BASREC

Best Practice Sharing

Municipal Energy Integration

Booklet 2 – Planning and Integral Operation

August 2015

NUORKIVI CONSULTING

COWI

Foreword

Increased focus on climate changes, CO_2-emission and other environmental considerations has made sustainability one of the most important focus areas – not least in the cities. Therefore, it is extremely important that we design and "operate" our cities and buildings in a sustainable way.

Looking at all EU countries both the structure and the character of the district heating systems are very differentiated. Basically, all existing studies exploring the road to a decarbonized energy supply in 2050 model generic solutions without investigating the possibilities and limits of their implementation in practice in an urban environment. Yet, future solutions must in the first instance be urban solutions.

Planning and pooled operation of several energy production plants in integrated urban CHP/DH systems based on RES (biomass/geothermal/solar) is important to optimise the use of different types of renewable sources in different heat and electricity markets. Flexibility and links between the electricity systems and the heat market are required to ensure that energy is not wasted.

One challenge to CHP is the reducing cost of RES such as solar, wind and various heat pumps. Moreover, the expected power price in Nordpool is low. Therefore, recently in the Nordic countries, reducing prices of various RES and low price expectation in the pool have led to construction of HoBs rather than CHP.

The booklet has been issued with and objective to:

Provide guidance to cities, regions and energy companies in the Baltic Sea Region in their process of accelerating conversion from fossil fuels, improving energy efficiency, and extending the use of renewable energy sources,

BASREC has initiated a project on Best Practice sharing within Municipal Energy Integration. The project scope included the following 3 main topics:

1. Integral Urban and Energy Planning
2. Planning and Integral Operation
3. District Cooling

Relevant stakeholders in a number of selected Cities have been interviewed and based on this three booklets (1,2,3) have been issued, one on each topic. The present booklet presents main conclusions in respect of "Planning and Integral Operation" of major DH/CHP systems in some major Cities in BASREC. It discusses the different opportunities and challenges in the different Cities and extract experiences and best practices based on the individual City cases and at a common level for the entire BSR.

Some urban areas are advanced in applying long- and short term planning tools and procedures in parallel with procedures for daily operational optimisation of integrated energy supply systems. The future will require this for all urban areas, different simulation tools as well as real time optimisation tools are needed and exchange of experiences, tools and best practice is very important.

Stakeholders (key pioneers) in selected Cities (Berlin Copenhagen, Helsinki, Stockholm and Warsaw) have been interviewed, and an overview of the main features and driving forces drawn from the questions below are included for the individual cities in chapter 5.

- *How local structures are developed and how they support fulfilling national goals for CO_2 reductions and integration of renewable energy sources?*

- *How short term actions are optimised in a long term perspective?*

- *Whether there is a tradition for cooperation between energy supply companies and authorities at local and national level. Are the different stakeholder able to communicate and have procedures for communication been defined?*
- *Whether there is a set of common assumptions and procedures for carrying out comparable cost benefit analysis in order to establish a consistent and robust decision basis for long term investments as well as short term actions?*

The authors of the booklet truly hope that the approaches and examples presented in the booklet will contribute to increased understanding and optimization of urban energy structures comprising renewable energy systems, and DHC/CHP as an integrator of various types of energy sources, in the BSR municipalities and beyond.

Contents

Abbreviations

BASREC	Baltic Sea Region Energy Co-operation
BSR	Baltic Sea Region
CHP	Combined heat and power plant
DC	District cooling
DHC	District heating and cooling
DH	District heating
DHW	Domestic hot water
EE	Energy efficiency
EU	European Union
HP	Heat pump
HoB	Heat-only boilers
RES	Renewable Energy Sources

1 Planning and Integral Operation – Concept and Main Features

The level of urbanisation in Europe is currently approximately 75%, and it is expected that from 2020 and onwards it will stabilize at a level over 80%. A huge challenge in connection to sustainable urban development is to address both present and future needs, which are dictated by resource scarcity and expected climate changes.

An interdisciplinary approach to sustainability is necessary. The main topic of physical regeneration needs to be seen in a context alongside social, economic, environmental and cultural aspects of urban life. Sustainable urban development is reached best through integrated urban development plans around long-term visions for cities and neighbourhoods in their regional and national context.

Focus on minimising the energy consumption, integrating renewable energy supply and making the use of fossil fuel more effective is important. Future-proofed, flexible quality solutions pay. But it may be difficult to assess which technologies will be optimal both now and in the future. Sustainable energy development requires an integrated approach to demand and supply options and a full understanding of the total chain from resources to requirements.

Figure 1: Communal energy system.

Initiatives can be taken from different stakeholders in the international, national and urban environment e.g. urban development planners, energy suppliers, building owners, technology suppliers and lobby institutions with different interests. Cooperation between all involved public and private stakeholders, however, is important to ensure implementation of development plans in accordance with agreed development goals. Monitoring and evaluation should be an integral part of each development plan. The success stories are found where the process has been planned and implemented in an interactive and not in a counteractive way.

