The IEA CHP and DHC Collaborative

CHP/DHC Scorecard: Sweden

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Executive Summary

Sweden's cold climate and framework of policies promoting sustainability make combined heat and power (CHP) and district heating and cooling (DHC) solutions attractive options to complement the country's current energy infrastructure. In 2013, Sweden's CHP capacity is 5.0 gigawatts electric (GW_e), of which 1.4 GW_e serves industrial sites and 3.6 GW_e is linked to district heating (DH) networks. More than half of the population is served by DH networks. However, a shift towards lower-cost competing technologies for heat and power generation, such as wind power and heat pumps, along with market saturation and improved energy efficiency in buildings have contributed to a slowdown of CHP and DHC deployment.

Along with high energy and CO_2 taxation on fossil fuels for heat production, Sweden's renewable electricity certificate programme creates a major incentive for biomass-CHP, but all certificate-receiving plants initiated prior to 2003 were phased out of the certificate programme at the end of 2012, leading to a drop in electricity production from CHP. Similarly, CHP heat production as a share of DH fell slightly to 49% from its peak of 52% in 2011 (though still up from 30% in 2000). The decrease, which can be attributed to low electricity prices, competition with other heat technologies, and phasing out of some plants from the certificate programme, has come primarily from main activity CHP production, while industrial CHP has remained relatively stable.

DH networks make up 58% of total energy use for space and water heating in residential buildings and 79% in commercial and public buildings. Fuel inputs to DH are varied, but in recent decades biomass has become the major fuel source with fossil fuels making up 19% of total fuel input as of 2013. Industrial excess heat contributed 4.8 terawatt hours (TWh), or 8.3% of DH production in 2013. District cooling, a relatively new market in Sweden, is growing, reaching just under 1 TWh of deliveries with an economic potential for an additional 2 TWh by 2030.

CHP and DHC deployment in Sweden has historically been supported by a number of incentives, including subsidies for infrastructure development, energy efficiency projects, and technology research and development. Recently, however, expansion of both CHP and DHC has slowed, as a result of market saturation and demand baseload reduction from energy efficiency in buildings.

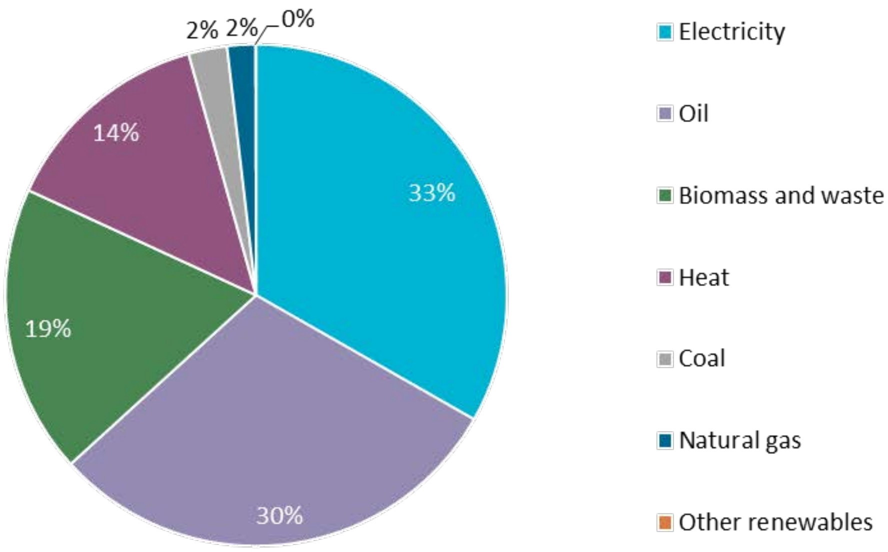
Despite this slowdown, Sweden continues to create innovative solutions in the CHP and DHC markets, such as new pricing structures for DH that allow it to compete with other technologies. New markets have also contributed to the economic viability of CHP and DHC. In addition, increased CO_2 taxation outside the European Union Emissions Trading System (EU ETS) gives incentives for conversions from fossil fuel-based heat to DH systems.

Sweden's current scorecard rating is a 4.5/5 when benchmarked against global best practices. Moving forward, Sweden should maintain a systemic approach in deploying modern, efficient CHP and DHC as part of an integrated and sustainable energy system. The creation of the Energy Commission presents an opportunity to outline a clear, stable path forward for energy policy in support of a sustainable energy system, considering the optimal use of efficient CHP and DHC technologies.

Energy Overview

In 2013, total primary energy supply (TPES) in Sweden amounted to 2.1 exajoules (EJ), of which nuclear energy accounted for the largest portion (35%), followed by oil (24%), biomass (22%), and hydropower (11%). Sweden was also a net exporter of 10 TWh of electricity (almost 7% of national electricity generation). Total transformation, transmission and distribution losses, including own use in the energy industry, amounted to 708 petajoules (PJ), where losses in nuclear power generation stood for the majority (443 PJ). Of the remaining 1.4 EJ of total final energy consumption, electricity accounted for 450 PJ, or 33%, followed by oil, biomass and waste, and commercial heat (Figure 1). The industrial sector was the largest final energy user at 555 PJ. The transport sector represented the second largest end user at 314 PJ, and residential buildings followed, consuming 294 PJ.[1,2]

Figure 1 • Total final energy consumption, 2013



Note: Coal includes peat and peat products.

Source: IEA (International Energy Agency) (2015), *Energy Balances of OECD Countries (2015 Edition)*, OECD/IEA, Paris.

Key message • The largest shares of Sweden's final energy consumption come from electricity and oil.

Heating demand in buildings

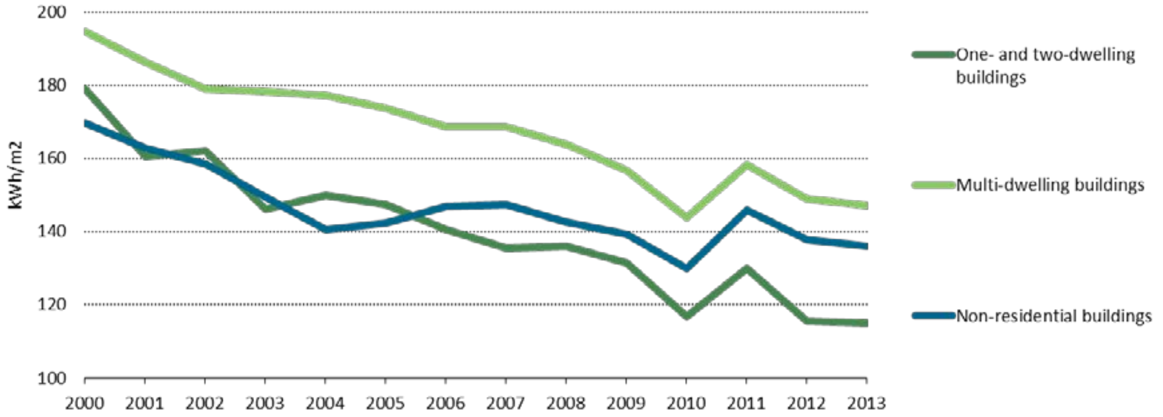
The demand for space heating in Sweden constitutes a significant part of overall energy consumption. Over the last decade, energy consumption for space heating and hot water

[1] The remaining 1.4 EJ of energy was consumed in other end-use sectors, which include agriculture, commercial and public services, forestry, fishing, and other non-specified end-uses.

[2] Further information on the energy policy context of Sweden can be found in IEA (International Energy Agency) (2013), *Energy Policies of IEA Countries: Sweden 2013 Review*, OECD/IEA, Paris.

declined, both in terms of the total final energy consumption and of the temperature-corrected[3] energy use. In 2013, 11% less total final energy was used for heating and hot water in residential and commercial buildings than in 2000, and temperature-corrected energy use for space and water heating in residential and commercial buildings declined by 18% during the same period.[4] This change is largely due to continued improvement of building envelopes in Sweden, along with energy efficiency improvements in heating equipment (e.g. heat pumps) in buildings and the energy intensity of district heat production. Since 2000, the average energy intensity (in terms of kilowatt-hours per square metre [kWh/m^2] for space heating and hot water) improved across both residential and non-residential buildings in Sweden (Figure 2).

Figure 2 • Energy for space heating and hot water, 2000-2013



Note: 2010 was a cold year, and the temperature correction methodology can yield over- or under-estimated results during periods of very cold or very warm weather.

Source: Swedish Energy Agency (Energimyndigheten) (2014), "Summary of energy statistics for dwellings and non-residential premises for 2013" (Energistatistik för småhus, flerbostadshus och lokaler 2013), ES 2014:06.

Key message • The average energy intensity of space and water heating improved in across building types since 2000.

Electricity generation

Nuclear and hydroelectric power together made up about 84% of Sweden's electricity generation in 2013, and fossil fuels played a minor role, at just 2.9% (Figure 3). The first major Swedish nuclear power reactor was commissioned in 1972. While most power generation was previously from hydropower, by 1985, eleven more nuclear power reactors were commissioned, nearly doubling Sweden's power production capacity.

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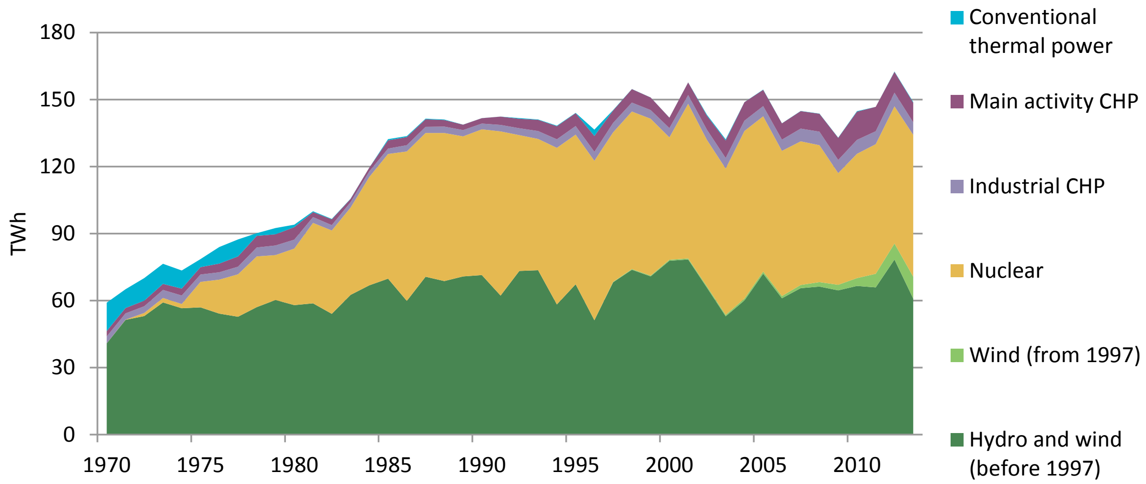
[3] "Degree days" measure how much the temperature deviates from a normal day, month, or year for a specific place. The Swedish Energy Agency utilises "degree days" (defined as days below 17 degree Celsius thus requiring heating) from 10 places in Sweden. Each location is weighed according to population size. A weighted degree day number that is representative of the country according to population distribution is then obtained through multiplying the degree days per location with its weight/factor and then summarizing all of them. The amount of degree days in a "normal year" is obtained through calculating the average number of degree days between 1981 and 2010.

[4] Swedish Energy Agency (Energimyndigheten), 2014.

Figure 3 • Electricity production, 1970-2013



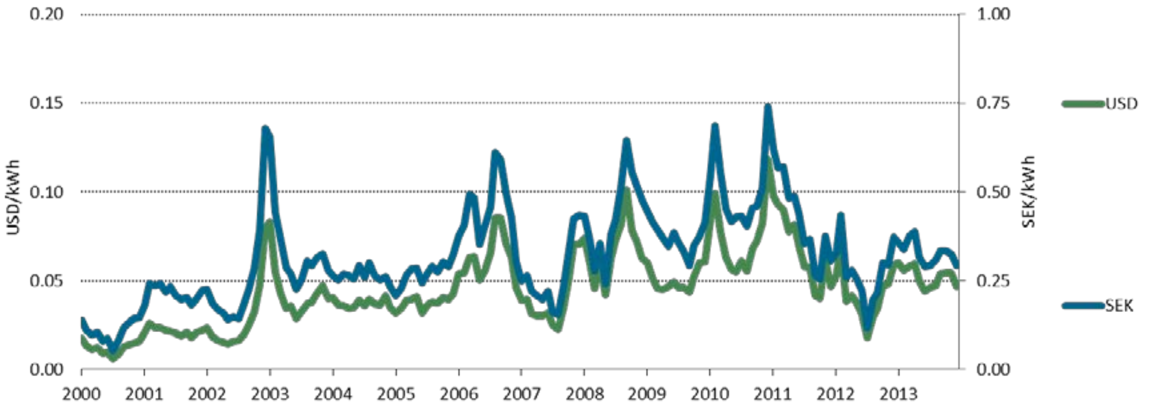
Note: Hydro and wind power are reported together until 1997, after which they are reported separately.

Source: Swedish Energy Agency (Energimyndigheten) (2015d), "Energy in Sweden: Facts and Figures 2015" (Energiläget i siffror 2015).

Key message • Low-carbon sources make up the large majority of Sweden's electricity generation.

