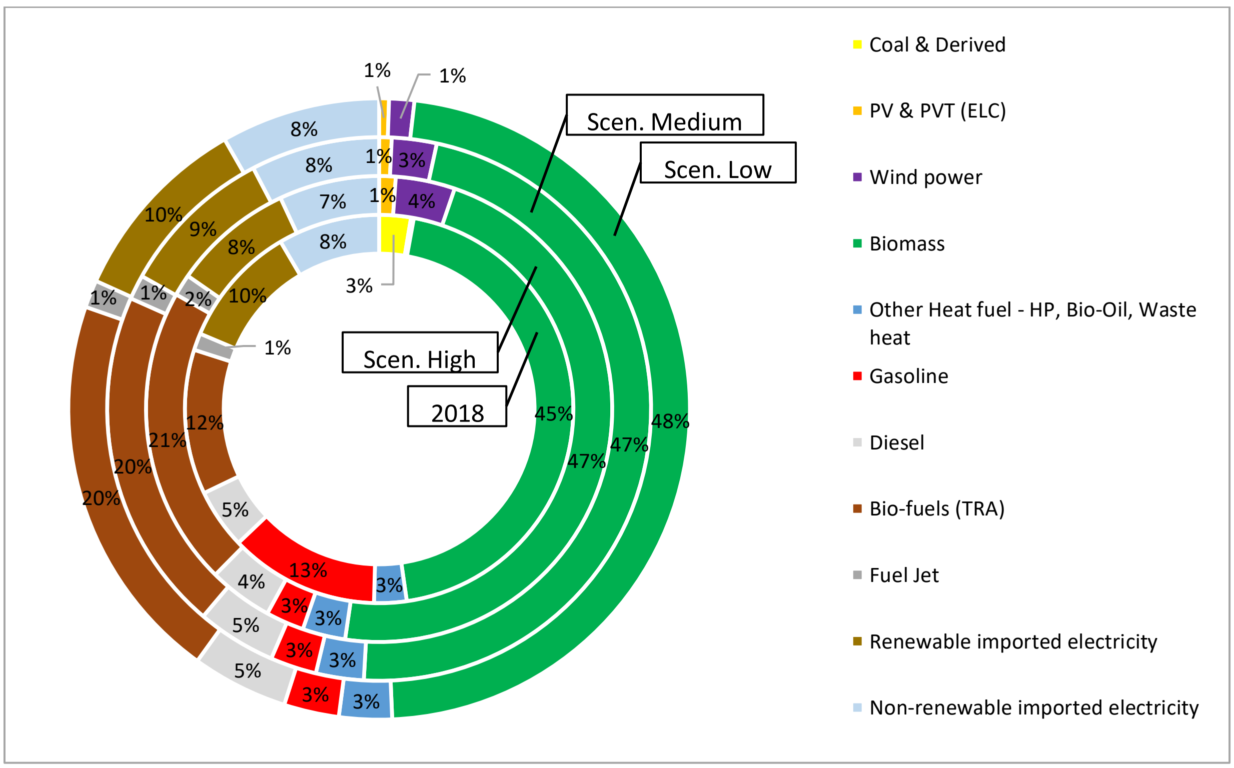
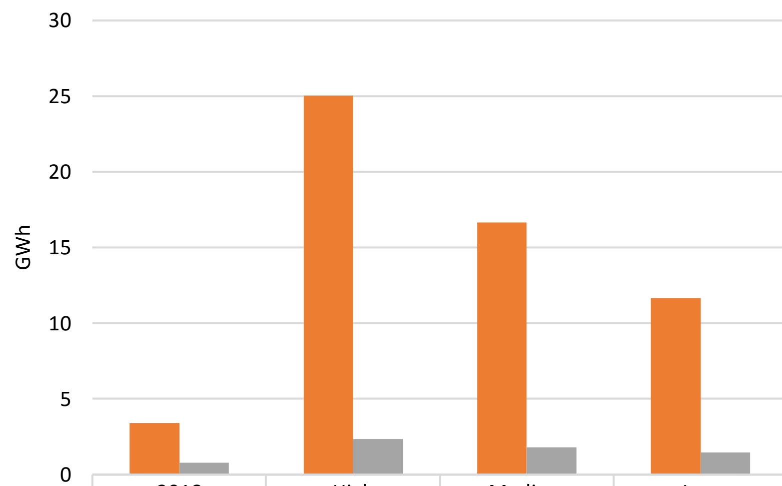


Figure 21: Total primary energy supply by fuel- Status quo (2018)/ scenario Low/Medium/High in Växjö

Moreover in Figure 21 is shown, that coal & derived gets in the scenarios substituted by renewable energies, mainly based on biomass wind power, PV and PVT.

Even if the share of PV, PVT and solar thermal energy in the total energy supply is small, the energy production of these increases in the scenarios (Figure 22).

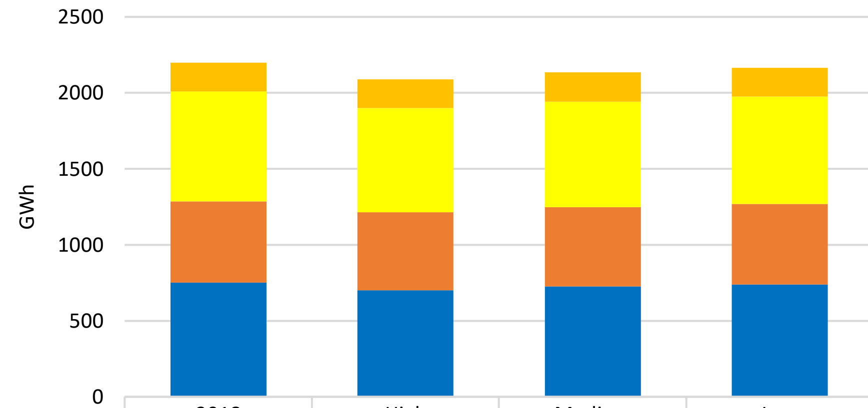


	2018	High	Medium	Low
PV & PVT (ELC)	3	25	17	12
Solar heating (incl. PVT)	1	2	2	1

Figure 22: Capacity of solar heating, PV & PVT in the status quo (2018) and in the scenarios Low/Medium/High

The Figure 22 illustrates, that the total energy production of PV & PVT and solar heating increases in the scenarios, compared to the status quo (2018). In the High- scenario, the total amount of energy generation of PV & PVT is more than 8- times and the of the solar heating more than 2-times higher compared to the status quo. This shows the high importance of solar energy in the energy supply of Växjö.

The energy demand for electricity, heating and transportation is in 2018 about 2,200 GWh and decreases in the scenarios because of the higher share of renovated buildings and the energy efficiency measures in the heating and electricity system of the service and residential buildings (Figure 23).

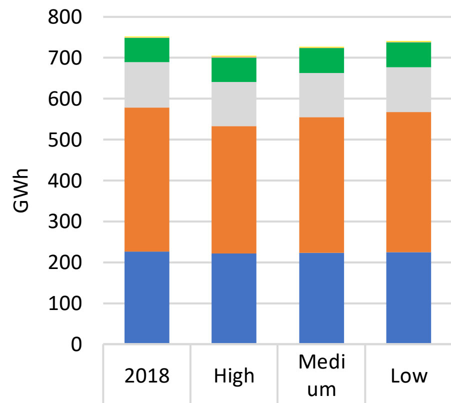


	2018	High	Medium	Low
Industry sector	190	190	190	190
Transport sector	726	684	696	708
Service sector	533	513	523	528
Residential sector	752	703	725	740

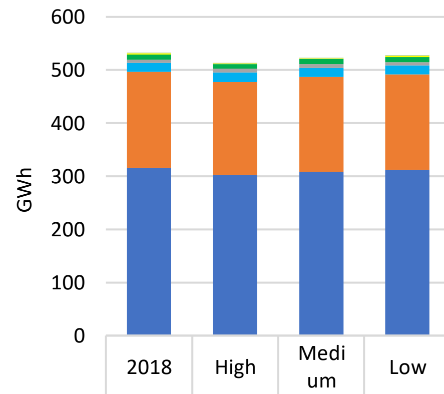
Figure 23: Total energy demand by sector in Växjö

Moreover Figure 23 shows, that in addition to energy efficiency measures for buildings in the residential and service sector, the transport sector also has a high energy efficiency potential due to the target of a high share of e-mobility. The industry sector has in all scenarios the same amount.

In the residential sector of Växjö, most of the energy demand (752 GWh) is the heating demand (2018: 70%), which is mostly covered by district heating (2018: 47%), by other heat fuels (2018: 15%) and biomass (2018: 8%). The other heat fuels in Växjö consider heat pumps, waste heat, bio-oil and synthetic fuels. The remaining used fuels in the residential sector are solar thermal energy (including PVT) and fossil oil. In the scenarios the amount of the heating and electricity demand decreases because of energy efficiency measures of the residential buildings. In the scenarios the amount of fossil oil declines and in the High-Scenario the oil gets substituted by solar thermal energy. Moreover, in the scenarios the amount of district heating decreases and the amount of biomass and other heat fuels are still constant (Figure 24- left figure).