The fast expansion of nuclear capacity created a surplus of electricity in Sweden, which led to prices as low as United States Dollar (USD) 0.01 per kilowatt-hour (kWh) in 2000. In this price environment, boilers were more often employed for DH production instead of CHP plants as investments in new CHP plants became unprofitable. During the period from 2000 to 2013, the price of electricity was volatile, with a maximum price 13 times greater than the minimum (Figure 4). Volatility in electricity prices is a result of a number of driving factors. Fluctuation in temperature levels is a main driver; as electricity is used extensively for space heating, changes in temperature affect electricity demand and therefore prices. The variability of wind power production also contributes, as well as congestion in interconnectors. Hydropower has a balancing effect, as the ability to control reservoir levels gives the system some flexibility, and counteracts some of the price volatility.

Figure 4 • Electricity spot price, 2000–2013



Notes: Prices are monthly average spot prices for the total system. USD exchanges rates are calculated on a monthly average basis.

Source: Board of Governors of the Federal Reserve System (2015), "Foreign Exchange Rates – H.10", www.federalreserve.gov/releases/h10/hist/ ; Swedish Energy Agency (Energimyndigheten) (2015d), "Energy in Sweden: Facts and Figures 2015" (Energiläget i siffror 2015); Organisation for Economic Co-operation and Development (OECD) (2015), "Monthly Monetary and Financial Statistics," *Main Economic Indicators* Database, accessed 28 October 2015.

Key message • Despite some volatility in recent years, electricity prices in Sweden remain low.

Climate Change Context

The goal of Swedish energy policy is to ensure the availability of electricity and other energy sources in both the short and long term in an energy market that functions under competitive conditions. The energy policy shall create the conditions for efficient and sustainable energy use, with a cost efficient energy supply, having a low impact on public health, the environment and the climate, as well as aiding the transition to an ecologically-friendly and robust energy system.[5]

One of the main policy actions taken in Sweden to address climate change has been the carbon tax, first implemented in 1991. Since then, a number of climate-related targets have been set. The targets for the Swedish Integrated Climate and Energy Policy to be met by 2020 are[6]:

- 50% renewable energy as a share of total final consumption[7]
- 10% renewable energy in the transport sector
- 20% increased energy efficiency compared to 2008[8]
- 40% greenhouse gas mitigation compared to 1990 (for the non-EU ETS[9] sector)[10]

In 2013, the renewable share of total final energy consumption in Sweden amounted to 52%, surpassing the 2020 target. 56% of the renewables target was met by biofuels used in industry[11] and CHP/DHC. Renewable electricity generation, in particular, has been promoted since 2003 via the electricity certificate programme, a market-based programme which incentivises renewable power.

In March 2015 the Swedish government announced the initiation of an Energy Commission aimed at forming a broad parliamentary agreement outlining the energy policy from 2025 to 2050. The agreement will focus primarily on electricity, and the role of nuclear power in the future Swedish energy system will be a key issue. The Commission will present a proposal in January 2017.

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[5] Swedish Energy Agency (Energimyndigheten), 2015b.

[6] Ministry of the Environment and Energy (Miljö och energidepartementet), 2008.

[7] The renewables directive (2009/28/EC) stipulates the methodology for calculating renewables: "The gross final consumption of energy from renewable sources in each Member State shall be calculated as the sum of:

(a) gross final consumption of electricity from renewable energy sources;

(b) gross final consumption of energy from renewable sources for heating and cooling; and

(c) final consumption of energy from renewable sources in transport.[…]

The share of energy from renewable sources shall be calculated as the gross final consumption of energy from renewable sources divided by the gross final consumption of energy from all energy sources, expressed as a percentage."

European Parliament, Council of the European Union, 2009.

[8] The energy efficiency target is stipulated as a total contribution from all sectors to reduce the total energy intensity, defined as TPES/GDP, by 20% between 2008 and 2020.

[9] Non EU-ETS sector refers to those sectors not already covered by the European Union Emissions Trading System.

[10] The target for greenhouse gas mitigation means reducing GHGs, CO_2 being the largest component, by 40% in 2020 as compared to 1990 or 33% compared to 2005 when the system was initiated.

[11] This includes both process heaters and auto-producers of electricity and heat.

Sweden is also part of the Intended Nationally Determined Contribution (INDC) submitted by the European Union (EU) in the context of the United Nations Framework Convention on Climate Change (UNFCCC) negotiations at the 21st Conference of the Parties (COP21) meeting in Paris in 2015, which commits the EU and its member states to a 40% reduction of greenhouse gas emissions by 2030, compared to 1990 levels.[12]

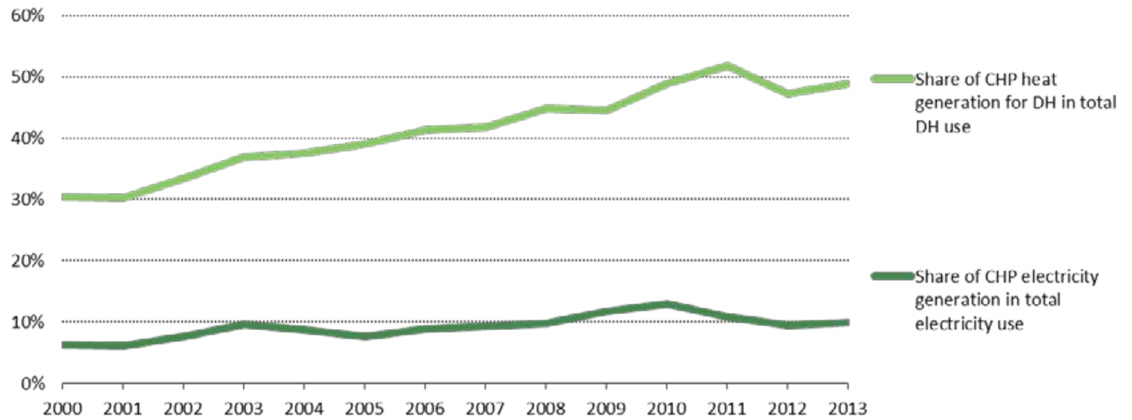
[12] Latvian Presidency of the Council of the European Union, 2015.

CHP/DHC Status: Technology, Applications and Market Activity

Sweden's reliance on nuclear and hydropower for electricity has created a market where the majority of heat delivered via DH networks comes from sources other than CHP. In 1983, the earliest year where data is available, only 11% of DH use was from CHP, because of low electricity prices due to the development of nuclear power which led to a greater market share for heat boilers as supply for DH networks. In the 1990s, support measures, such as investment grants, coupled with gradually increasing electricity prices and growing heating demand, made CHP increasingly profitable, and it gained in share of DH production.

The 2003 introduction of the electricity certificate programme reinforced this trend by incentivising biomass-based CHP (Figure 5). Over the past few years, though, expansion of wind power has lowered electricity prices and had a negative effect on CHP production of electricity. This has consequently led to low production of heat in CHP mode. In 2010, however, a cold year led to an all-time high of CHP generation. In the future, the closing of nuclear plants could also have a positive impact on CHP.[13]

Figure 5 • Shares of CHP electricity and heat production, 2000-2013



Note : Includes transmission losses. Total heat generation is not fully reported; for autoproducers, only the portion of heat that is sold is reported, and on-site use is not included.

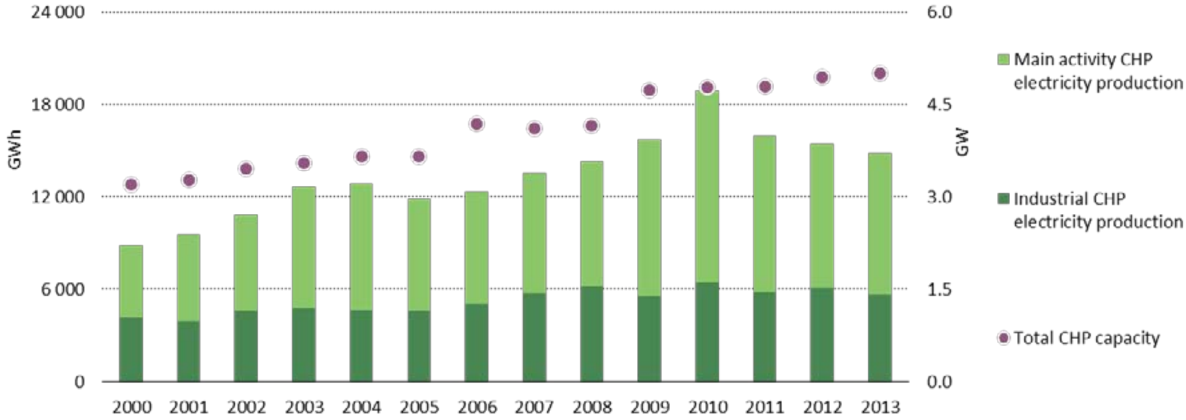
Source: Swedish Energy Agency (Energimyndigheten) (2015b), "Energy Indicators 2015: Monitoring Sweden's Energy Policy Objectives" (Energiindikatorer 2015: Uppföljning av Sveriges energipolitiska mål).

Key message • The share of CHP electricity generation has increased slightly since 2000, while the share of CHP in DHC heat production has increased considerably.

[13] In June 2010, the Swedish Parliament voted to repeal a 1980 law requiring the phase out of nuclear capacity, allowing replacement of current units at the end of their lifetimes. However, there is some uncertainty as to the future of nuclear power in Sweden, as several decisions have been made recently to close older reactors rather than extending their lifetimes. The recently formed Energy Commission will take up the question of a long-term electricity generation strategy, including the role of nuclear.

Total CHP electricity production amounted to 14.8 TWh in 2013 of which 5.6 TWh was produced on industrial sites. The electricity certificate system introduced in 2003 has been an important measure to stimulate the growth of biomass-based CHP leading to an increase in total CHP. A drop in electricity production recent years occurred due to lower electricity prices, but plants being phased out of the electricity certificate programme also affected CHP producers.[14] There is currently some overcapacity in CHP plants, which explains the sensitivity of certain plants' electricity production to the phase-out of the incentive (Figure 6). This phase-out has affected CHP integrated with DHC networks more than industrial CHP. Industrial CHP producers typically have on-site heat demand and cheap and readily available industrial energy by-products that incentivise continued operation of CHP plants, particularly in the pulp and paper sector.

Figure 6 • CHP electricity production and capacity, 2000-2013



Source: Swedish Energy Agency (Energimyndigheten) (2015d), "Energy in Sweden: Facts and Figures 2015" (Energiläget i siffror 2015).

Key message • CHP electricity production has dropped off since 2010 due to the phase-out of some plants from the electricity certificate programme.

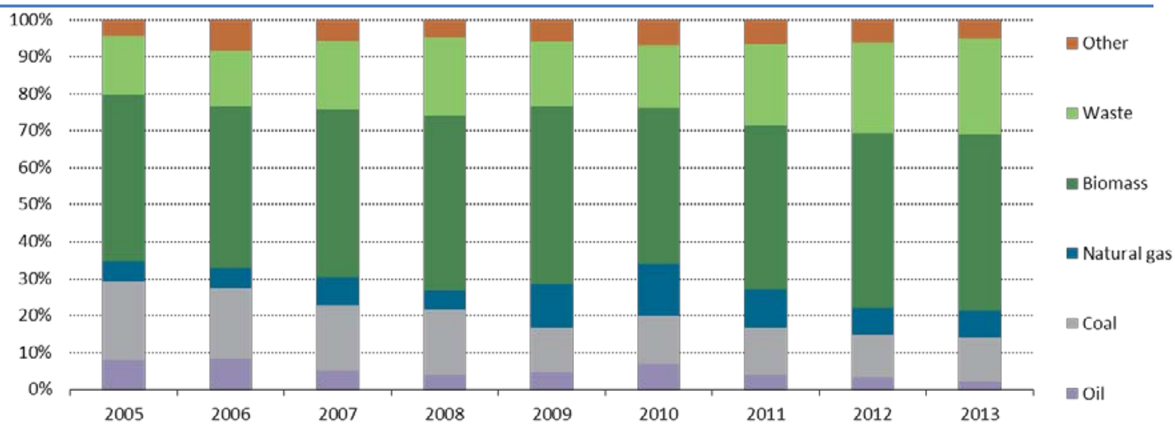
Existing energy policy in Sweden, including renewable targets, the electricity certificate programme, and other climate-related policies, promotes biomass and waste-based generation and encourages deployment of technologies with low environmental impacts. The 2002 landfill ban on combustible waste and 2005 landfill ban on organic waste have provided additional incentives to utilise waste as fuel. Currently, biomass and waste sources dominate Swedish CHP production (Figure 7). They have a low CO_2 emissions footprint, although they also have relatively low efficiency for electricity production.

Natural gas CHP briefly gained share in 2009 and 2010, due to cold weather, lower natural gas prices, and the opening of a new gas-fired plant, but since 2010 this trend has reversed. Currently several demonstration projects for biomass gasification, primarily in the transport sector, are being subsidised in order to develop the technology, which could increase electricity production from biomass. Gasification of biomass and waste for CHP has already been demonstrated in

[14] Plants commissioned before the certificate system was introduced were entitled to certificates only until the end of 2012; plants that received a public investment grant after 15 February 1998 were entitled to certificates until the end of 2014. See "The electricity certificate system" in Government CHP and DHC Promotion Policies for more information.

several projects in other countries, and could have applications in Sweden if it eventually becomes more economically competitive.

Figure 7 • Share of fuel input to CHP production, 2005-2013



Note: Coal includes peat fuel input.

Source : Swedish Energy Agency (Energimyndigheten) and Statistics Sweden (Statistika centralbyrån) (2013), "Electricity supply, district heating, and supply of natural gas 2013" (El-, gas- och fjärrvärmeförsörjningen 2013, Definitiva uppgifter), EN 11 SM 1401.

Key message • Biomass and waste make up the majority of CHP fuel in Sweden.

Average gross efficiency for main activity CHP plants in 2013 was 86% (Figure 8). Among CHP plants using gasified fuels facilities, synthesis gas engines ranging from 0.5 to 10 megawatts (MW) have an efficiency of power generation at around 25 to 30% and a total efficiency at around 80 to 90%. Increased utilisation of processes and motors, as well as possible combinations with steam engines or organic Rankine cycles (ORC), could increase the power efficiency to 30 to 35% while maintaining the total efficiency or slightly increasing it.[15] For larger facilities combined cycle gas turbines could be used instead of engines with a power efficiency of 35 to 45% and total efficiency of 85 to 89%. In waste incineration, the power efficiency is about 20%. This could be increased to around 30% through gasification of waste if that technique is commercialised. In industrial CHP plants, in 2013, average efficiency was 73%, slightly lower than the main activity producers, due to several factors such as the high share of biomass fuel input to CHP in the pulp and paper sector and operational needs.

[15] Waldheim, L., 2015.

Figure 8 • Gross CHP efficiency, 2003-2013

Note: Lower efficiency of industrial CHP is likely due to the high share of biomass fuel input to CHP in the pulp and paper industry.

Main activity CHP refers to CHP plants that generate electricity and heat for sale to third parties as their primary activity. They may be privately or publicly owned, and the sale need not take place through the public grid.

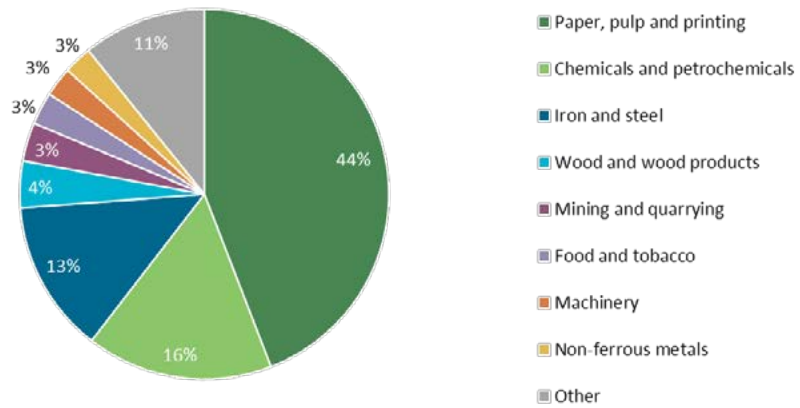
Source: Swedish Energy Agency (Energimyndigheten) and Statistics Sweden (Statistiska centralbyrån) (2013), "Electricity supply, district heating, and supply of natural gas 2013" (El-, gas- och fjärrvärmeförsörjningen 2013, Definitiva uppgifter), EN 11 SM 1401.

Key message • Average efficiency for main activity CHP producers has been stable, while industrial CHP performance seems to have been affected by the 2009 economic downturn.

Industrial applications

Pulp, paper and printing is by far the largest industrial energy user in Sweden, making up 44% of final energy consumption in industry in 2013. Chemicals and petrochemicals (16%) and iron and steel (13%) follow, and no other industry reaches more than 5% of industrial energy use (Figure 9). This distribution has been relatively stable over the past decade.

Figure 9 • Total final energy consumption in industry, 2013



Note: Energy use in blast furnaces and coke ovens is included in the iron and steel sector, and energy use as petrochemical feedstock is included in the chemicals and petrochemicals sector.

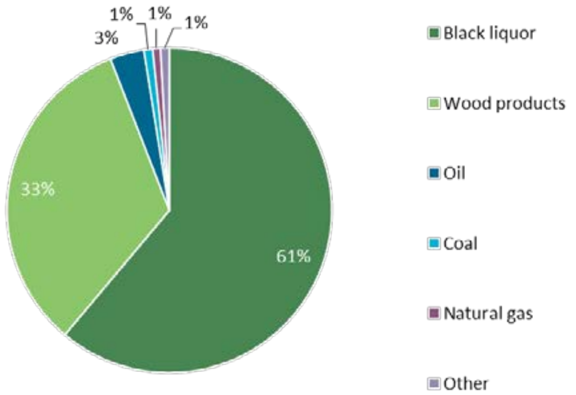
Source : IEA (International Energy Agency) (2015), *Energy Balances of OECD Countries (2015 Edition)*, OECD/IEA, Paris.

Key message • Industrial energy use in Sweden is concentrated in a few energy-intensive sectors, with almost half used in the paper, pulp and printing sector.

Industrial CHP in Sweden is almost entirely deployed in the pulp and paper sector, with around 90% of industrial CHP capacity. The main fuels are comprised of black liquor, which is a by-product in the pulp and papermaking process (61% of all fuel input to industrial CHP), and bark and other wood products (33%) (Figure 10).

A survey of the forestry industry from 2011 found that stakeholders expect electricity production from industrial CHP in forestry to increase from 5.9 TWh in 2010 to 6.8 TWh in 2015 and 7.3 TWh in 2020. Respondents indicated a number of reasons for their optimism in terms of the outlook for CHP, including support from the electricity certificate programme and future increases in production and on-site thermal demand in the sector. Some of those surveyed also mentioned the negative impacts of uncertainty related to the electricity certificate system as well as competition for biomass leading to increased prices of raw materials.[16]

Figure 10 • Fuel input for CHP electricity in industry, 2013



Note: Wood products include bark, chips, sawdust, briquettes and pellets. Coal includes peat and coal-derived gases such as blast furnace gas and coke oven gas.

Source : Swedish Energy Agency (Energimyndigheten) and Statistics Sweden (Statistiska centralbyrån) (2013), "Electricity supply, district heating, and supply of natural gas 2013" (El-, gas- och fjärrvärmeförsörjningen 2013, Definitiva uppgifter), EN 11 SM 1401.

Key message • By-products from the pulp and paper-making sector are the main fuels for industrial CHP.

District heating

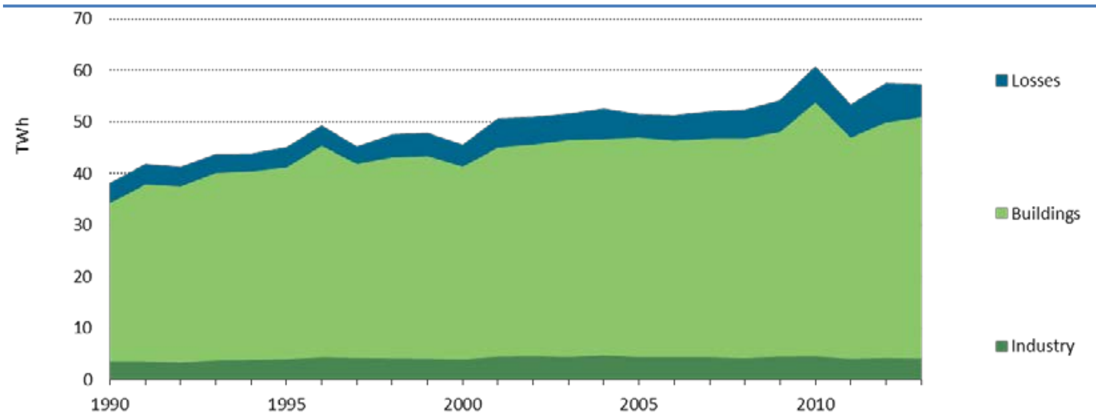
The first DH system in Sweden was installed in Karlstad in 1948 and consisted of a number of industrial buildings being connected to a municipal heat central. Nine more cities installed DH systems in the 1950s as local municipalities saw an increasing market for heat as a result of extensive city development in many parts of the country.

In 2013, industrial users received 4.2 TWh of the heat from Sweden's 23 000 km of DH networks, while 46.8 TWh went to dwellings. Transmission and distribution losses have remained relatively constant over time, and now stand at around 11%. Industrial sites in Sweden connected to DH networks early in the development of DH infrastructure. Deliveries of DH to industrial sites,

[16] Swedish District Heating Association (Svensk Fjärrvärme), 2011.

mainly in the pulp and paper sector, have remained stable since 1990, in line with overall industrial energy demand trends (Figure 11).

Figure 11 • Deliveries of DH, 1990-2013

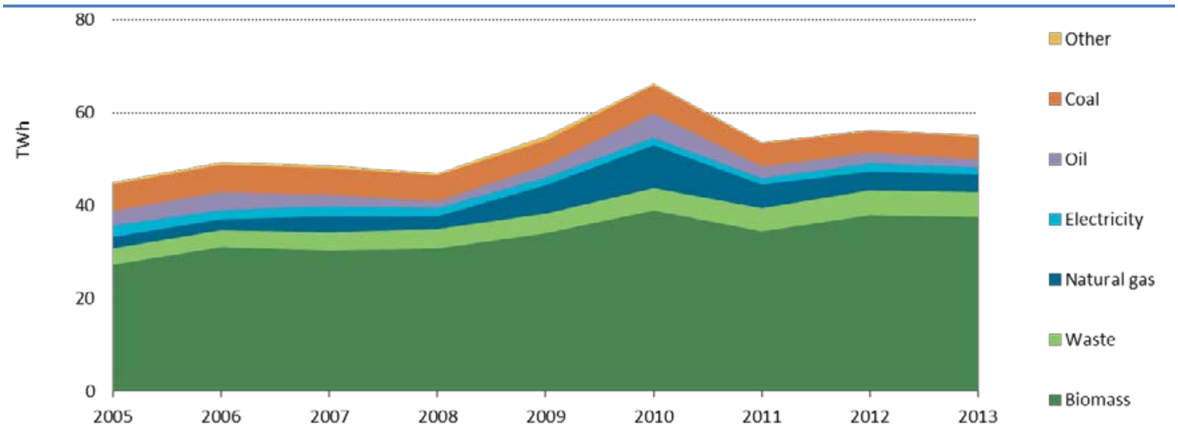


Source: Swedish Energy Agency (Energimyndigheten) (2015d), "Energy in Sweden: Facts and Figures 2015" (Energiläget i siffror 2015).

Key message • Most district heating delivered goes to buildings, and heat deliveries to industry have remained nearly constant since 1990.

The input fuels for DH production have shifted from primarily fossil fuels toward mainly biomass and waste incineration over the years. In 1970, oil and oil products accounted for 98% of fuel input for heat generation for DH networks. In 2013, biomass was the main fuel input for DH networks in Sweden, accounting for 60% (Figure 12). Over the past few decades, natural gas and waste fuels have also gained share, though their share remains minor compared to biomass inputs.

Figure 12 • Input energy for DH production, 2005-2013



Note: Biomass also includes the part of waste incineration that is renewable.

Source: Swedish Energy Agency (Energimyndigheten) (2015d), "Energy in Sweden: Facts and Figures 2015" (Energiläget i siffror 2015).

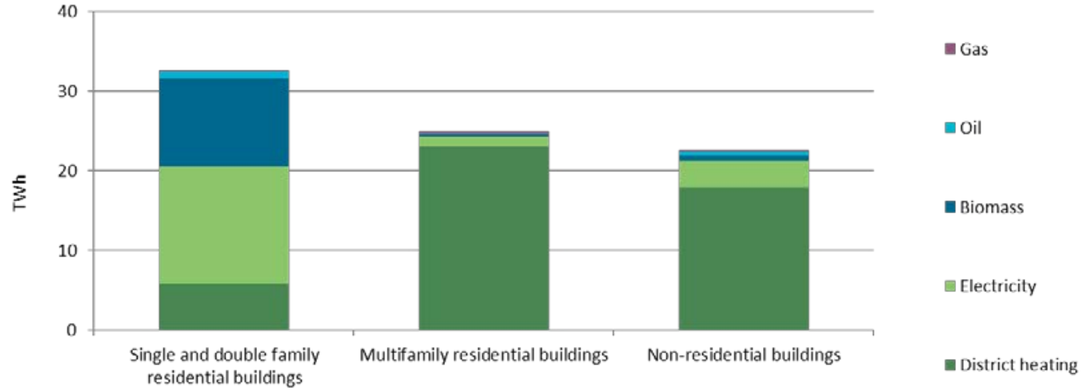
Key message • Fossil fuels play a limited role in Sweden's DH networks.

Industrial excess heat (IEH) also plays a significant role in DH in Sweden; in 2013, around 4.8 TWh of IEH was delivered to different DH networks. In 2004, the number of connection points for excess heat deliveries amounted to around 60 and today there are around 80. The number of industrial sites delivering excess heat is around 70. About 25% of the excess heat is generated from the paper and pulp industry, another 25% comes from refineries, and the chemicals and iron and steel sectors deliver about 10 to 20% each.[17] A growing number of data centres also deliver excess heat to DH networks.