	2018	High	Medium	Low
Oil	2	0	1	2
Solar Ther including PVT	1	2	2	1
Biomass	60	60	60	60
Other Heat Fuels	111	107	108	111
DH	352	312	332	342
Electricity	226	221	223	225

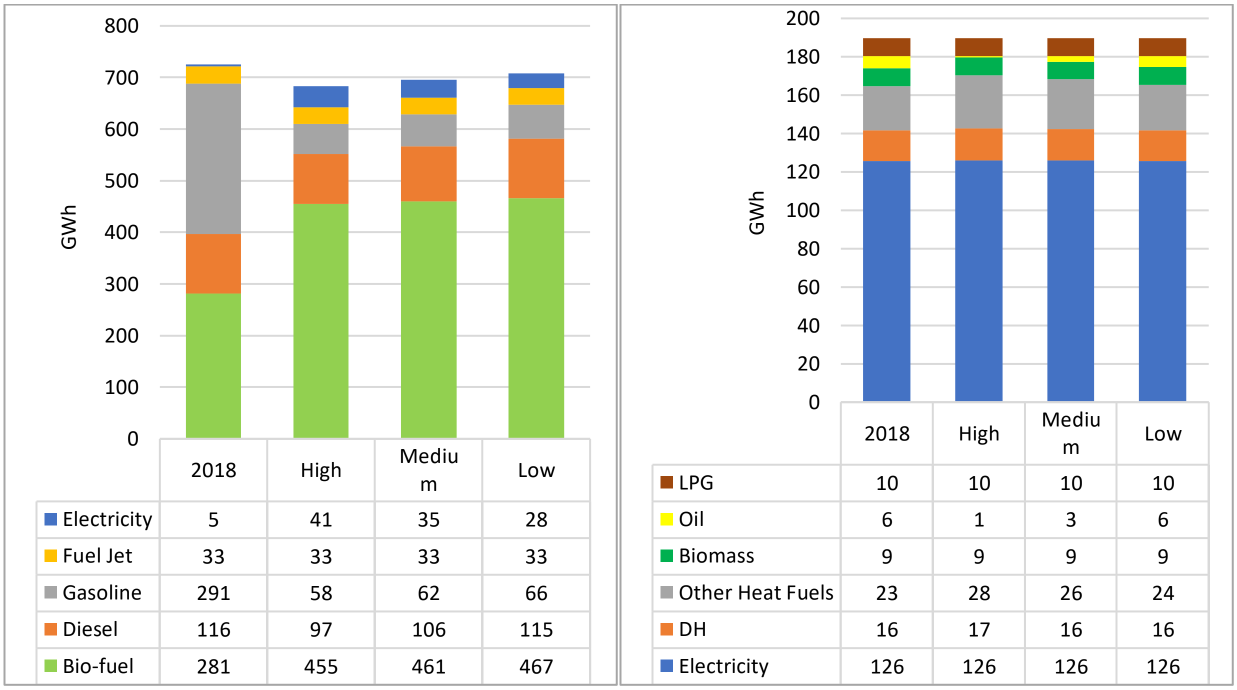


	2018	High	Medium	Low
Bio-Gas	1	1	1	1
Oil	3	0	1	3
Biomass	9	9	9	9
Other Heat Fuels	6	8	7	6
DC	17	17	17	17
DH	181	176	178	179
Electricity	316	302	309	312

Figure 24: Share of energy demand for the residential sector (left figure) and service sector (right figure) in Växjö

In the right figure of Figure 24, there is the energy demand of the service sector of Växjö illustrated. In 2018, the final energy demand of the service sector is about 533 GWh. The highest amount of the energy demand is electricity (2018: 59%). The heating demand is mainly covered by district heating (2018: 34 %) biomass (2018: 2%), other heat fuels (2018: 1%) and fossil oil (2018: 1%). 3% of the energy demand of the energy demand is cooling demand, which is covered by district cooling. Because of the energy measures of the buildings, the amount of electricity and district heating is in the scenarios lower than the status quo (2018). The amount of district cooling and biomass is in all scenarios the same as in the status quo (2018).

In addition to the residential sector, the transport sector has the highest energy demand (726 GWh) by sectors. In 2018, the transport sector of Växjö is mostly covered by gasoline (40%), biofuel (39%), diesel (16%), fuel jet (4%) and electricity (1%). The biofuel includes the blending from diesel and gasoline cars. Växjö has the target to reach a higher energy security and sustainability. So, a switch of fuels also should happen in the transport sector. In the scenarios, gasoline and diesel was partially substituted by biofuel and electricity. In the High- Scenario, electricity has a total share of 6% and biofuels of 66%. In this High-scenario, gasoline decreases by about 80% and diesel by 16%, compared to the status quo (Figure 25-left figure).



	2018	High	Medium	Low
Electricity	5	41	35	28
Fuel Jet	33	33	33	33
Gasoline	291	58	62	66
Diesel	116	97	106	115
Bio-fuel	281	455	461	467

	2018	High	Medium	Low
LPG	10	10	10	10
Oil	6	1	3	6
Biomass	9	9	9	9
Other Heat Fuels	23	28	26	24
DH	16	17	16	16
Electricity	126	126	126	126

Figure 25: Share of energy demand for the transport sector (left figure) and industry sector (right figure) in Växjö

In Figure 25 (right figure) is shown the final energy demand of the industry sector of Växjö (190 GWh). The energy demand of the status quo in Växjö is mainly based on the electricity demand (66%). The remaining demand is mainly covered by other heat fuels (heat pump, waste heat, bio-oil and synthetic fuels- 12%) district heating (8%), biomass (5%), LPG (5%) and fossil oil (3%). In the scenarios the share of electricity, district heating, biomass and LPG is the same as the status quo (2018). The amount of fossil oil gets in the scenarios substituted by other heat fuels. In the High- Scenario the share of fossil oil is reduced by 91% compared to the status quo (2018).

The energy of the **heating demand** is mainly consumed by the residential sector (526 GWh) and by the service sector (200 GWh). The remaining heating demand of 64 GWh is consumed by the industry sector (Figure 26- left figure). Because of a high share of renovated buildings (40%- High scenario/20%- Medium scenario/10%- Low scenario), the heating demand decreases, especially in the residential and service sector. In the High scenario, the heating demand of the service sector or rather of the residential sector is compared with the heating demand of the status quo (2018), reduced by 3% or rather by 8%. The total heating demand of the High- scenario is about 6% lower than the status quo (2018).

The total heating demand (2018) of the status quo of Växjö is 790 GWh and is mainly covered by district heating (549 GWh/70%), other heat fuels (heat pump, waste heat, bio-oil and synthetic fuels- 141 GWh/18%), biomass (78 GWh/10%), fuel oil (11 GWh/1%) and LPG (10 GWh/1%). In the scenarios, the share of fossil decreases and gets mainly substituted by biomass and other heat fuels. In the High-scenario, the fossil oil has no share in the using fuel to cover the heating demand (Figure 26- right figure).

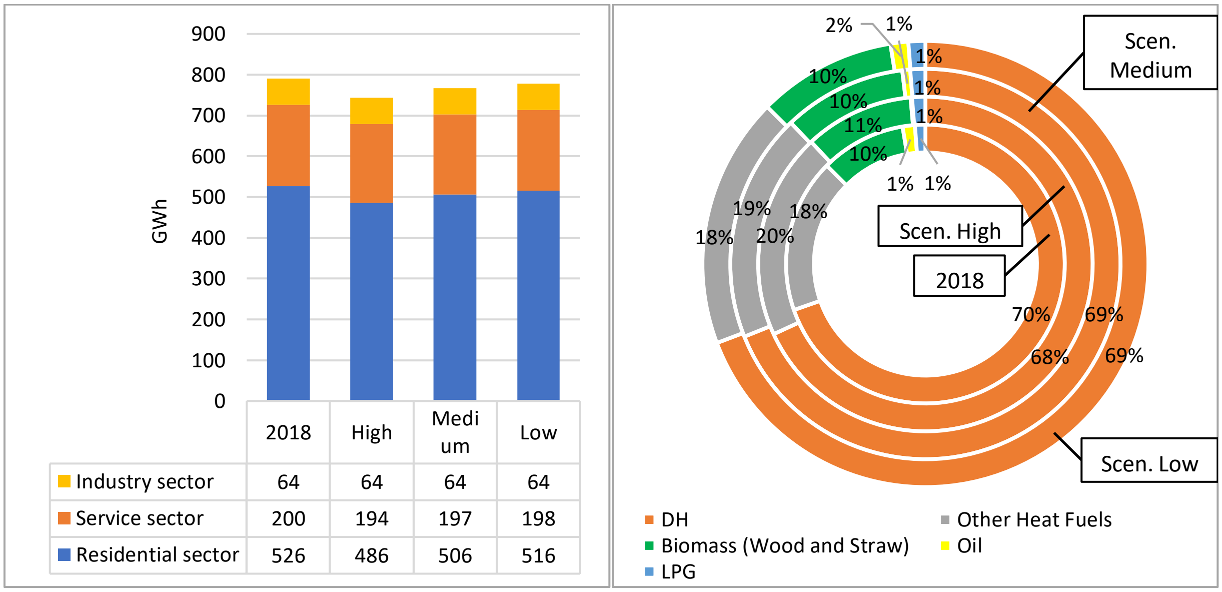


Figure 26: Heating demand by sectors (left figure) and heating demand by fuel (right figure) in Växjö

The other heat fuels are in Växjö mainly based on ground heat pumps (73 GWh) and air heat pumps (51 GWh). Växjö has the target to use more heat pumps with waste-heat recovery, which is the scenarios considered (Figure 27). In the High-Scenario, the total share of heat pumps with waste-heat-recovery from the heat production with heat pumps is about 11% (14 GWh).

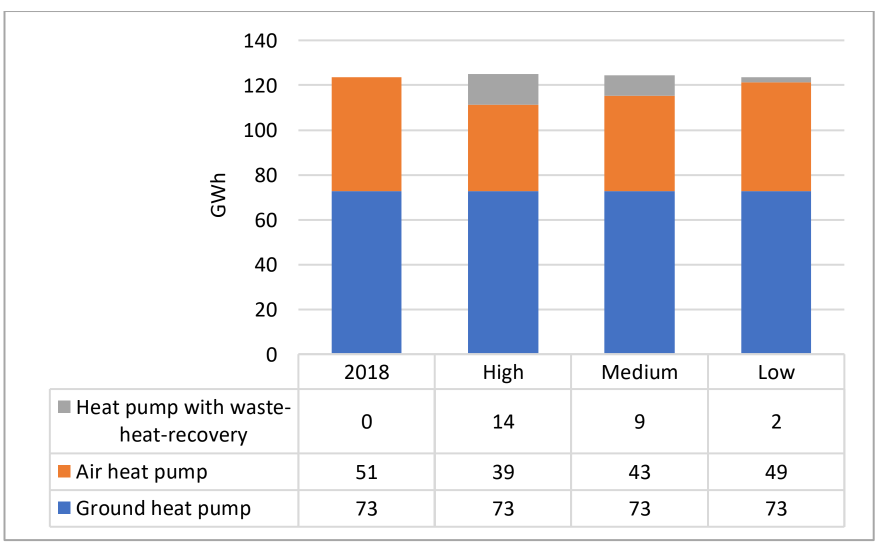
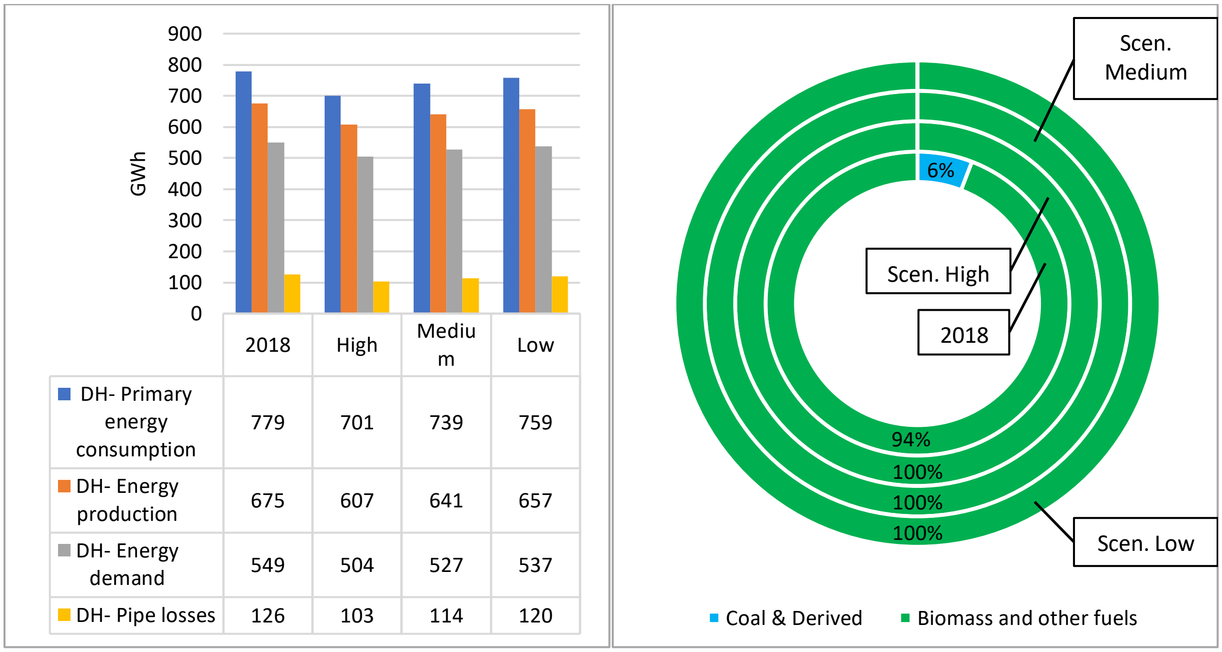


Figure 27: Heat production from heat pumps in Växjö

The heating demand is mainly covered by district heating (Figure 26), which uses in the status quo (2018) biomass (633 GWh/93.8%), coal & derived (39 GWh/5.8%) and other fuels (2 GWh/0.4%) to generate heat. In the scenarios the amount of other fuel is constant (2 GWh/0.4%) and the biomass (99.6%) substitutes the coal & derived (Figure 28- right figure). This substitution of fossil fuels in the heat production of district heating is necessary, because Växjö has the target to reach CO_2- neutrality by 2019 in the district heating supply (see chapter 2).



	2018	High	Medium	Low
DH- Primary energy consumption	779	701	739	759
DH- Energy production	675	607	641	657
DH- Energy demand	549	504	527	537
DH- Pipe losses	126	103	114	120

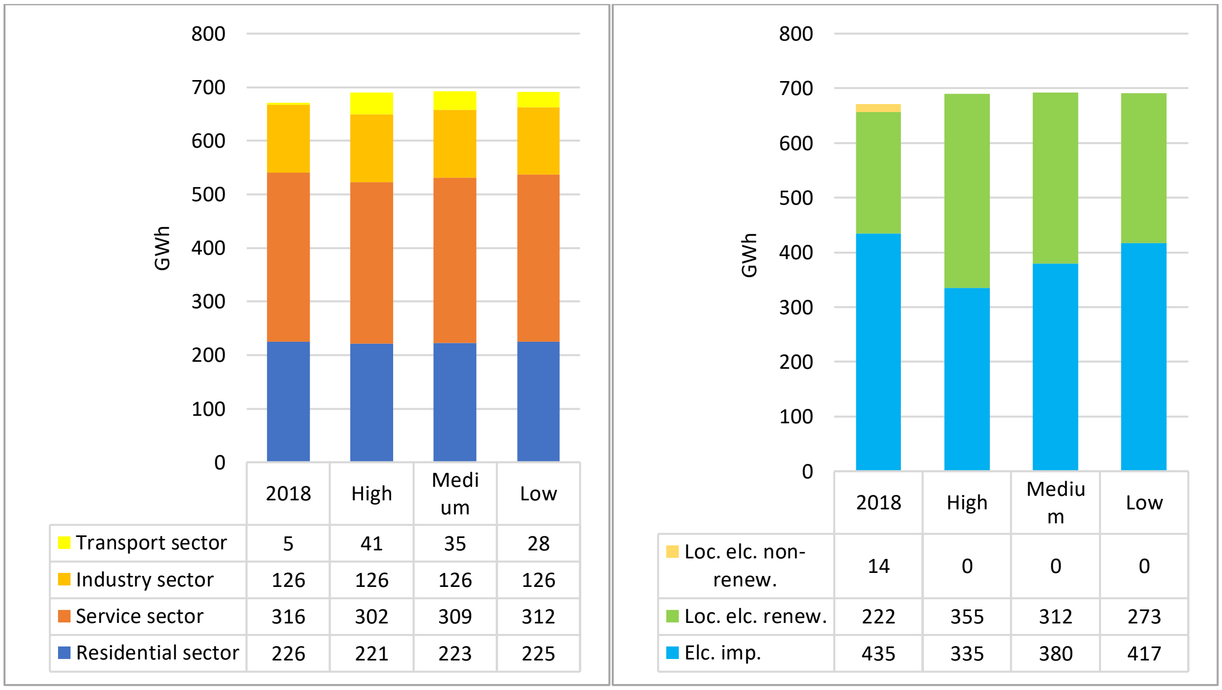
Figure 28: District heating (DH)- primary energy consumption/production/demand/pipe losses and DH by fuel

In the left figure of Figure 28 is shown, that in the status quo (2018) the primary energy consumption of the district heating accounts 779 GWh. The energy production is a value, which considers the process efficiency in the heating plant (transformation from fuel to heat) and accounts in Växjö 675 GWh in 2018. By considering also the pipe losses from the district heating network, an energy demand of 549 GWh is calculated for the status quo (2018) in Växjö. In the left figure of Figure 28 is shown, that in all scenarios the primary energy consumption, energy production and the energy demand decreases compared to the status quo (2018). This is the result of a higher share of renovated buildings and energy efficiency measures. Furthermore, in the scenarios there is also a higher efficiency of the district network considered, which means lower pipe losses compared to the status quo.