Since 2000, district heating has been the most common type of heating in the residential sector in Sweden. In 2013, a total of 80.3 TWh was used for space heating and hot water in residential and non-residential buildings, excluding energy extracted using heat pumps. 46.7 TWh, or 58% of the total amount of energy used for space and water heating, was from DH (Figure 13). Around 50% of the energy from DH was used in multifamily residential buildings; just over 38% was used in non-residential buildings; and the remaining 12% was used in single and double family buildings.

The second most used energy carrier for heating and hot water in buildings was electricity (19.3 TWh in 2013). This corresponds to 24% of the total amount of energy used in residential and non-residential buildings. 76% of the electricity for heating and hot water was used in single and double family buildings, as smaller residences are more likely to use individual heat pumps or electric boilers.

Figure 13 • Heating in buildings, 2013



Note: Electricity shown here can primarily be attributed to heat pumps and electric boilers.

Source: Swedish Energy Agency (Energimyndigheten) (2014), "Summary of energy statistics for dwellings and non-residential premises for 2013" (Energistatistik för småhus, flerbostadshus och lokaler 2013), ES 2014:06.

Key message • DH was the main source of space heating in multi-dwelling buildings and non-residential buildings.

In 2013, 92% of the energy for space heating and hot water in multifamily residential buildings came from DH. In non-residential buildings, the share was 79%. In single and double family

[17] Swedish Energy Agency (Energimyndigheten), 2013a.

houses, it accounted for 18%.[18,19] A small portion was delivered to industrial users for process heat and space heating.

As DH companies explore new markets to offset decreasing demand from traditional sources, there are other applications for DH being investigated and in some cases, implemented, including heating of white goods (e.g. washing machines and dishwashers), swimming pools[20], and boats at dock (Box 2), street heating, drying processes for wood, absorption cooling and others. Technology developments and new business models could unlock demand in such alternative areas and might partly compensate for losses in revenue due to decreasing building heating demand from energy efficiency measures and the uptake of competing technologies such as heat pumps, if these new applications prove to be economical.[21] The Open District Heating business model (Box 1) is one way that new applications could be integrated into DH networks to improve the business case for network operators.

In order to stay competitive, companies in the DH market need to increase revenues through increased efficiency and decreased heat losses. Fourth generation district heating is a technology for reducing network temperatures to around 50°C delivery and 20°C return as compared to about 100°C delivery and 50°C return in most current networks. The new DH technology allows networks to achieve reduced energy consumption, reduced thermal distribution losses, and reduced insulation material requirements, as well as greater flexibility to facilitate integration with both new and existing building stock. Theoretical assumptions for the whole DH sector in Sweden implies possible savings of around USD 154 million (SEK 1 billion)[22] should all networks lower their temperatures.[23]

Substantial energy savings can also be achieved by lowering network temperatures and improving insulation in conventional DH networks to minimise thermal losses, even without reaching the levels of fourth generation DH technology. Better heat demand prediction and planning along with improved control and regulation in buildings could make this feasible.

In Västerås and Linköping there are projects for housing areas utilising these principles; currently these networks reach temperature levels of 60°C delivery and 30°C return. There are costs associated with the adaptation of buildings to be connected to these networks. However, the cost savings from lower temperature networks demonstrate the possibility to offset these investment costs.

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[18] Swedish Energy Agency (Energimyndigheten), 2014.

[19] 83% of the area in multi-dwelling houses used only district heating, for commercial space heating the share was 72% and for houses 12%.

[20] Tekniska verken, 2016.

[21] Interviews with a DH company indicate the theoretical possibility of a 5% overall increase in deliveries by 2025 due to implementation of white goods applications.

Swedish District Heating Association (Svensk Fjärrvärme), 2009a.

[22] USD 1 = SEK 6.513 (2013 average). Board of Governors of the Federal Reserve System, 2015.

[23] Lauenberg, P., 2015.

Box 1 • Case Study 1 – Open District Heating™

Open District Heating™, developed by Fortum Värme together with, among others, the City of Stockholm, Bahnhof, Coop, ICA, Stiftelsen Stora Sköndal and Hemköp, provides a business model that enables companies to increase their revenues by recovering excess heat for the DH system. In Stockholm, the energy company Fortum Värme offers long-term and transparent terms for trade in excess heat and surplus capacity in heating and cooling systems. All companies and businesses which have excess heat and that are located close to the DH or district cooling networks are able to sell energy to Fortum Värme at a market price, determined based on a price model that takes into account time and temperature level, with the highest prices paid for heat delivered during cold days at a temperature level high enough to meet the requirements of the district heating customers.

During the development of the business model for *Open District Heating™* in 2013 several pilot installations were carried out including two data centres, Pionen and Thule, hosted by the internet supplier Bahnhof.

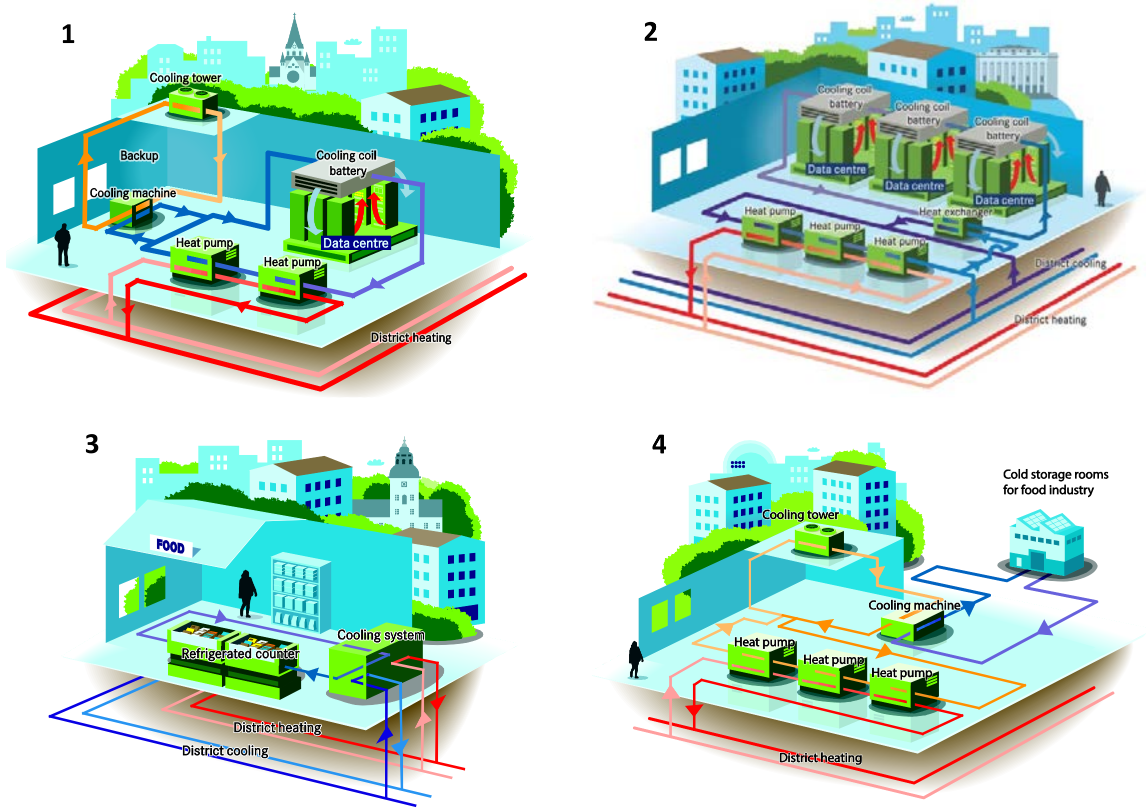
In Pionen (Södermalm, Stockholm), Bahnhof has installed a cooling plant for primary cooling of the data centre which delivers the excess heat to the DH network. The cooling facility comprises two heat pumps connected in series, with a total cooling output of 694 kW and a heat output of 975 kW. During normal operation the plant supplies around 600 kW heating to the DH system at a delivery temperature of 68°C. The heat pumps design enables them to be directly connected to the DH network, whose local pumping capacity can absorb the additional pressure drop.

Thule, another Bahnhof data centre in central Stockholm comprising three modern data rooms, is cooled by three series-connected heat pumps delivering the recovered data centre heat to the DH system. Even though the data centre is not fully occupied, the heat pumps' full capacity for heating and cooling can be utilised due to the fact that energy can be taken both from the data rooms and from Fortum Värme´s district cooling network return pipeline. In this way, after cooling the data centre, Thule´s remaining heat pump capacity for cooling can be utilised for delivering cooling to Fortum Värme´s district cooling system, at the same time as the recovered heat is delivered to the DH system. Fortum Värme pays Bahnhof market price for the delivered energy as well as the provided cooling capacity. Other pilots include installations for recovery of excess heat to Fortum Värme´s DH system from supermarkets and food industry facilities in the Stockholm area (Figure 15).

Bahnhof has invested a total of USD 522 thousand (SEK 3.4 million) in the new Pionen cooling plant, including heat pumps, pipe installation, hot tapping, electrical work, control equipment, construction and insulation. Bahnhof has also invested in two other data centres in Stockholm. For these other projects, Bahnhof estimates payback times in the range of three to five years. Fortum Värme has also invested USD 200 thousand (SEK 1.3 million) in the new supply pipeline from Bahnhof's plant to the DH network.

Source: Open District Heating (2015a), www.opendistrictheating.com/ 2015.

Figure 14 • Illustrations of selected *Open District Heating*^{TM} pilots



Notes : 1. Data centre Pionen ; 2. Data centre Thule; 3. Recovery of excess heat from the supermarket COOP Rådhuset; 4. Excess heat recovery in the Stockholm Slaughter House District.

Source: Open District Heating (2015a), www.opendistrictheating.com/ 2015. Illustration by Kjell Thorsson.

Key message • The open DH model can be applied in a variety of contexts, providing flexibility benefits to DH networks by incorporating additional sources of heat that may be available at different times or temperature levels to balance other heat sources, and are sometimes at lower cost than these other sources.

Box 2 • Case study 2 – District heating to ship at quay

The Gothenburg city-owned energy company *Göteborg Energi* runs the EU Smart Cities Celsius project, where shipping company Stena Line connects one of their regular ferries, *Stena Danica,* to the city's DH system when at quay. The ferry carries up to 2 274 passengers and 480 passenger cars, and docks in Gothenburg Port twice per day.

The overall objective with the pilot project is to reduce emissions: both regulated emissions such as SO_2 and particulate emissions, as well as CO_2 and noise from ships when docked at quay in Gothenburg. Emissions from ships at quay can be reduced if heating and power generation is switched from the ship's marine gas oil (MGO) fuelled engines to more sustainable energy sources. The option to connect ships to the power grid is already available in Gothenburg Port. *The Göteborg*

Energi DH system stretches for 1 200 km and covers about 90% of the city's apartment blocks. 30% of the DH originates from the solid waste-fuelled CHP plant Sävenäs.

The adaption of the ferry connection to DH includes installation of a heat exchanger in a container on the quay, and flexible pipes to the ferry's four heat exchangers. It was assumed that the demand for DH would mainly occur during the cold season. However, the environmental advantages to heating the ship's main engines when at quay has led to a demand for DH also during the summer.

The pilot project, which was initiated in 2013, is regarded as a successful project in terms of improving environmental performance, even if it does not increase profitability of the shipping company. For Gothenburg city the instalment also carries positive side effects such as reduced noise from ships at quay which enables housing development in port areas. The ferry's consumption of DH during 2015 is estimated at 800 MWh. The expected reduction of CO_2e-emissions is 340 tonnes with DH instead of marine gas oil for the ferry at quay in Gothenburg.

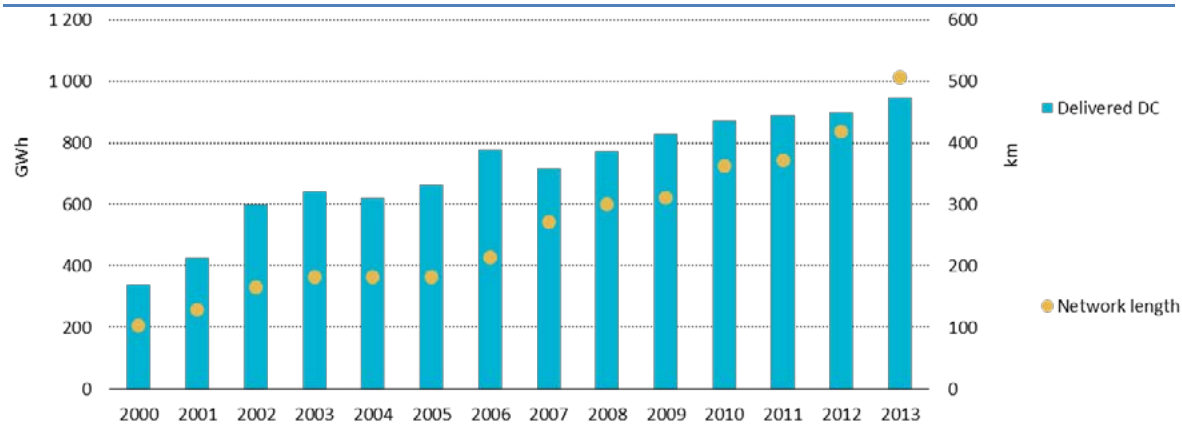
The project was jointly funded by Stena Lines, who contributed EUR 77 000 worth of working time, and the EU, whose contribution was EUR 52 000.