The **cooling production** from the CCHP (Combined cooling, heat and power) is in 2018 covered by biomass (16 GWh/94%) and coal & derived (1 GWh/6%). In all scenarios, coal & derived gets substituted by biomass and so in the scenarios the cooling production is like the district heating fossil-fuel-free.

The **electricity demand** in Växjö (2018) is 671 GWh and is covered by electricity imports (elc. imp.- 65%) and by local electricity production from renewable energies (loc. elc. renew.- 33%). The remaining 2% of the electricity demand is covered by the local electricity production from non-renewable fuels (loc. elc. non-renew.). In the scenarios, the share of local electricity production increases and in the High scenario the local electricity production from renewable energies (51%) is higher than the electricity imports (49%).

In all the scenarios, the non-renewable fuels in the local electricity production gets substituted by renewable sources (Figure 29- right figure). The switch to generate electricity locally from renewable sources is necessary to reach energy security and sustainability in Växjö.



	2018	High	Medium	Low
Transport sector	5	41	35	28
Industry sector	126	126	126	126
Service sector	316	302	309	312
Residential sector	226	221	223	225

	2018	High	Medium	Low
Loc. elc. non-renew.	14	0	0	0
Loc. elc. renew.	222	355	312	273
Elc. imp.	435	335	380	417

Figure 29: Total electricity demand by sector (left figure); Electricity- imports and local production (right figure)

In the left figure of Figure 29 is illustrated, that in Växjö the biggest consumers of electricity are the service sector (316 GWh) and the residential sector (226 GWh). In the status quo (2018), the transport sector has a very low amount (5 GWh) on the electricity demand. The scenarios show, that on one hand, the energy efficiency measures of the buildings reduce the electricity consumption of the residential and service sector, but on the other hand the high share of e-mobility increases the electricity demand in total.

The total electricity production in Växjö is mainly based on biomass (89 %), peat (6%), hydropower (3%), wind (1%) and PV & PVT (1%). In the scenarios, there is a high increase of wind energy and PV & PVT included. The High scenario considers a share of 25% wind energy and 7% PV & PVT, which causes a total substitution of fossil fuels (peat) and a decrease of biomass (63%) in the total electricity production (Figure 30- left figure).

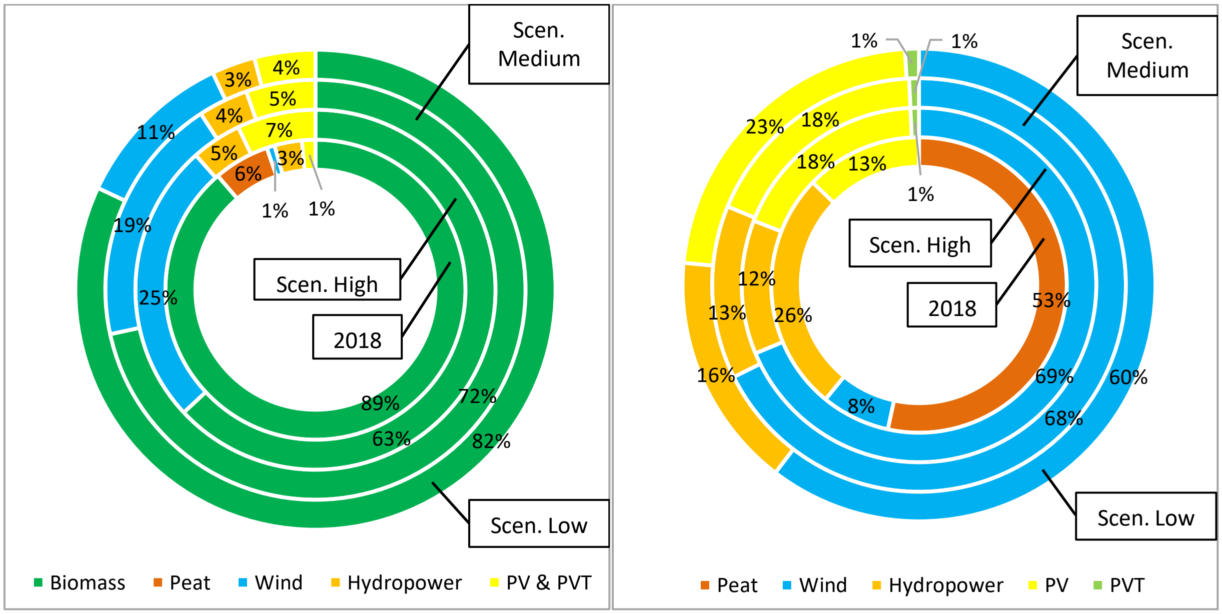
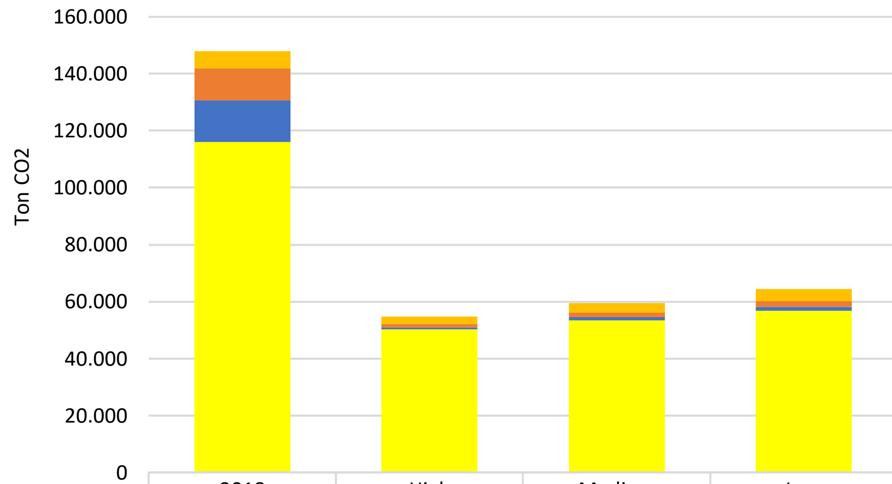


Figure 30: Total electricity production by fuel (left figure) and by fuel without biomass (right figure) in Växjö

The right figure of Figure 30 shows, that in the status quo (2018) the main energy sources, excluding biomass, are peat, hydropower and PV. In the scenarios, the share of wind, PV, PVT increases and the share of hydropower decreases. In the scenarios, peat is not used in the electricity production anymore. This trend in Växjö shows, that more decentralised energy systems and fewer centralised energy systems is getting used to cover the electricity demand.

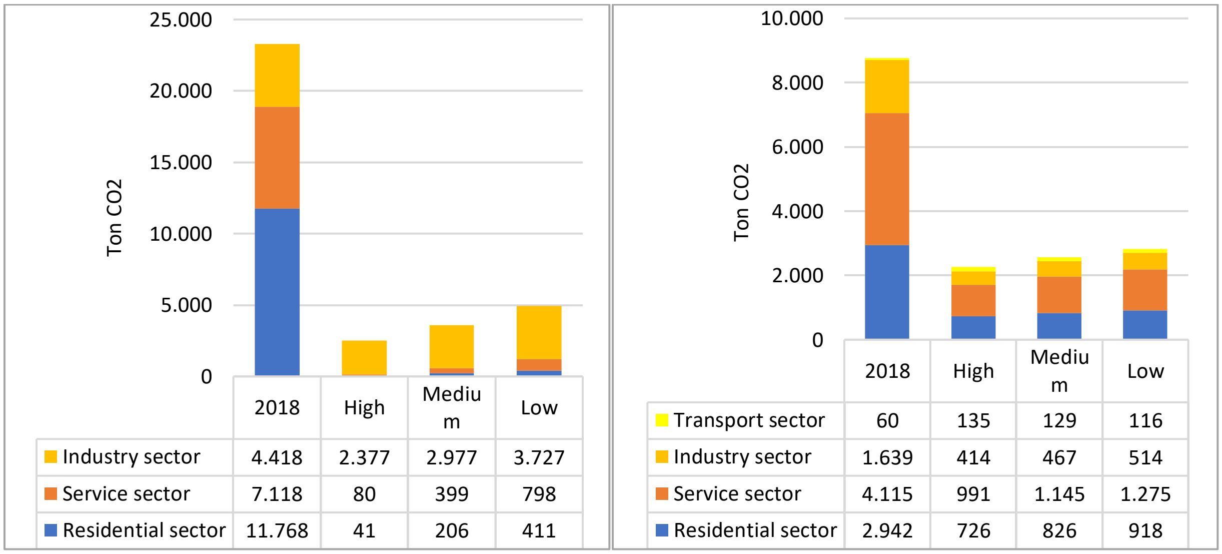
Most of the CO_2- emission in the status quo (2018) is assigned to the transport sector (78%), the residential sector (10%) and the service sector (8%). Because of the switch of the fuels in the transport sector (higher share of biofuel and electricity), the amount of the CO_2- emissions of the transport sector in the High scenario can be reduced by 57% compared to the status quo (2018). Because of the high amount of the switch of fossil fuels (especially coal & derived) to renewable sources and the high share of renovated buildings, the CO_2- emissions of the service and residential sector in all the scenarios decrease compared to the status quo (Figure 31).