Sources: Andersson, C. (2015), Stena Line Environmental Controller; Arvsell, P. (2015), Göteborg Energi; and Celsius smart cities (2015), "District heating for ships in harbour," http://celsiuscity.eu/Demonstrator/%E2%80%8Bdistrict-heating-for-ships-in-harbour/, October 2015.

District cooling

District cooling is relatively new to Sweden; the first network started in Västerås in 1992. Though it is still a relatively small market compared to DH, growth has been steady. In 2014 there were 35 companies delivering district cooling. The biggest supplier of district cooling (DC) is Fortum in Stockholm, which produced 440 GWh of cooling in 2014, almost half of all DC produced. There are about 1 500 district cooling customers, with total deliveries just passing 1 TWh (Figure 1515).

Figure 15 • District cooling deliveries and network length, 2000-2013



Source: Swedish District Heating Association (Svensk Fjärrvärme) (2015), "District Heating Research Programme" (Forskningsprogrammet Fjärrsyn), www.svenskfjarrvarme.se/Fjarrsyn/Om-Fjarrsyn/.

Key message • Growth in both DC network length and deliveries has been strong since 2000.

The most common techniques for district cooling in Sweden are heat pumps and natural cooling[24] (Table 1). Around 80% is delivered for space cooling in commercial or public premises and 20% is delivered to industrial sites (as of 2012).[25] The desiccant/sorptive cooling system installed at a new IKEA store in Erikslund, Västerås, is an example of how these systems can be integrated with commercial buildings (Box 3).

Table 1 • Technologies for district cooling, 2013

	Cooling production [GWh]	Share [%]
Heat pumps	197	26%
Free cooling	185	24%
Vapour compression cooling	134	17%
Absorption cooling	86	11%
Other	168	22%

Note: "Other" is mainly comprised of waste cooling from heat pumps pertaining to DH and non-specified technologies from Fortum's district cooling production.

Source: Swedish Energy Markets Inspectorate (Energimarknadsinspektionen) (2013), "Mapping the market for district cooling" (Karläggning av marknaden för fjärrkyla), EI R2013:18.

Box 3 • Case study 3 – District heating for desiccant/sorptive cooling

The municipality-owned energy company *Mälarenergi* in Västerås, operator of a new 167 MW circulating fluidized bed (CFB) boiler for waste, which began operation in late 2014, was looking for new DH demand during the summer season, focussing on properties with a demand for cooling. At the same time the multinational furniture retailer IKEA planned a new 48 000 m^2 store in Erikslund, Västerås and needed cooling. IKEA chose to employ a desiccant ventilation and cooling system using DH hot air (+55˚C) for regeneration of the desiccant provided to them by Energy Company Mälarenergi.

Desiccant/sorption cooling uses a series of natural physical processes: dehumidification of air using a desiccant rotor, a rotating heat exchanger and an evaporative cooler. The hygroscopic material in the desiccant rotor is regenerated (dried) with low temperature heat. The technology is mostly beneficial in Northern European and similar climates. The average co-efficient of performance[26] (COP) during cooling season is approximately 1.5 (output cooling energy/input heat energy).

The desiccant/sorption cooling system was chosen from a combined environmental and lifecycle cost perspective. The system, called "DesiCool" is reliable and easy to maintain, uses neither refrigerants, nor compressors, and acts as a ventilation air heat exchanger during the cold season. The DesiCool double heat exchangers for the warm exhaust air are more effective than a standard air handling unit

[24] Natural cooling (also sometimes called free cooling) refers to the use of available natural resources – such as ambient air or water temperatures – to provide partial or full cooling to buildings.

[25] Swedish Energy Markets Inspectorate (Energimarknadsinspektionen) (2013).

[26] Coefficient of performance (COP) is the ratio of heating or cooling provided to the work required (energy input).

(AHU-system) during wintertime. Desiccant technology can be used with other low temperature sources, such as solar panels and low temperature excess heat for regeneration. The “footprint”, or space needed, for the IKEA DesiCool combined ventilation and cooling equipment, is smaller than that of a conventional separate ventilation system and cooling system.

Source: Granstrand, A. (2015), Personal Communication.

Government CHP and DHC Promotion Policies

Subsidies to CHP/DHC development

The Swedish government has provided various subsidies to encourage CHP and DHC development since the 1970s. Table 2 outlines the major subsidies and incentives for infrastructure, labour and equipment costs related to heat generation for DH and conversion to CHP.

Table 2 • Timeline of Swedish government subsidies to CHP/DHC development

Year	Policy description
1979	General investment grants for the construction of heat boilers
1980	Labour market subsidies for DH infrastructure development
1983-85	General investment grants for peat incineration and peat boilers
1984	Labour market subsidies for heat pumps (in DH networks and individual dwellings)
1988	Research and development (R&D) subsidies for new technologies for coal use and gasification
1991-98	Subsidies to CHP through programmes for investment grants, efficient electricity and energy technology development
1995	Subsidies to investments in DH systems mitigating carbon emissions: of up to 15% subsidy of the investment cost for the part of the distribution network between a consumer and the production facility. Subsidies could also be granted for connections between existing networks. The investments grants should contribute to CO_2 reduction.
1998-2004	Energy policy programme, in which heat and electricity were focus areas for subsidies[27] NUTEK (the Swedish Business Development Agency)[28] provided grants to demonstration projects of 25% of the investment cost or a maximum of 50% of investment cost for development of small scale technologies. Subsidies had environmental conditions and projects were required to be economically and technically viability for market commercialisation within a reasonable time frame. Bio-CHP investment grants (extended from 1991), were permitted for a maximum of USD 614 (4 000 SEK) per installed kW and 25% of the facility cost. Grants were also available for conversion of heat plants in to CHP plants. Labour market subsidies were available to municipalities amounting to a certain percentage of the labour cost for heat and electricity infrastructure development.

Source: "Regulation on state contributions to certain investments in the energy sector" (1999), (Förordning (1991:1099) om statligt bidrag till visa investeringar inom energimorådet, m.m), www.riksdagen.se/ , accessed 8 December 2015 ;

Royal Institute of Technology, Department of Energy, Power and Heat Technology Division (Kungliga Tekniska Högskolan, Institutionen för Energiteknik Avdelningen Kraft och Värmeteknologi) (1996), "Cogeneration in the Nordic Region: A comparison of CHP utilization in Sweden, Denmark and Finland" (Kraftvärme I Norden: En jämförelse av kraftvärmeutnyttjandet I Sverige, Danmark och Finland), www.svenskfjarrvarme.se/, accessed 28 October 2015.

[27] Ministry of the Environment and Energy (Miljö och energidepartementet), 2003.

[28] Active until 2009

Taxation

The carbon tax that was introduced in 1991, amounting to USD 160/tCO_2[29] (SEK 1.05/kg CO_2), encouraged the shift in the DH system from fossil fuel-based to mainly renewable-based. The gradual lowering of CO_2-taxation levels within the EU ETS for CHP heat production has contributed to increasing the CHP share in DH production. Since 2013, CHP-produced heat and heat delivered to industry from heat boilers within the EU ETS are entirely exempt from the Swedish CO_2 tax.[30] In 2014, the CO_2 tax for heat-only production was lowered to 80% from 94% of the full tax level.

CHP plants are also subject to a lower energy tax on fossil fuel consumption than other main activity heat producers, at 30% of the standard rate. The energy tax is also reduced for on-site industrial heat production.

The electricity certificate system

Electricity certificates are a market-based subsidy to producers of renewable energy. For each MWh of renewable electricity produced, a certificate is granted by the government. The certificates can then be sold on a free market where the price is decided between buyers and sellers. Power suppliers and certain power consumers are obligated by law to buy a quota of electricity certificates corresponding to a certain proportion of their electricity sales or usage.

Sweden's electricity certificate market has existed since 2003, and since 1 January 2012, Norway and Sweden have had a joint target and a joint market for electricity certificates. Facilities initiated before May 2003 were phased out by the end of 2012, while all other plants have a 15-year time limit. The programme expires in 2035.

The two countries' goal is to develop new power production based on renewable energy sources corresponding to 28.4 TWh by the end of 2020. The market decides where and when it is most economically efficient for the new production to take place. The Swedish budget for 2016 (Bill 2015/16:1) proposes a new goal of 30 TWh by 2020 but it must be negotiated with Norway.[31]

The electricity certificate system has proved an important policy measure as the effects of the system initially meant a shift from fossil to biomass CHP and then an increase in total CHP production. However, the programme has contributed to the electricity surplus that leads to low spot prices for electricity, as a consequence of rapid wind power expansion.

[29] USD 1 = SEK 6.513 (2013 average). Board of Governors of the Federal Reserve System, 2015.

[30] The district heating sector in Sweden is "opted in" to the EU ETS.

[31] Swedish Energy Agency (Energimyndigheten) and Norwegian Water Resources and Energy Directorate (Norges vassdrags- og energidirektorat), 2013.

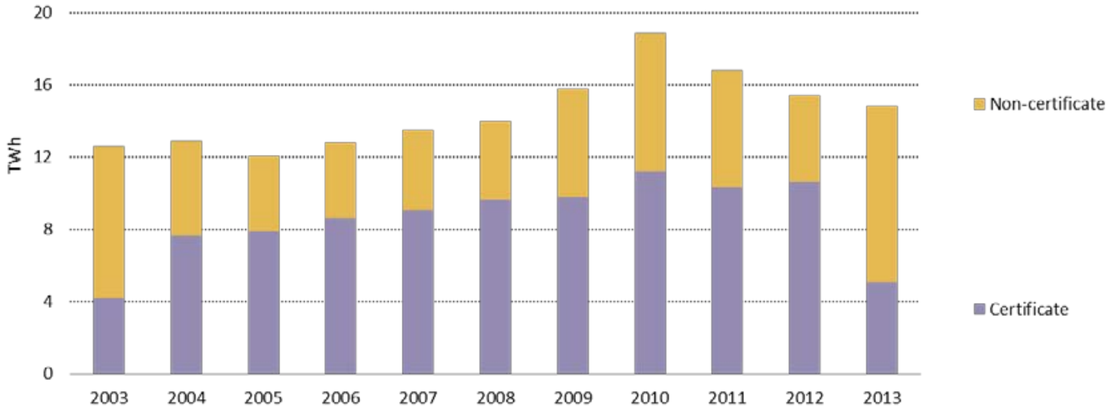
Figure 16 • Electricity production receiving electricity certificates, 2003-2015

Source: Swedish Energy Agency (Energimyndigheten) (2015e), Energy statistics.

Key message • In 2013, wind began passed biomass CHP as the source receiving most certificates.

Figure 16 shows total CHP production shares receiving electricity certificates compared to other types of production. Figure 17 shows the amount of CHP receiving certificates (i.e. biomass-based CHP) of all CHP production. The slight decline in 2013 is due to the phasing out of plants from the certificate programme after the time limit on receiving certificates. It is difficult to measure the full impact of the phase-out of electricity certificates without also having complete data on heat production in CHP plants. However, the share of CHP heat production for DH networks (Figure 5) has declined slightly, and CHP electricity production has declined (Figure 6), due both to the phase-out of benefits and to increased competition with other heating technologies in a low electricity price environment.

Figure 17 • CHP receiving electricity certificates, 2003-2013



Note : Only biomass-based CHP is eligible for electricity certificates.
Source: Swedish Energy Agency (Energimyndigheten) (2015e), Energy statistics.

Key message • In 2013, as the first plants were phased out, for the first time in a decade the majority of CHP plants did not receive electricity certificates.

Investment programmes: LIP, KLIMP and KLIMATKLIVET

Local Investment Programme (LIP) 1998-2002 and the Climate Investment Programme (KLIMP) 2003-2012 allowed municipalities as well as other actors to apply for subsidies for ecological and climate change-mitigating measures. These programmes led to a total of 260 DH-projects receiving some kind of funding and acted as a catalyst for co-funding of projects.[32] The newly launched Local Climate Investment programme (KLIMATKLIVET) starting in 2015 is a similar programme to LIP and KLIMP, supporting measures in non-EU ETS sectors at the local and regional level where climate investments have the largest impact. The programme will distribute USD 307 million (SEK 2 billion)[33] between 2015 and 2018. Because DH networks with more than 20 MW capacity have opted in to the EU ETS, they will not be eligible for support through this programme.

Energy efficiency programme

A total of USD 261 million (SEK 1.7 billion) during the period 2015-2018 will fund energy efficiency projects in public housing built between 1965 and 1974 under a project called "the million programme." The funding, however, needs to be approved by the European Commission. There is also USD 154 million (SEK 1 billion) in funding for energy efficiency in schools. Both of these programmes could include measures to improve the efficiency of space and water heating.

Research and innovation

The Swedish research and innovation policy complements other policies and plays an important role in the Swedish energy policy to meet climate and energy goals. The Swedish Energy Agency finances research and innovation in the energy sector; in 2014, funding from the agency amounted to USD 210 million (SEK 1 365 million) in total, of which USD 35 million (SEK 226 million) was allocated to bioenergy (feedstock supply, heat and power production and district heating). The research projects are fully or partly public financed and usually conducted in close collaboration with market players.

[32] The LIP programme had a budget of USD 1.0 billion (SEK 6.2 billion) of which USD 660 million (SEK 4.3 billion) was utilised. Total investments, including non-subsidies amounted to USD 2.5 billion (SEK 16 billion) during the LIP period. The KLIMP programme had a budget of USD 276 million (SEK 1.8 billion) of which USD 184 million (SEK 1.2 billion) was utilised and fuelled an additional USD 921 million (SEK 6 billion) from external actors in investments. It has, however, been argued that many of these investments would have been carried out anyway.

Swedish District Heating Association (Svensk Fjärrvärme), 2009b; Environmental Protection Agency (Naturvårdsverket), 2013; Environmental Protection Agency (Naturvårdsverket), 2015; and Samakovlis, E. and M. V. Johansson, 2007.

[33] USD 1 = SEK 6.513 (2013 average). Board of Governors of the Federal Reserve System, 2015.

Conversion subsidies

Between 2006 and 2010 subsidies for conversion to DH, ground source heat pumps or small scale biomass-based installations[34] from oil or direct electric heating could be obtained. The subsidies for conversions from direct electric heating totalled around USD 70 million (SEK 455 million) for the whole period, of which 75% went to DH conversions. Around USD 69 million (SEK 450 million) was paid for conversions from oil heating (2006-2007) but only around 20% went to DH installations, with the other 80% going to ground source heat pumps or small-scale biomass heating.[35]

Market regulation

The government has carried out several investigations to regulate the natural monopolies of the DH market in order to hold prices down and protect consumers. The main legislation regarding DH is the District Heating Act, which was introduced in 2008 to increase the transparency in pricing of DH.[36]

The DH market has experienced various regulatory interventions, which have created some degree of regulatory uncertainty. Various pricing mechanisms have been discussed, including regulated prices for the unbundled network products. A governmental investigation into third party access was first conducted in 2005. In 2008, the District Heating Act was introduced in order to increase the transparency on the DH market obliging DH companies to justify their prices and link them to customer consumption.[37]

In 2011 the *Third Party Access (TPA)* investigation proposed to divide the DH market, like the electricity market, creating different companies for network, trade and supply in order to increase competition. Due to the inability to foresee how the DH market would be affected it was not implemented.[38]

In 2013 the Energy Markets Inspectorate issued another report proposing a "lighter version" of the TPA investigated previously. Named *Regulated Access to the District Heating Grid,* the proposal would allow third parties (e.g. excess heat producers) to access the grid as long as the grid owner has its production costs covered, and the grid owner cannot deny access. The proposal was adopted in a proposition and enacted as a law in 2014 but is not foreseen as having much of an impact, as excess heat co-operations are happening anyway without this regulation, and because the entire risk is borne by the third party for the investment in additional networks.

[34] Only biomass-based systems which were fully or partially water-based were eligible for the subsidy.

[35] Swedish Energy Agency (Energimyndigheten) and Swedish Energy Markets Inspectorate (Energimarknadsinspektionen), 2011.

[36] SOU2008:263, 2008.

[37] SOU2008:263, 2008.

[38] SOU2011:44, 2011.

The latest 2013 heat market review focused on affordability and competition issues. The *price regulation investigation* in 2013 was another attempt at regulation through a price mechanism. The investigation proposed an index based on costs that would then constitute a limit for price increases by the companies. However such a policy could act as a driver for increased prices instead of holding prices down, as each company would rationally increase their prices as much as possible within the framework of the index in order to have a margin in case of unexpected costs for fuels for DH production. The proposal was ultimately turned down.

Stakeholders

Government

Energy Markets Inspectorate

The Energy Markets Inspectorate supervises the Swedish electricity, natural gas and district heating markets.[39] The Inspectorate also works to improve the functioning and efficiency of these markets. The customer's position is strengthened through the Inspectorate's supervision and an increased transparency in the operations of the DH companies.

Swedish Energy Agency

The Swedish Energy Agency works for the use of renewable energy, improved technologies, smarter end-use of energy, and mitigation of climate change. The Agency regularly produces reports and statistics on DH and CHP. It also finances research and innovation. Selections of relevant research programmes financed by the Agency include:

- Fjärrsyn – A district heating research programme, financed 60% by the Swedish District Heating Association and 40% by the Swedish Energy Agency. The programme has a budget of USD 10 million (SEK 66 million) for 2014-2017. This programme includes the regional excess heat study (Box 4) which identified potential excess heat clusters, facilitating integrated planning of heating infrastructure.
- Cooperation programme for bioenergy-based electricity and heat production[40] – R&D support mechanism for efficient and renewable CHP, heat plants, and industrial CHP.[41] The programme is financed 40% by the Swedish Energy Agency and 60% by the private sector. The budget is USD 9 million (SEK 60 million) from 2013-2015.
- Material Technology for thermal energy processes – Focus on material technology development as a base to make thermal energy processes more effective. The programme is financed 40% by the Swedish Energy Agency and 60% by the private sector with a budget of USD 18 million (SEK 115 million) from 2014-2018.
- The Bioenergy Feedstock Programme is three coordinated programmes on increased, sustainable and effective production and use of bioenergy and bioenergy feedstock. The programmes run from 2011 to 2017 with a budget of USD 45 million (SEK 290 million). The programmes are initiated and managed by the Swedish Energy Agency, but depending on the specific project, projects can be co-financed with private sector funding.
- Two competence centres located at universities: CECOST (Centre of Combustion Science and Technology) and HTC (High Temperature Corrosion Centre) are financed one third by

[39] Every year on 31 July the Energy Markets Inspectorate collects financial and operational data from the previous year for all DH companies. Companies also report their prices according to law EIFS:2009:3.

[40] Swedish Energy Agency (Energimyndigheten), 2015a.

[41] Swedish Energy Agency (Energimyndigheten), 2015a.

the Swedish Energy Agency, one third by the private sector, and one third by the Universities with a budget for each centre of USD 4 million (SEK 24 million per year).

- EFFSYS EXPAND[42] - A collaborative research programme including industry and universities, for efficient heat pump and cooling technologies, with a budget of USD 15 million (SEK 96 million), of which the Swedish Energy Agency contributes USD 7 million (SEK 48 million) between 2014 and 2018.

Swedish District Heating Authority

The Authority, initiated in 2008 with the District Heating Act (2008:263) mediates in the case of conflicts between sellers and consumers/clients on the DH market. Mediation must be voluntary and the authority has no decision-making power. The Authority has received around 240 requests, of which 49 have resulted in mediation and 30 in an agreement. Apart from energy companies, the other party can be a real estate owner, a company, a conglomeration of houses or another type of consumer.

Industry structure

District heating exists in 285 of Sweden's 290 municipalities. There are around 200 DH companies and 500 networks. The ownership is around 65% municipal and 35% private or state-owned.

Swedish District Heating Association (Svensk Fjärrvärme)

This association is very active with regular seminars and conferences on strategies, challenges, and technical developments for their members. It is also a prominent stakeholder in Swedish energy politics. The organisation includes 140 companies and covers 98% of the heat delivered in DH networks.

The Price Dialogue

The Price Dialogue is the association's initiative to avoid governmental regulation through a model where consumers and DH companies have meetings and dialogues about prices.[43]

The evaluation conducted by the Energy Markets Inspectorate concluded that the effects of the Price Dialogue on price increases are unclear, though the prices among participating companies are more "gathered" and there is less of a spread. Additionally, trust has increased between the parties. As of 2015, half of all DH in Sweden supplied was included in the initiative and 38% of customers were represented. Membership is expected to increase to 33 members by 2016, corresponding to 57% of DH supply (Figure 18).

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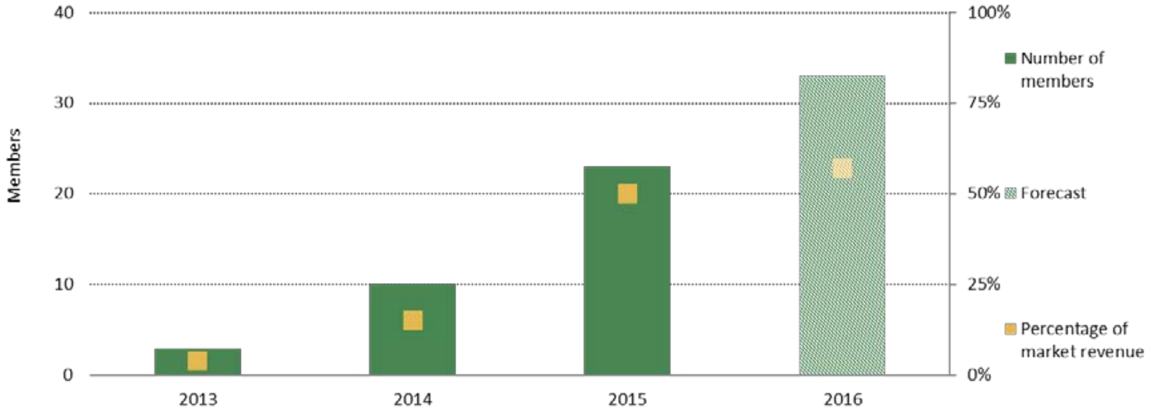
[42] Effektiva Kyl- och Värmepumpsystem samt Kyl- och Värmelager (EFFSYS EXPAND), Effective cooling and heat pump systems and cooling and heating storage.

[43] Jardfelt, U., 2015.

Figure 18 • Member participation in the Price Dialogue, 2013-2016



Note: Year 2016 is a projection based on interviews with DH companies.

Swedish Energy Markets Inspectorate (Energimarknadsinspektionen) (2015), "Evaluation of the Price Dialogue industry initiative" (Utvärdering av branschinitiativet Prisdialogen), Ei R2015:04.

Key message • Membership in the Price Dialogue has more than tripled since 2013, and now covers half of all market revenue.

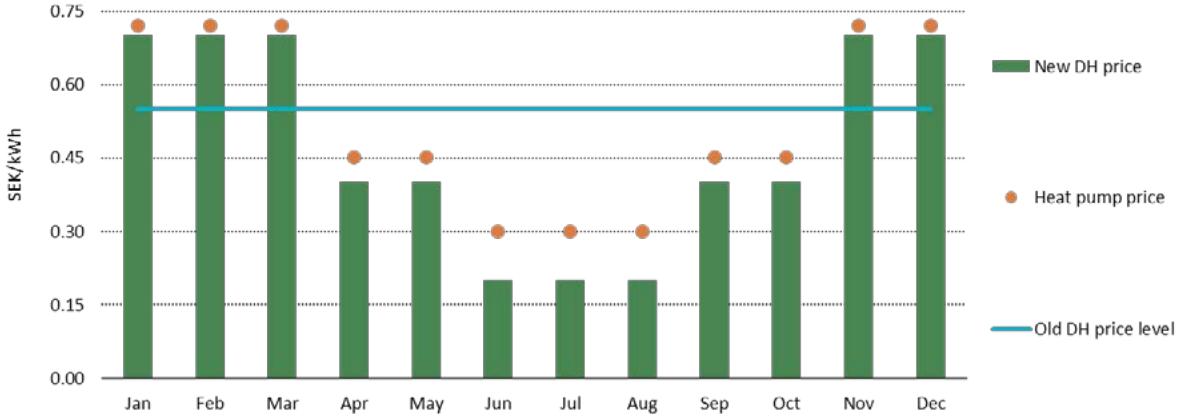
CHP/DHC Challenges

The potential for further DH deployment is limited by the fact that the market is mature and largely saturated. The second major barrier to further growth in DH is the diminishing heat demand due to continued improvements in the energy performance of Sweden's buildings stock. Increasingly energy-efficient buildings and building envelopes will limit demand growth for DH, and cause demand decreases for delivered district energy. Additionally, since very few new buildings are being built there is little room for network expansion to new customers.

In addition to the diminishing heat demand, increasing wind power production is leading to cheaper electricity prices and currently causing overcapacity among CHP plants. Many plants use as little as 25% of their capacity. The dismantling of some nuclear reactors, due to changes in steering measures and market conditions that make investments and reinvestments in reactors less profitable, could, however, lead to increased prices and benefit CHP production.

Increased competition and changing business models

Figure 19 • Seasonally adjusted prices - alternative price setting strategy example



Note: Heat pump prices are represented by marginal costs to consumers, which vary depending on heat source (ground or air) temperatures.

Source: Swedish Energy Agency (Energimyndigheten) (2015f), "The role of heat pumps in the heating market: Development and competitiveness in a changing energy system" (Värmepumparnas roll på uppvärmningsmarknaden: Utveckling och konkurrens I ett föränderligt energisystem), ER 2015:09.

Key message • DH pricing strategies have shifted in response to the low cost of heat pumps.

Decreasing heat demand together with increased competition from heat pumps, related to low electricity prices, has changed the business models of many DH companies. Previously, DH companies typically had one price for all seasons (blue line in Figure 19), but increased competition from heat pumps has forced many DH companies to change their pricing (green columns) to just underbid the marginal cost from a heat pump (orange dots), which varies depending on both the temperature of the heat source/heat sink used (i.e. more electricity needed per unit of heat delivered when ground and air temperatures are low in the winter) and on electricity prices. Raising prices in winter also means compensating for losses during warmer seasons and better mirrors the actual production costs. An alternative strategy for increasing competitiveness is charging for capacity and not just delivered energy, hence making it more difficult for customers to install a heat pump and then use DH for peak load only.[44]

[44] Larsson, 2011.