	2018	High	Medium	Low
Industry sector	6.057	2.790	3.443	4.240
Service sector	11.233	1.071	1.544	2.073
Residential sector	14.710	767	1.031	1.329
Transport sector	115.975	50.145	53.480	56.809

Figure 31: Share of the total CO_2- emissions by sector in Växjö

In the status quo (2018) of Växjo, the CO_2- emissions for heating is higher than the CO_2- emissions for electricity (Figure 32). This is the result of the use of coal & derived (6%) in the district heating and the use of fossil oil (1%) and LPG (1%) to cover the heating demand. Because of the use of fossil -free-fuels in the district heating and the lower use of fossil oil in all scenarios, the CO_2- emissions for heating are in all scenarios lower than the CO_2- emissions for electricity. Especially the CO_2-emissions for heating and electricity in the residential and the service sector have a big decline in all scenarios compared to the status quo (2018). The only increase of the CO_2- emissions is in the electricity production of the transport sector. The reason is the higher share of e-mobility in the scenarios compared to the status quo (2018).

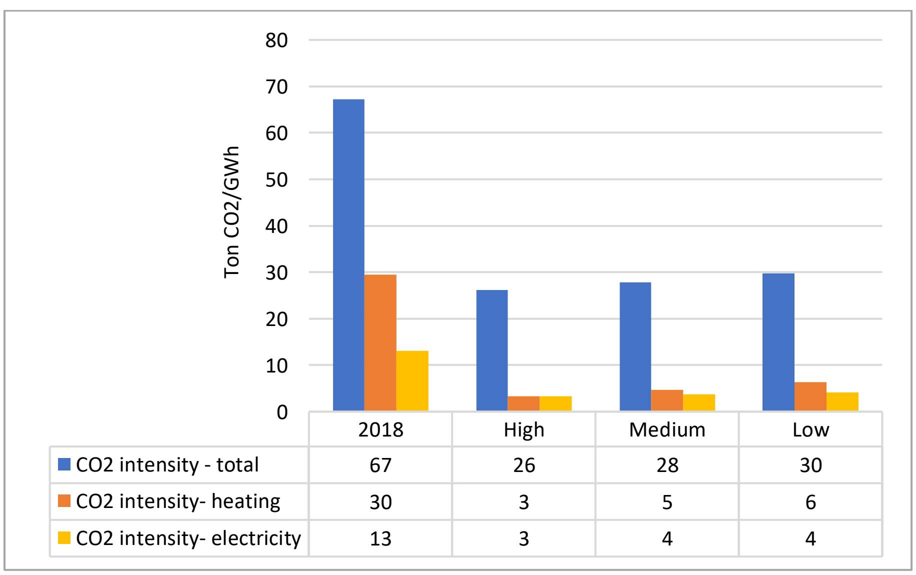


	2018	High	Medium	Low
Industry sector	4.418	2.377	2.977	3.727
Service sector	7.118	80	399	798
Residential sector	11.768	41	206	411

	2018	High	Medium	Low
Transport sector	60	135	129	116
Industry sector	1.639	414	467	514
Service sector	4.115	991	1.145	1.275
Residential sector	2.942	726	826	918

Figure 32: CO_2- emissions for heating by sector (left figure) and for electricity by sector (right figure) in Växjö

By comparing the CO_2- intensity for heating and electricity, in the status quo of Växjö, the CO_2- intensity for heating is higher than for electricity (Figure 33). The reason is the 2.7- times higher CO_2-emissions for heating compared to the CO_2-emissions for electricity, even the heat production is 17% higher than the electricity production. Because of similar CO_2-emissions for heating and for electricity in all scenarios (Figure 32), the CO_2- intensity for heating and electricity is also nearly similar in the scenarios. Furthermore, the difference between the total CO_2-intensity and the CO_2- intensity for heating and electricity shows, that a high CO_2- intensity is also assigned to the transport sector.

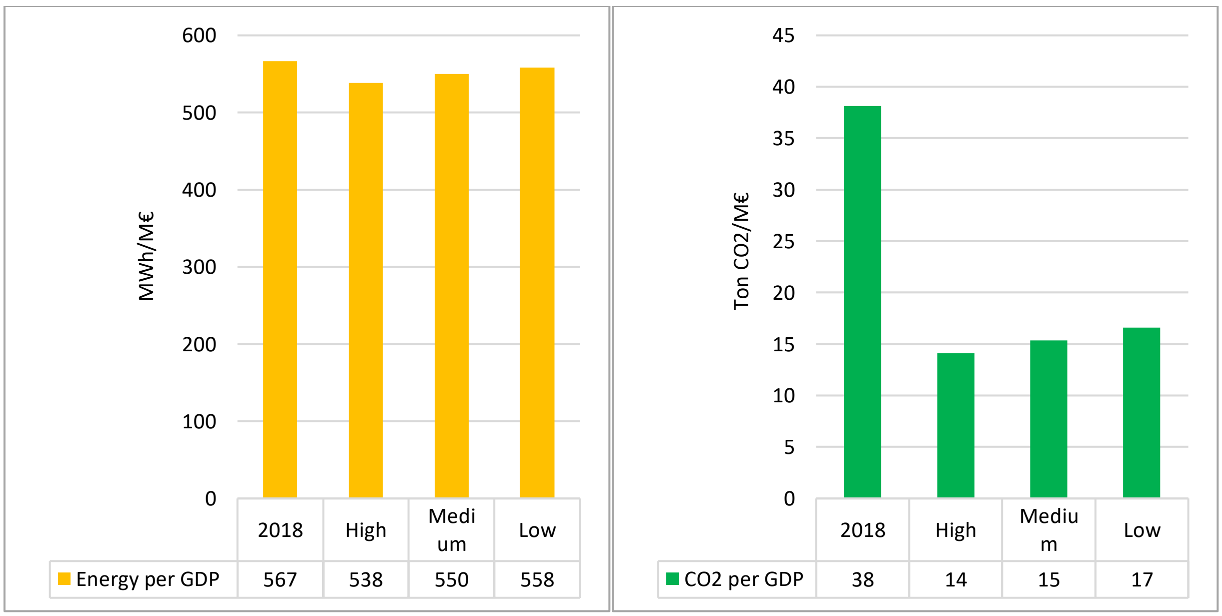


	2018	High	Medium	Low
CO2 intensity - total	67	26	28	30
CO2 intensity- heating	30	3	5	6
CO2 intensity- electricity	13	3	4	4

Figure 33: CO_2- intensity of Växjö in total, for heating and for electricity

In Figure 34 are shown the economic indicators (Energy per GDP/ CO_2 per GDP) of Växjö. The indicator Energy per GDP is calculated by the division of the final energy demand and the GDP of Växjö. Because of lower final energy consumption, the indicator Energy per GDP decreases in the scenarios compared to the status quo (2018). In the High scenario, the energy per GDP is about 5% lower than the status quo (Figure 34- left figure).

The comparison of the economic indicator CO_2 per GDP shows, that because of the high decrease of the CO_2- emissions in the scenarios (Figure 31), the decline of the CO_2 per GDP in the scenarios compared to the status quo is much higher than of the Energy per GDP. In the High scenario, the CO_2 per GDP is about 63% lower than the status quo (Figure 34- right figure).