CHP/DHC Potential and Benefits

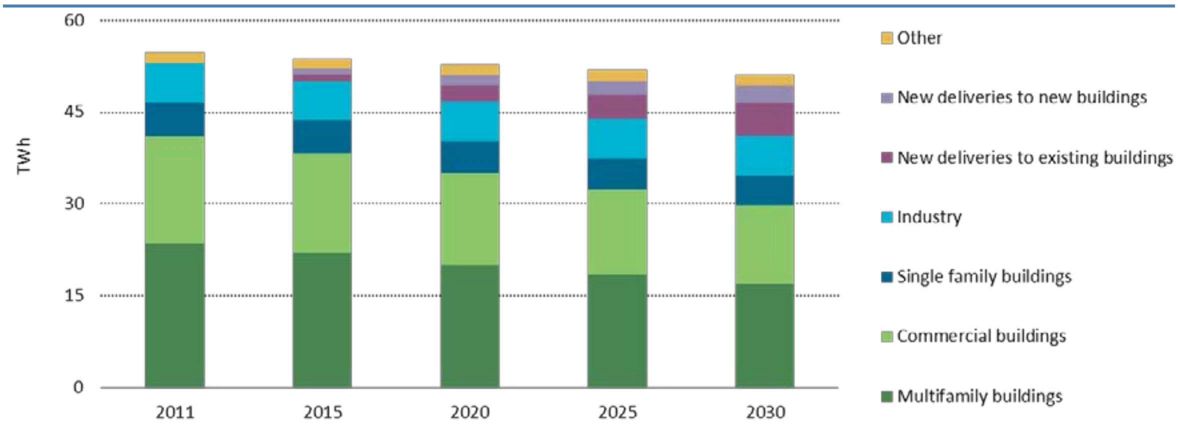
Potential for CHP

The Swedish Energy Agency estimated the realisable potential for electricity generation from CHP is an additional 4.8 TWh per year by 2020, compared to 2011 production levels. This gain would be primarily based on biomass-based CHP capacity installations, both integrated with DHC networks (2.2 TWh) and on industrial sites (2.6 TWh).[45]

In industry, there are no direct barriers to grid access; surplus electricity produced by industrial CHP can be exported at market prices. Pulp and paper sector stakeholders expect production growth and opportunities for CHP expansion through 2020. However, all potential in CHP is particularly sensitive to fuel prices, electricity prices, and relative costs of other heat and electricity generation technologies. Competition from wind power and nuclear power, depending on how Sweden's energy policy strategy evolves, will have an important impact on the potential for additional CHP capacity.

Potential for DHC

Figure 20 • DH demand development through 2030



Note: Projections based on an energy efficiency potential study. This figure shows a base scenario where energy efficiency of heating in existing multi-dwelling and commercial buildings improves at a rate of 1.6% annually, and by 0.5% annually in single dwelling buildings. Single and multi-dwelling buildings and commercial buildings are shown as the heating demand needed to meet the same level of final demand for heat, in buildings already connected to DH networks. This decreases over time as buildings are renovated and become more efficient, or begin using alternative technologies such as heat pumps.

Source: Swedish Energy Agency (Energimyndigheten) (2013b), "Comprehensive assessment of the potential for high-efficiency CHP and district heating and cooling" (Heltäckande bedömning av potentialen för att använda högeffektiv kraftvärme, fjärrvärme och fjärrkyla), ER 2013: 24.

Key message • Very little growth is expected in DH demand through 2030.

[45] Swedish Energy Agency (Energimyndigheten), 2013b.

Energy efficiency in buildings is expected to decrease total DH demand by about 10 TWh by 2030, and an additional 2-3 TWh in decreased DH demand could result from heat pumps gaining market share (from 2011). At the same time DH demand is expected to increase by 8 TWh by 2030 resulting in a net decrease of only around 4 TWh (Figure 20).

District cooling growth has slowed in the last few years and remains at around 1 TWh. Significant upfront investment costs in a DC network, competition from heat pumps, and the cold climate are the main reasons for the slowdown in growth. For district cooling the additional economically feasible potential has been estimated at an additional 2 TWh by 2030.[46]

Potential for electricity and heat production from excess heat

Through the Organic Rankine Cycle (ORC), excess heat can be used for electricity production with an efficiency of 4 to 5% at 90°C, allowing recovery of low-temperature heat that otherwise could not be used. Further development of the technique could increase efficiency to around 10%.[47] The ORC technique, though commercially available, is rarely used, because it is typically not economically competitive.

In 2013, 4.8 TWh of excess heat was supplied directly to DH networks. Data is limited on additional potential for excess heat inputs to DH from industry, though one study estimated a theoretical potential of between 6.2 and 7.9 TWh of excess heat recovery from industrial sites. The same report estimated a theoretical potential for excess heat recovery from sewage and central heating and cooling processes in the commercial sector of 3 to 5 TWh.[48] Estimating the practical, economically feasible potential requires a more detailed, site-level analysis. Some potential has also been identified through the Regional Waste Heat Cooperation programme (Box 4). This is an area of interest for further study.

Potential for micro-CHP

The potential for micro-CHP is estimated to be about 0.3 TWh by 2020. Currently it is not economical and therefore it is practically non-existent in Sweden. In areas with a natural gas network, such as the Gothenburg region, micro-CHP could develop in the long term. Fuel cells might be more economical in the range of 1 to 100 kW.[49] However, micro-CHP is less suited to the Swedish market, with its high level of existing district heating infrastructure, than to other contexts.

[46] Swedish Energy Agency (Energimyndigheten), 2013b.

[47] Ibid.

[48] Swedish District Heating Association (Svensk Fjärrvärme), 2009c.

[49] Ibid.

Box 4 • Case study 4 – Regional Heat Cooperation

Research programme "Fjärrsyn" has financed a study on regional heat collaboration. The overall aim of the project has been to identify obstacles and driving forces for the development of regional DH systems and based on that to compile success factors for new DH collaborations. New potential DH clusters have also been identified and analysed. The project is based on open literature and in-depth interviews with 20 DH suppliers where 12 of these have an existing regional DH system, whereas the others eventually have the potential to connect their DH network with another adjacent network.

The most important driving forces for merging local DH system to a larger regional system can be categorized in three main groups: profitability, production, and environment. In the study, ten potential clusters have been identified with potential to connect the DH networks. Most market actors already have investigated the opportunity to connect their networks. District heating networks with large production cost differences which are geographically close to each other have generally already connected the networks to a large regional system. It is therefore likely that new regional DH systems will mainly occur when a DH supplier is in need of re-investment or investment in new production capacity and a transmission pipe to an adjacent network is a more profitable option.[50]

The identification of potential DH regions is limited by choosing only networks with a minimum of 100 GWh of yearly deliveries of DH. This encompasses some 90 DH networks with the possibility of connecting to other networks (both under and above 100 GWh). Networks with less than 30 GWh annual deliveries have not been considered. Figure 21 depicts the geographic location of DH networks identified for possible regional cooperation.

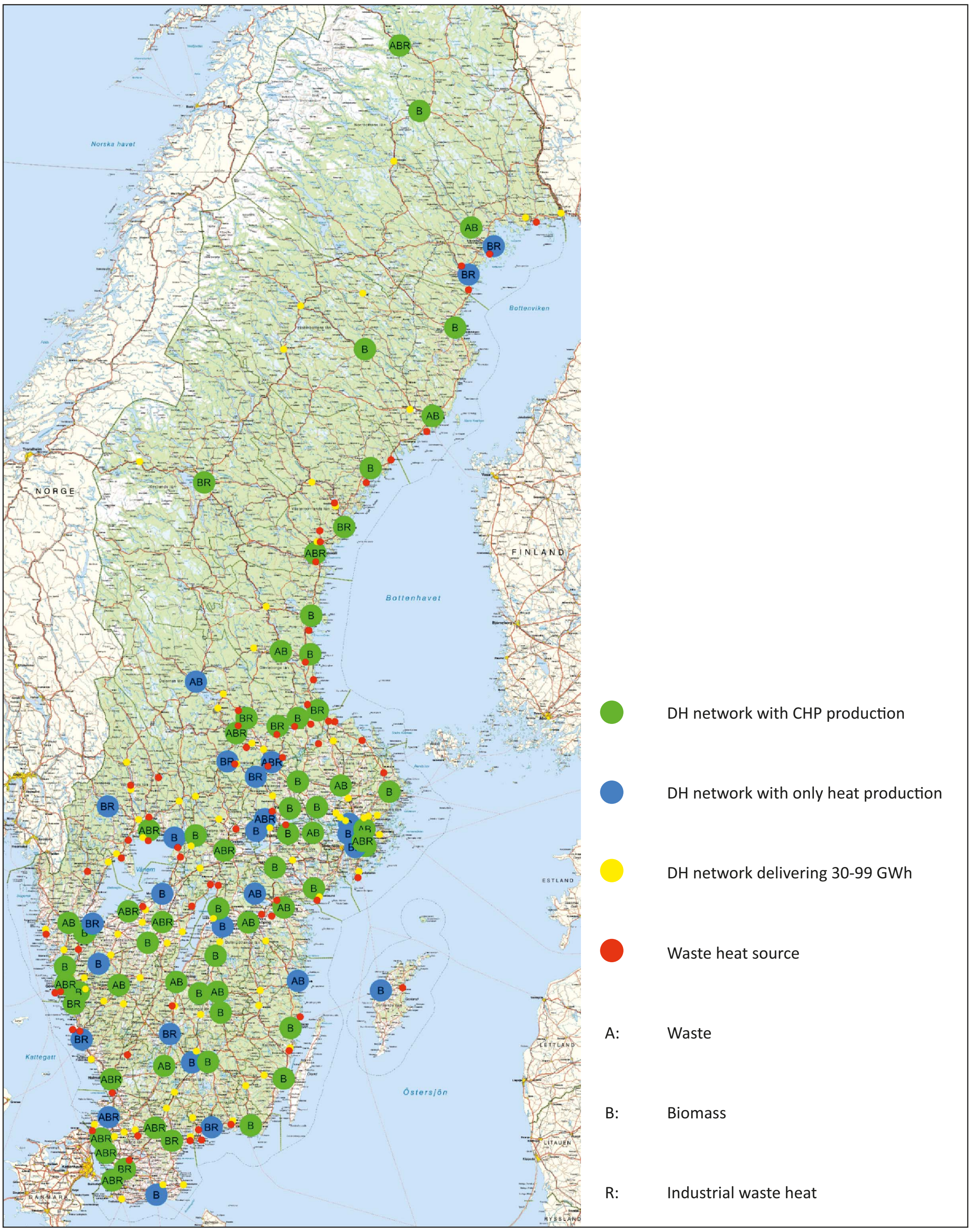
The map furthermore assumes that distance between connecting parts must not exceed 40 km. The potential delivery of DH in the "new connected network" has been assumed to be at maximum 30% of the connected producers' volume. This then yields a number in terms of GWh per kilometre. If the factor is 5 or higher it has been deemed interesting to study further. Given this methodology, 10 possible regional DH collaborations have been identified with 19 different DH actors. In the research study 4 of these have been closer examined. Two of these have already made extensive economic analyses. Among the four there are possible profits in at least two of them although no immediate investments have been initiated. Discussions are ongoing concerning future collaboration.[51]

Source: Source: Liljeblad, A., M. Jansson, and I. Noghlgren (2015), "Regional district heating collaboration: Drivers and success factors" (Regionala fjärrvärmesamarbeten: Drivkrafter orch framgångskaftorer), Fjärrsyn, Report 2015:102.

[50] Note that in accordance with article 14.5 in the Energy Efficiency Directive (EED) a cost-benefit analysis (CBA) should be done to verify the potential of using excess heat instead of building new capacity.

[51] Between Gävle – Sandviken and Trollhättan – Vänersborg.

Figure 21 • Geographical placement of identified possible new DH collaborations



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Notes: The original map of Sweden is taken from Lantmäteriet and modified by WSP and IEA.

Source: Liljeblad, A., M. Jansson, and I. Noghlgren (2015), "Regional district heating collaboration: Drivers and success factors" (Regionala fjärrvärmesamarbeten: Drivkrafter orch framgångskaftorer), Fjärrsyn, Report 2015:102.

Key message • Potential for additional DH collaboration is concentrated in the southern part of the country.

CHP/DHC Scorecard

To aid in comparing amongst countries, the IEA has developed a Scorecard of a country's CHP and DHC policy efforts that takes into account the effectiveness of the policy framework to create an **energy efficiency rewarding environment which enables realising cost-effective CHP/DHC potentials** from the perspective of past and existing policies, as well as statements and commitments of intent respect to future related policies.