	2018	High	Medium	Low
Energy per GDP	567	538	550	558

	2018	High	Medium	Low
CO2 per GDP	38	14	15	17

Figure 34: Economic indicators of Växjö- Energy per GDP (left figure) and CO2 per GDP (right figure)

7 Potential barriers to implementation of energy and climate strategies for Aarhus and Växjö

7.1 Aarhus, Denmark

The transition to sustainable energy coming from solar and wind power in Aarhus is already at its advance stage, however there are still some barriers to the full implementation of such systems:

Starting from the essential uncontrollable factors which are dependent on the nature itself – as majority of energy production depends on whether the sun is shining, or the wind is blowing. This leads to fluctuating energy production from the sun and wind. **The positive aspect of this issue is:** the building sector will advance due to the fact that the buildings will have to be more flexible and able to cope with these fluctuations, calling for the development of technology that is able to even out production and consumption.

With more focus on electrical-powered transport and supporting infrastructure (e.g. hybrid and electrical cars, power needed for charging stations for electrical cars), increase in demand for electrification will put more stress on energy production. **The positive aspect of this issue is:** the resulting need to create balance in the energy system will call for the overall reduction in energy consumption advancing thus the progress towards the CO_2-neutrality.

The transition from fossil fuels to sustainable energy in industrial processes, i.e. transition from fossil fuels to biomass and refuse, may face some difficulties for businesses due to extensive costs and complicated tax structure. **The positive aspect of this issue is:** this calls for a general collaboration between energy companies, consultants and government bodies leading to provision of professional consultancy and funding opportunities to support change of technology in industry.

The transition to sustainable energy also calls for major investments in new energy infrastructure (wind turbines) and energy plant. **The positive aspect of this issue is:** on one hand, citizens will be pressured change their choices and behaviour related to the energy use and to lower energy consumption in buildings, eliminating thus the need for new infrastructure. On the other hand, smart energy optimization for buildings and tougher criteria for renovation of existing buildings will also lower the energy consumption but also lead to raising the overall construction standard and general transition to sustainable models of construction.

Broad social involvement and commitment to the green transition is challenged by many people who are not interested in nor motivated by the climate agenda. However, this is essential for reaching the targets in those areas that are outside the influence of the city authorities (e.g. private homes, private motoring). **The positive aspect of this issue is:** this is the situation that can be easily changed through efforts to raise awareness, that will eventually increase the motivation to take part and create common ownership for climate management.

7.2 Växjö, Sweden

The progressive environmental work of the City of Växjö has brought the city closer to becoming a leading green municipality and a fossil fuel free city. However, the city is still facing some barriers to reaching its green targets:

Introducing renewables in the transport sector continues to be the greatest challenge. **The positive aspect of this issue is:** City of Växjö will put more effort into green urban planning so as to reduce the need for cars and promote cycling and walking. Additionally, more efforts are put into research in biomass gasification, biodiesel and ethanol blends, which may result in faster shift from the dependency on fossil fuels to renewable energy sources.

There is a new legislation by the Swedish government that municipalities cannot set stricter rules on the energy consumption of new buildings than national regulations. These are equally big challenges. **The positive aspect of this issue is:** City of Växjö will have to put more effort into the development of new technologies and materials in the construction sector, thus minimizing the need for energy consumption by having well-insulated and robust buildings.

The locally-sourced renewable energy still doesn’t meet the needs of the city. The City of Växjö depends in part on the national electric production, which includes nuclear energy. **The positive aspect of this issue is:** as the City of Växjö sets an example of climate-change mitigation through locally-sourced renewable energy towards becoming the fossil-fuel free by 2030, this will inspire the whole country to put even more effort into fast transformation of its energy system.

7.3 General barriers for implementing READY solutions

A) Technology integration

Within in the READY project, a number of technologies have been implemented, contributing to the above-named targets and strategies. The following section summaries the barriers for the integration of following technologies, identified in different deliverables, including especially D8.5, but also others have been used (e.g. D.3.4.2)

7.3.1 Thermal photovoltaic panels (PVT)

- The main barrier for their market adoption is their high initial costs, thus funding schemes for PVT are extremely important to ensure the expansion of the technology. However, as a hybrid technology, PVT systems often suffer from a regulatory confusion as to their classification. Especially when it comes to subsidies and incentives, PVT are often stuck in a limbo due to their delivery of both electricity and heat.

7.3.2 Battery storage solution (2nd life batteries)

- There are several legislative barriers at the European and member country level for using battery storages, i.e. a lack of definition, lack of incentives, and double fee imposition.

- Low tax levels on electricity are currently preventing the technology from penetrating the market.
- Uncertainty linked to the manufacturers and materials included inside of the batteries.
- Unclear responsibility for the final disposal due to the different actors involved,
- Uncertainty about the future of the market, bringing some actors to argue that it would be better to directly recycle EV batteries instead of reusing them

7.3.3 Electric vehicles (EV) charging stations

The main barrier was the decision of parking lots for only EVs. As a result, citizens complained that they couldn't charge their EVs as fossil cars were blocking the charging station.

7.3.4 Waste-water heat recovery at building scale

- Limited economic feasibility (due to high investment costs) and the potential need for maintenance are two factors that could potentially hinder the sale of the technology according to partners.
- Challenges for the estimation of heat recovery potential and efficiency of the system.
- In Sweden, one main issue was a poor feed in tariff on the district heating grid between blocks. Therefore, the energy should be used in the building itself for the system to be feasible.

7.3.5 Smart Heat Metering

- The norm for heat energy meters (EN-1434) is only directed at meters used for accounting, and is not sufficient for the operational optimization that the smart meters are used for. Thus, the district heating companies should impose additional requirements for the norm when incorporating the smart meters into the system. Ideally, the norm should be revised.

7.3.6 smart interface

- The development and the implementation of such platform require the involvement and data access of all parties. However, to get all the parties onboard can be difficult, since it represents a new way of doing business (opening data versus protectionism).

7.3.7 Low temperature DH

- According to deliverable D.3.2.2, lowering the DH supply temperature for an existing Danish single-family dwelling built in the 1960'ies/early 1970'ies from 70/40°C to 55/30°C results in 9.5 days where a room temperature of 20°C cannot be maintained. To avoid this, the building envelope can be upgraded in an energy retrofit. However, the economic efficiency of the investment in the measures needed has to be considered.

7.3.8 District cooling

- The absence of high temperature heat sources in Aarhus during summer time. Unlike in Växjö the power and heat generation are reduced in summer time, thus absorption chillers are not an ideal choice for cooling production, as exemplified with e.g. the case of DNU (see report D3.1.2).
- The taxation structure, regulations and ownership structures are significantly different in a way that does not favour replication of the technical setup. For these reasons continuing with sea-water chillers and/or heat pumps is adviced. Also DNU type setups are worthwhile to persue.

These options may not currently be economically feasible, but appear stronger in the long run compared to the setup in Växjö which depends on high temperature waste from primarily CHP.

- The deliverable analyzing the DC potential in Aarhus (D.3.4.2) points out that taxation structure, regulations and ownership structures are significant barriers to replicate a system like the one in Växjö. Furthermore, unlike in Växjö, the power and heat generation are reduced in summer time to lower costs and increase energy efficiency. This means that absorption chillers are not an ideal choice for cooling production. However, novel combinations of absorption chillers and large-scale solar thermal installations could potentially overcome this issue (see D.4.7.1)

7.3.9 Other barriers

- There is a **scarcity of incentives and subsidies from public authorities**, or the existence of subsidies that do not take into account innovative technologies. This is the case for PVT systems for instance, a hybrid technology that often struggles to correspond to one category or the other.
- **Outdated or absent regulations, complex governance structures and absent infrastructures** further represent major barriers to the development of these new technologies. An example is the **lack of infrastructure for electric vehicles** for instance or the **complexity of bringing together different actors** from different sectors in order to develop integrated systems for energy efficiency.
- The project **management complexity** of major infrastructure project: delays, approval and negotiations between the different parties, etc.
- housing companies reported issue related to the need of changing **local regulations**, reducing the **time schedule** or being aware of potential delays, and the need for **upgrading the district's infrastructures together with its housing**

B) Systemic integration:

The following barriers are resulting from a general perception of the technologies and challenges described as well a general overview of the European situation:

Flexibility of local district heating (DH) networks for compensating variable renewable energy sources, especially wind power: CHP and power-to-heat are unable to compete with heat-only boilers that use tax-free biomass under the present price and tax conditions in Denmark and Sweden. This is due to following regulatory barriers and barriers for the current energy market designs for exploiting this potential for flexibility[11]:

Combined heat and power (CHP) is widely integrated in the power market, but it is threatened by low electricity prices due to the increasing amounts of wind power.

Power-to-heat technologies, electric boilers and heat pumps are blocked by high tariffs and taxes

[11] Skytte, Klau et al: Barriers for District Heating as a Source of Flexibility for the Electricity System (June 6, 2017). Journal of Energy Markets, Forthcoming. Available at SSRN: https://ssrn.com/abstract=2981610

Waste heat utilization: There is significant heat recovery potential from waste heat sources, including industrial waste heat and waste heat from sewage water, supermarkets cooling etc. However, these resources are not utilized as much as their potential would allow. Important barriers include:

Identification: For planning DH decarbonization strategies, data on waste heat sources is little available and sometimes confidential. This is especially true for unconventional waste heat sources, such as data centres, tunnels and subway stations as well as cooling from offices or supermarkets.

Low interest and know-how of the waste heat owner: The extraction of waste heat might change the characteristics of the processes and available waste heat potentials might preferably be used within the company itself. Also, there are diverging views on the value of the waste heat, i.e. DH network operators are trying to minimize expenditures for waste heat supply and private companies want to exploit their waste heat potential in monetary terms.

Temporal mismatch: This concerns especially the seasonal mismatch to the heat demand, especially surplus waste heat in summer times and the resulting supply competition between waste heat and most of the renewable heat sources (solar- and geothermal energy as well as heat pumps using sewage water or ambient heat)

Long payback periods of waste heat utilization investment: since waste heat utilization has potentially high investment costs, together with relatively low total revenues, long payback periods and high risk due to possible future changes appear (e.g. possible improvements and adaptations of the processes or the company might go bankrupt or move to other premises).

Dependency on the electricity markets: low-temperature waste heat utilization require heat pumps, and thus an uncertainty due to the future development of the average price and its volatility appear. Also, HPs can only operate on the electricity market with additional efforts (continuous waste heat supply)

Limited standardization of the waste heat utilisation: due to Individual and site specific boundary conditions as well as a higher number of stakeholders to be considered resulting in a high effort for planning, designing and operating the system. Also there is a lack of standardised contracts.

Little awareness of the potentials of waste heat utilisation on a national level: Waste heat, especially from unconventional sources, is often not considered / electricity centred view on the energy system. Also modelling tools are not considering the full potential of waste heat.

It is difficult to sell waste heat as a “green” product to end users and customers: District heating sometimes still perceived as being “fossil-fuelled” and also the related industry processes are driven by fossil fuels sometimes. Extra costs for waste heat utilization are difficult to justify passing on to the customer. In contrast, the electricity sector offers green electricity and services for similar prices as non-green electricity, and there is a clear commitment and pathways for 100% renewable electricity.

No or very fragmented legal frameworks for driving waste heat recovery: this is including limited standardised permit procedures and the uncertainty on the stability of regulative boundary conditions.

In Denmark, SKAT[12] puts a tax on **surplus heat from Industry** of 33-pct. of the price for the heat sold[13]. This apply for all industries producing goods that uses fuel from which the companies have obtained a reduction in taxation (usually fossil fuels). The resulting heat price is not cheap enough for the district heating company to compete with other alternatives (such as biomass-based production or heat pumps using sources that are not taxed).

System Integration: The integration of different energy networks, i.e. the electricity grid, the gas as well as the district heating (DH), district cooling (DC) and/or district heating and cooling (DHC) network, also referred to as "sector coupling" or "sector integration", is considered one of the key measures for decarbonizing the energy system. However, following barriers apply[14]:

Complexity: An increasing level of system integration results in an increased complexity for planning, designing and operating of the integrated energy system. This is including

- A higher number of optimization parameters and different time responses of the systems implemented as well as
- Multiple stakeholders involved that have different and sometimes contradictory interests together with individual regulatory boundary conditions. Further on, there is
- A general lack of experience for high system integration levels due to a limited number of fully implemented best-practice examples, together with
- A general lack of experts for planning, installation and operation of such systems. Finally,
- an insufficient availability of suitable products/services for enabling an optimized sector integration can be seen on the market, together with
- A limited interoperability of the different systems and technologies due to low level of standardization activities. Also,

a. A highly integrated and interdependent system offers multiple gateways for attacks, thus resulting in an increased threat to cybersecurity.

Social/ Business model:

b. Silo thinking of many actors and stakeholders including decision makers, utilities and network operators might reduce the interest to invest in / operate integrated energy infrastructures. This includes
c. A possible change in the existing value chains in the energy system and thus some (established) stakeholders might lose market shares. Further on,

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[12] SKAT is the taxation authority in Denmark

[13] see Deliverable D.3.1.2_Report on feasibility of the investigated technologies for utilising surplus heat from industry

[14] According to the IEA DHC TS3 SWOT assessment of hybrid energy networks (unpublished)

d. The social acceptance of the integrated solution might be lower, due to a low understanding and awareness of the opportunities offered by the coupled system while being confronted with higher investment costs and increased system complexity.

Economic / financing:

e. Many banks are still reluctant to provide financing to RES and other innovative projects due to a lack of credit history and uncertainty about financial arrangements with the buyers
f. Risk of stranded investments in HEN / coupling points due to uncertainties of the future development of key enabling factors such as
    i. political situation and framework (including subsidies and taxes for the implementation of renewables and energy efficiency measures) as well as
    ii. regulatory framework and market design;
    iii. the future market development (including average electricity prices / times with low electricity prices, number of flexibility providers / degree of diffusion of coupling points and resulting competition) as well as
    iv. the availability of waste heat as a source for HPs.

Systemic /Infrastructure: The overall higher electricity demand due to a high integration of the energy system and the resulting higher level of electrification will require additional fossil-free electricity supply as well as transmission and distribution infrastructure and thus investment costs (if not planned and coordinated properly)

8 Recommendations

This section concludes with a set of recommendations for decision-makers in local and regional governments to accelerate the adoption, replication and upscaling of smart city measures in their territories. Political, technical, financial and social challenges had to be overcome during the assessment and planning phase of implementation. The following conclusions and recommendations could be identified that shall support the further replicability and upscaling of smart solutions within Europe and beyond.

8.1.1 Recommendations to local governments

General recommendations[15]

1. Cities **must adopt a strong governance towards energy efficiency and sustainability**. Despite changes in the leading political parties, **sustainable policies** must be ensured through time. Thus, the different measures for EVs or EE in buildings for example, will be consistent and the market for solution providers will be easier to enter.

Renovation and building retrofitting

1. To **reassure potential customers about the efficiency of a solution**, the benefits demonstrated in every past project should be **disseminated** and promoted. This would enable to make new solutions known and provide **references**.
    - The pilot projects implemented during READY highlighted the **importance of convincing tenants on the positive impact of the technologies** installed. The **acceptance and awareness of tenants** indeed constitutes another important obstacle, this is including to
    - **improve the implementation process** for the refurbishment of old buildings and to monitor energy and water consumption **by shortening the time schedule through the preparation of more temporary apartments** for the tenants that wait for their apartments to be renovated.
    - **Actively communicate** positive effects of the improvement measures, such as lower indoor noise and the increased living comfort, the possible improved general perception of the neighbourhood, leading to higher social standards and improved quality of life, including less criminality.

Low temperature district heating / waste heat utilization

1. **the promotion of low temperature DH** as part of the energy supply and climate strategy by local authorities and to integrate low temperature DH as part of the urban development projects (e.g. undertaking a long-term cost-benefit analysis, establishing low temperature DH zones or maximum temperature requirements for buildings etc.).

[15] According to Deliverable D8.5

2. **Identify and make available local low temperature heat sources** such as sewage channels, waste water treatment plants, data centres, tunnels and metro stations, as well as cooling from buildings (offices, hospitals, supermarkets, shopping malls).

3. **For considering the costs of retrofitting** of the building stoke to comply with lower supply temperatures, methods like "Cost of conserved energy"[16] or alike should be utilized. This is including the investigation of measures which are not private-economic efficient and if they may be economic efficient for district heating companies. I.e. development of new business models.

EV charging stations[17]:

1. **More standardisation and interoperability**: There are currently substantial differences in back-end communications, payment and power supply offers of the EV charging infrastructure. The EV driver then needs a variety of memberships, accounts and cards, to charge its car in different charging stations. Recommendation: Developing standards and promoting interoperability, both for drivers and charging network operators is crucial for market growth.

PV generation

1. **Denmark: PV on municipal buildings** is faced with significant constraints as to ownership, size and application. These constraints are serious barriers for PV deployment by several municipalities, and proposals to lift same barriers have been submitted to the government. Recommendation: municipalities should benefit from the special regulations and higher FIT in force

8.1.2 Recommendations for national and European authorities

General:

1. **Set a uniform CO_2 price:** The most efficient type of policy measure to drive the decarbonisation of energy, increasing the share of renewables and waste heat, is to ensure a level-playing field for instance with a carbon tax or an extension of the scope of the EU ETS to e.g. buildings.

2. **Promote best practices:** EU countries have different market conditions and regulatory frameworks. The European Commission should promote good practices such as those realized in the READY project, for example, in the framework of concerted actions aiming at supporting the implementation of EU legislation.

[16] Markussen, Michael.Heat Pumps for Domestic Hot Water Preparation in Connection with Low Temperature District Heating . 2013. EUDP 11-I, J. nr. 64011-0076

[17] According to Deliverable D8.5

3. **Long-term-planning:** The EU could play an active role in fostering the development of long-term planning for cities, also in connection with providing more funding opportunities for energy supply and distribution infrastructure (i.e. district heating).