Each country is given a scorecard rating as follows:

No material policy effort or intent to promote CHP/DHC. The market is not expected to grow for the foreseeable future. Rating: 1

Some minor recognition of the benefits of efficient CHP/DHC, but policies are not fully effective or are otherwise insufficient to promote CHP/DHC deployment. Rating: 2

There is recognition of the benefits of efficient CHP/DHC, accompanied by the introduction of some measures to accelerate the development of CHP/DHC, but these technologies are not effectively prioritized compared to other energy solutions. In addition, the country lacks an integrated CHP/DHC strategy. As a result, realized CHP/DHC potentials are likely to be modest. Rating: 3

Efficient CHP/DHC and cost-reflective heat and electricity tariffs are an energy policy priority and a series of effective policies are implemented as part of a coherent energy strategy which rewards energy efficiency. Significant growth is expected in the deployment of CHP/DHC. Rating: 4

A world reference in realising CHP/DHC potentials, with a clear and proven strategy for rewarding energy efficiency. CHP/DHC role is expected to remain important with a CHP/DHC integrated policy strategy aiming to continuously seek for further deployment opportunities. Rating: 5

Sweden's CHP/DHC Policy Rating Benchmarked against Global Best Practice: 4.5

Summary Policy Recommendations

The historically strong policy framework around CHP and DHC deployment in Sweden has lessened slightly in recent years, with direct government support for infrastructure development and deployment of CHP and DHC waning. However, opportunities remain to reinforce the already strong positions of CHP and DHC within the Swedish energy system, despite the maturity of the market and increasing competition from other sources of energy.

- **Develop a comprehensive and long-term national energy strategy:** The current process underway to develop a new strategy for Swedish energy policy through 2050, via the Energy Commission and other bodies, will provide clarity, stability and visibility that are crucial for long-term planning. Ensuring that this strategy takes a long-term integrated view is a good first step to encouraging a well-planned energy system. Certainty through 2030 with respect to the replacement of current nuclear capacity will have a particular impact on investment decisions for CHP. The government should continue to ensure that the strategy considers all aspects of the energy system, including both electricity and thermal energy, and the interfaces and interactions between the two.

- **Continue support for climate change goals**: Sweden has already made significant progress towards its climate goals. However, continuing to incentivise emissions reductions will encourage deployment of CHP and DHC where optimal, in order to capture their associated emissions benefits. Tracking progress towards these goals, by continuing to collect highly detailed data, will allow future efforts to be more targeted and effective.

- **Support integrated planning**: Particularly in Sweden, where electricity generation is largely decarbonised, and heat generation is well on its way, energy system planning must consider all costs and benefits of different technology options. For example, integrating local excess heat sources from industry to existing district energy networks can provide system-wide benefits at limited economic cost as compared to installing new generation capacity, but requires detailed data collection, mapping and planning and policy frameworks which allow such arrangements. Regional solutions, such as common markets and joint infrastructure planning, could also contribute to Sweden’s energy and climate goals. An integrated approach to thermal and electricity grid planning will be most beneficial to society as a whole, and will ensure that system-level benefits of CHP and DHC are considered.

- **Protect the ability of technologies to compete on a level playing field**: In particular, neither DHC nor heat pumps should be favoured over the other in building codes or regulations. Solutions should be chosen on a case-by-case basis according to the particular design, limitations, and thermal needs of the end user.

- **Encourage innovation in energy delivery**: Swedish DHC companies, in particular, have created innovative new ways to expand their businesses. Partnerships and collaboration between public and private sector stakeholders, as well as between producers and consumers, are common. The cooperation programme for bioenergy-based electricity and heat production is an example of a public-private collaboration to support low-carbon innovation (including renewable-based CHP).

The Swedish government should continue to encourage innovation in CHP and DHC applications, as well as the development of new sustainable business models. Research projects like the District Heating Research Programme, Fjärrsyn, should be supported in order to better assess the potential and future needs of Sweden's energy system.

Additionally, the impact and effectiveness of public-private collaborations should be tracked through mechanisms demonstrating, documenting and monitoring achievements. This will allow future government support for these types of programmes to be strategically targeted to the areas where it will yield the best results.

The IEA CHP and DHC Collaborative and IEA-supported Related Initiatives

The IEA CHP and DHC Collaborative was initiated in 2007 with the goal of accelerating deployment of cost-effective, clean CHP and efficient DHC technologies leading to reduced CO_2 emissions and increased overall efficiency of the energy system by an increased use of excess heat and low-carbon renewable energy resources; and of providing a platform for stakeholders to share best practices policies, experiences and applied solutions on these technologies. Collaborators of this initiative include governments, international organizations, regional industrial associations and the private sector, including equipment suppliers and utility companies.

This initiative has completed so far several publications which provide a vision of CHP and district energy potential, along with an overview of policy best practices and recommendations of options to consider when implementing these policies. The Collaborative results also highlighted the benefits of an integrated energy system approach with CHP technologies assisting in balancing electricity production from variable renewables. For more information about the Collaborative, please visit www.iea.org/chp/.

The Technology Collaboration Programme on District Heating and Cooling, including the Integration of Combined Heat and Power (DHC TCP), is a multilateral technology initiative supported by the IEA. The nine member countries of the DHC TCP deal with the design, performance and operation of distribution systems and consumer installations. In operation since 1983, the DHC TCP is dedicated to helping make DHC and CHP powerful tools for energy conservation and the reduction of environmental impacts of supplying heat. For more information, please visit www.iea-dhc.org.

Annex: Sweden CHP and DHC Background Data

Table 3 • CHP installed capacity, by sector and application

		2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total CHP capacity (GW_e)		**3.2**	**3.7**	**4.2**	**4.1**	**4.2**	**4.7**	**4.8**	**4.8**	**5.0**	**5.0**
CHP installed capacity by sector	*Industrial*	0.9	1.0	1.2	1.2	1.2	1.2	1.2	1.2	1.4	1.4
	DHC	2.3	2.6	3.0	2.9	3.0	3.5	3.6	3.6	3.6	3.6
CHP installed capacity by technology	*Combined cycle*					0.3	0.3	0.3	0.3	0.3	0.5
	Gas turbine with heat recovery					>0.0	>0.0	>0.0	>0.0	0.5	0.5
	Internal combustion engine					>0.0	>0.0	>0.0	>0.0	>0.0	>0.0
	Steam backpressure turbine					3.8	4.2	3.9	3.7	3.8	3.8
Total national electricity generation capacity (GW_e)		**30.9**	**33.2**	**33.8**	**34.1**	**34.2**	**35.3**	**35.7**	**36.5**	**37.4**	**38.3**
CHP as % of total capacity		**10.3%**	**11.0%**	**12.4%**	**12.1%**	**12.1%**	**13.4%**	**13.4%**	**13.1%**	**13.2%**	**13.1%**

Note: The sum of installed capacity of CHP by technology does not equal the total CHP capacity, as these come from different surveys. CHP capacity in industry and DHC may also not equal total CHP capacity, due to rounding.

Source: Swedish Energy Agency (Energimyndigheten) (2015e), Energy statistics.

Table 4 • CHP electricity and heat production, fuel input, and efficiency

		2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total CHP electricity production (GWh)		**8 821**	**11 843**	**12 307**	**13 523**	**14 264**	**15 741**	**18 874**	**15 970**	**15 400**	**14 809**
CHP electricity production by sector	*Industrial*	4 150	4 572	5 034	5 707	6 201	5 560	6 418	5 790	6 100	5 640
	DHC	4 671	7 271	7 273	7 816	8 063	10 181	12 456	10 180	9 300	9 169
Total national electricity production (GWh)		141 951	154 492	139 400	145 601	146 905	133 674	145 642	147 569	162 612	149 193
CHP electricity production as % of national total		6.2%	7.7%	8.8%	9.3%	9.7%	11.8%	13.0%	10.8%	9.5%	9.9%
Total CHP heat production (GWh)*		13 783	19 973	21 667	22 133	23 030	25 474	31 299	28 136	28 333	28 412
Total national heat production (GWh)*		90 717	84 914	80 730	78 136	75 190	78 500	84 900	76 100	79 400	80 200
CHP heat production as % of national total		15.2%	23.5%	26.8%	28.3%	30.6%	32.5%	36.9%	37.0%	35.7%	35.4%
Total CHP fuel input (GWh)			**34 795**	**38 801**	**39 418**	**40 874**	**44 170**	**57 929**	**50 244**	**47 867**	**47 861**
CHP fuel input by fuel type	*Natural gas*		2 023	2 215	3 299	2 556	5 232	8 919	4 995	3 798	3 728
	Coal		4 440	5 398	4 901	4 355	3 579	5 303	4 258	3 773	4 668
	Peat		2 210	1 900	2 092	2 651	1 737	2 475	2 245	1 800	1 490
	Oil		2 734	3 043	1 840	1 469	1 741	3 106	1 583	1 332	804
	Biomass		17 097	17 736	18 273	19 812	22 006	24 904	23 006	23 708	23 610
	Waste		4 764	5 515	7 146	8 354	7 385	9 348	10 887	10 623	11 446
	Other		1 528	2 994	1 870	1 678	2 489	3 875	3 269	2 833	2 115

Note: CHP refers to heat production of CHP units in CHP mode. Heat output excludes small heat pumps. Heat used on-site produced by industrial users is not reported, only the portion sold externally is included in national statistics, and thus total heat, CHP heat production, and CHP fuel input are underestimated.

Source: Swedish Energy Agency (Energimyndigheten) (2015e), Energy statistics.

Table 5 • DH production, consumption and fuel input

		2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total DH production (GWh)		**45 481**	**51 202**	**52 375**	**53 048**	**51 379**	**57 195**	**64 116**	**54 360**	**59 938**	**58 089**
DH production by application	*CHP*	13 783	19 973	21 667	22 133	23 030	25 474	31 299	28 136	28 333	28 412
	Heat only	17 549	19 340	18 339	18 349	18 815	22 001	22 759	17 508	20 701	20 147
	Industrial excess heat	4 644	5 375	6 302	6 523	3 687	4 320	4 505	3 565	4 886	4 837
	Heat pumps	7 484	6 194	5 839	5 789	5 698	5 194	5 424	5 056	5 793	4 461
	Electric boilers	2 021	320	211	250	149	205	130	95	225	232
Total DH consumption (GWh)		**41 351**	**47 007**	**46 436**	**46 808**	**46 812**	**48 101**	**53 842**	**46 978**	**49 989**	**50 980**
DH consumption by sector	*Industry*	4 003	4 396	4 397	4 376	4 223	4 499	4 527	4 119	4 269	4 183
	Commercial & residential buildings	37 348	42 611	42 039	42 432	42 589	43 602	49 315	42 859	45 670	46 797
Total DH fuel input (GWh)			**44 841**	**49 122**	**48 455**	**46 715**	**54 746**	**66 061**	**53 370**	**56 052**	**54 909**
DHfuel input by fuel type	*Natural gas*		2 479	2 363	3 467	2 728	6 112	9 262	5 088	4 032	3 834
	Coal		5 657	5 905	5 741	5 661	5 222	6 103	4 968	4 583	4 976
	Oil		3 212	3 847	2 444	1 464	2 702	5 251	2 504	2 303	1 670
	Biomass/ biogas		27 299	31 042	30 334	30 750	34 041	38 948	34 445	37 935	37 514
	Waste		3 499	3 622	3 897	4 212	4 246	4 823	5 004	5 373	5 371
	Electricity		2 431	1 995	2 181	1 777	1 634	1 603	1 344	1 821	1 504
	Other		263	307	391	123	789	72	17	5	39
DH share of national heat production		**50.1%**	**60.3%**	**64.9%**	**67.9%**	**68.3%**	**72.9%**	**75.5%**	**71.4%**	**75.5%**	**72.4%**

Note: Peat is included under coal and coal products according to IEA definitions.

Source: Swedish Energy Agency (Energimyndigheten) (2015e), Energy statistics.

Acronyms, Abbreviations and Units of Measure

Acronyms and abbreviations

AHU	air handling unit
CBA	cost-benefit analysis
CFB	circulating fluidized bed
CHP	combined heat and power (also called cogeneration)
CO_2	carbon dioxide
COP	coefficient of performance
COP21	21st Conference of the Parties
DC	district cooling
DH	district heating
DHC	district heating and cooling
EED	Energy Efficiency Directive
EFFSYS EXPAND	Effective cooling and heat pump systems and cooling and heating storage
EU	European Union
EU ETS	European Union Emissions Trading System
GDP	gross domestic product
GHG	greenhouse gas
IEA	International Energy Agency
IEH	industrial excess heat
INDC	Intended Nationally Determined Contribution
KLIMP	Climate Investment Programme
KLIMATKLIVET	Local Climate Investment
LIP	Local Investment Programme
MGO	marine gas oil
NUTEK	Swedish Business Development Agency
OECD	Organisation for Economic Co-operation and Development
ORC	Organic Rankine Cycle
R&D	research and development
SO_2	sulfur dioxide
TPA	Third Party Access
TPES	total primary energy supply
UNFCCC	United Nations Framework Convention on Climate Change

Units of measure

°C	degrees Celsius
EJ	exajoule
EUR	Euro
Gt	gigatonne

Gtoe	gigatonne of oil-equivalent
GW	gigawatt
GW_e	gigawatt electric
GWh	gigawatt hour
Km	kilometre
kW	kilowatt
kWh	kilowatt hour
m^2	square metre
MW	megawatt
MWh	megawatt hour
PJ	petajoule
SEK	Swedish krona
TWh	terawatt hour
USD	United States dollar

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