Building retrofitting

1. **Optimize the processes related to building retrofitting** with regards to local regulations, flexible time schedules in order to account for potential delays and to coordinate with the upgrading processes of the district's infrastructures

Integrated energy systems:

1. **Support digitalization initiatives,** together with a higher penetration of sensors and other data collectors, since this could open many opportunities in design and operation of the integrated energy system (including advanced planning tools as well as predictive analytics and optimization)

2. **Development of methodologies for assessing the risk** of investing into integrated energy infrastructures, considering the local boundary conditions including the policy framework (taxes and subsidies), regulatory constraints, electricity prices, network tariffs, as well as availability of renewable resources. This should include sound scenario calculation for the technical lifetime of the assets.

3. **Create suitable incentives for investing and operating integrated energy infrastructures,** i.e. reflecting environmental externalities in energy prices. Adapting current economic calculation models do include the actual costs of emissions due to the utilization of fossil fuels (e.g. local health issues and global warming impacts).

District heating and cooling / waste heat utilization[18]

1. **Denmark: fixed payment per unit of energy:** New rules have been suggested that implies a fixed payment per unit of energy, but are not yet agreed-on. These rules, if agreed upon, will imply a slightly less payment for the same excess heat, although quite a few that has not been paying anything until now will have to pay tax if the suggestion is agreed-on.

2. **Denmark: remove regulatory barriers for district cooling:** modify the taxation structure, regulations and ownership structures for implementing district cooling solutions

3. **Setting up a suitable national energy policy and regulatory environment,** providing adequate

[18] some of the following recommendations are based on https://www.euroheat.org/uncategorized/recommendations-waste-heat-recovery-urban-agenda-energy-transition-partnership/

ground and incentives for the development of low temperature DH systems This is including

- setting ambitious CO_2 targets, establishing specific fiscal measures promoting the use of low temperature heat, etc.
- direct/indirect subsidies (e.g. investment grants, support schemes and/or dedicated financial instruments

4. **EU Level: Define a consistent EU legislative framework**: The recently adopted energy package, in particular the amendment to the Energy Efficiency and renewable energy Directives acknowledged the role of waste heat for energy efficiency and decarbonisation. However, the definition should stay uniform across EU legislation. Also, with regards to article 23 of RED II, when Member States want to count waste heat towards their renewable heating and cooling target, the renewable share increase raises from 1.1 to 1.3 percentage point per year

5. **Revise the norm for heat energy meters** (EN-1434) in order to make it suitable for the operational optimization and not only accounting, as it is done currently.

6. **Ensure the cooperation between governance levels:** A structured dialogue to ensure the alignment and coherence between local actors such as cities and EU level decision-makers is absolute necessary. Opportunities should be provided for the local level to share its experience of decarbonisation and to participate more actively in the definition of EU policies. Authorities should consider waste heat utilisation when spatial planning, designing, building and renovating urban infrastructure. This provision should be further strengthened.

7. **Promote advanced risk management mechanisms:** Waste Heat recovery projects have rather high CAPEX and financial risks (e.g. change in the availability or quality of the waste heat). They require long-term commitments with long pay-back periods, sometimes not compatible with the constraints associated with the development and operation of businesses. These risks are a major challenge to the development of more projects. Comparably, geothermal energy projects which have similar but not identical challenges already benefit from risk insurance or risk mitigation schemes. → investigate the mitigation of risks for waste heat projects, for example, insurance schemes and risk analysis methodologies.

8. **Recognise waste heat as a sustainable investment:** There is an increasing demand for sustainable investments and bonds. The recognition of the sustainability of waste heat projects in the EU taxonomy[19] and the European Investment Bank lending criteria is a positive and encouraging signal for investors and should promote further investments.

9. **Support the development of standardized contracts and business models:** Overall waste heat projects are rather complex and there is great diversity or contracts and business models depending

[19] The report of the Technical Expert Group on Sustainable Finance (TEG) lists waste heat as an economic activity that makes a substantial contribution to climate change mitigation, the report will feed into an EU legislation establishing a unified classification system for sustainable economic activities; https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf

on the source, number of players involved, size, technology, etc. Therefore, it is important to identify best practices for business models derived from real projects.

EV charging stations[20]:

1. **More providers of charging stations**: an increased competition between hardware providers would result in a decrease of the cost for an EV charging station. Even if their cost has substantially declined in the past several years, their cost remains high for municipalities, especially if they have to add costs for land procurement, administration and maintenance.

PV installations and supply[21]

1. **Sweden: Clarify the direct capital subsidy programme:** The current programme will officially expire 31st of December 2020. Since the interest for this subsidy for several years have been larger than the budget, it is estimated that the government need to allocate about 2.4 billion SEK if everyone who has applied for the support will receive support. 2.4 billion SEK is a very large increase of the budget (The budget for 2019 is 736 million SEK).

2. **Sweden: Energy tax also on the self-consumed PV electricity**. The tax law is a major hurdle for larger real estate owners. This tax has a negative impact on the market segment of large commercial PV systems (>255 kWp) and should be modified.

3. **Denmark: Financing and cost of support measures**: The government provides economic support for PV installations in terms of mentioned feed-in and auction schemes. However, the government has declared its wish completely to phase out economic support for PV deployment. Recent developments in commercial PPA schemes may turn out to be a new source of support for PV.

4. **Denmark: Grid access fees**: The Danish utilities in 2010 announced, that they will not charge PV system owners for access to the grid (related to the use of the net-metering scheme), and several distribution utilities will not charge for the metering system needed to benefit from the net-metering scheme. However, the Danish regulator has found this free service in principle illegal and a new process needs to be developed.

5. **Denmark: The new energy plan** from 2020 up to 2030 has now been prepared and agreed upon on the political level. Strategies and action plans still have to be minted out in more detail. The new energy plan is expected to provide a better framework for the PV technology i.e. Technology neutral tender/auction schemes; Strong focus on using the market to control deployment of

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[20] According to Deliverable D8.5

[21] From the READY project with additional information from the National Survey Report of PV Power Applications in Sweden 2018, Prepared by: Johan Lindahl, Cristina Stoltz, Amelia Oller-Westerberg and Jeffrey Berard; https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Sweden_2018.pdf AND the National Survey Report of PV Power Applications in Denmark 2018, Prepared by: Peter Ahm, PA Energy Ltd. https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Denmark_2018.pdf

energy technologies; Promotion of an EU scale energy market; Development of a Danish integrated and flexible energy system

6. **Create dedicated funding schemes for PVT** and / or include PVT collectors in PV or Solar thermal funding schemes

7. **Remove legislative barriers for installing and operating batteries** at the European and member country level, i.e. a clear definition, significant incentives, and remove double fee imposition

8.1.3 Recommendations to industry and business partners

(Further) develop and implement market ready and scalable solutions for

- More flexibility in the energy system, including
    - Thermal and electrical storages as well as demand side management
    - Advanced predictive demand and supply models as well as control strategies
    - Advanced digitalization solutions, including suitable sensors and other data collectors, for optimized design and operation of the integrated energy system (including advanced planning tools as well as predictive analytics and optimization)
    - Advanced coupling points Including heat pumps, electric boilers, electrolysis processes and CHP plants on different scales and for different applications (utilities, industries, service sector, tertiary buildings, residential houses etc.)

- More cost-effective building retrofitting, including development of new technologies and

materials in the construction sector.

8.2 General

- Minimizing the need for energy consumption by having well-insulated and robust buildings
- Increasing the economic feasibility of waste-water heat recovery systems including lower investment costs and reducing the maintenance efforts

- EV charging stations[22]:

    - An improved digital solution: to convince drivers to switch from a fossil-fuel car to EV, the digital interfaces when charging an EV must be intuitive, so that it doesn't represent an additional barrier in the use of an EV. The improvement of digital tools could also

[22] According to Deliverable D8.5

enable to interact more efficiently with the grid and thus, integrate renewable energy sources.

- <u>Batteries</u>
    - Reduce uncertainties linked to the manufacturers and materials included inside of the batteries as well as setup a scheme for ensuring responsibility for the final disposal of the batteries

Setup new collaborations between energy companies, consultants and government bodies including co-creating and design thinking involving end users and regulatory sand boxes.

9 List of Abbreviations

Abbreviation	Explanation
API	Application Programming Interface used to interface computer programs
CRISP-DM	Cross Industry Standard Process for Data Mining
CSV	Comma-Separated Values
DH	District Heating
ETL	Process to Extract, Transform and Load data from various structured data sources
KPI	Key Performance Indicator
PVT	Hybrid solar module of Photovoltaics and Thermal energy
RMS	Root Mean Square, used as effective value in electrical engineering
SCIS	Smart Cities Information System
SDK	Software Development Kit
SoC	State of Charge, an indicator for the charging status of a battery