An integrated top-down and bottom-up development process is the way forward. ***The top-down process*** is needed as basis for decisions regarding long-term development strategies to achieve national and local goals and commitments in respect of environmental sustainability, security of supply and economy. A ***bottom-up process*** initiated in parallel with the top-down process define specific actions to analyse and demonstrate options and implementation steps related to specific projects mainly at local level. For both processes, however, it is important to keep an overview and to understand the interrelationships in the entire demand/supply chain. The interfaces and the balancing over time in all dimensions are important to efficiency in the short, medium and long term.

An integrated approach for implementing national strategies and goals for EE and RES in specific urban energy structures with technical limitations and opportunities is a prerequisite for the development. Action plans at urban level under national and internal framework conditions need efficient simulation tools and planning procedures covering all technical, economic and organisational issues.

Combined Heat and Power (CHP) production in combination with district heating is one of the most energy-efficient and climate-friendly ways to produce energy, making it possible to use renewable energy with high efficiency at lower prices for the heat costumers.

This has been recognized in many major BSR cities. Over the past years the district heating systems have developed both in respect of integration of several smaller systems through larger transmission systems and by connection of a variety of heat production facilities like different types of CHP plants based on different fuels including biomass and waste, industrial surplus heat, heat pumps, solar plants etc..

2 Planning and Integral Operation – Driving Forces and Motivation

DH can be highly flexible in terms of switching between production plants and fuels. Looking at the actual development in Denmark illustrated in the following 3 figures it is clear that district heating and CHP has been a main actor in the restructuring of the Danish energy sector towards efficiency, security of supply and reduction of CO_2.

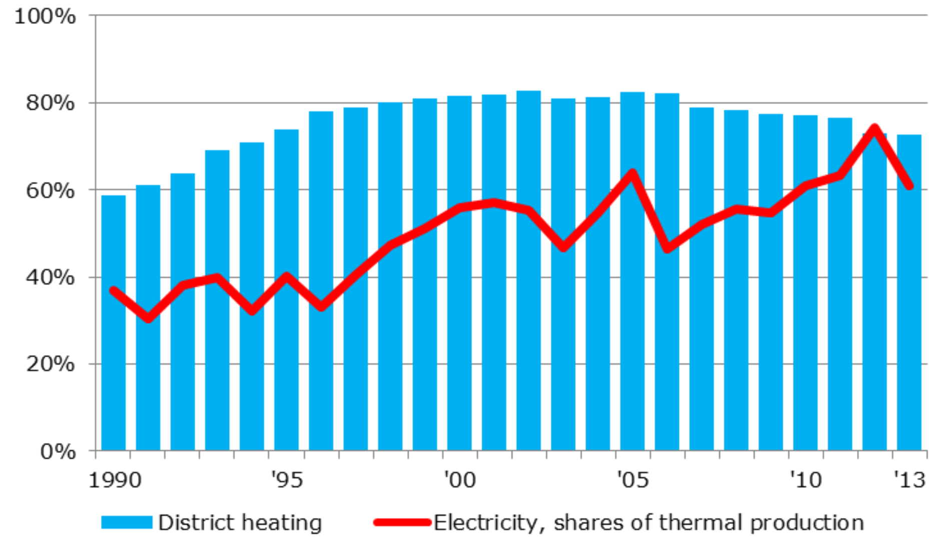

Figure 2: CHP share of electricity and heat production in Denmark.

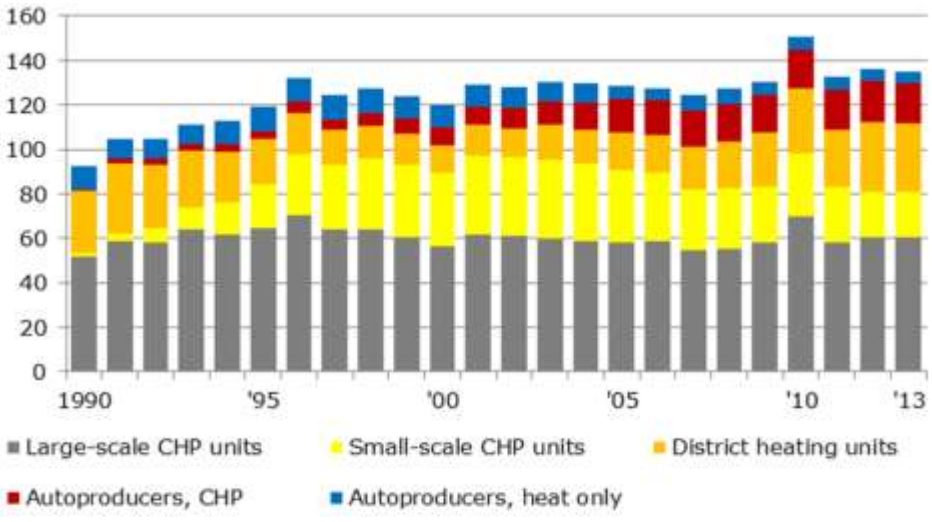

Figure 3: District heating production in Denmark on different production units

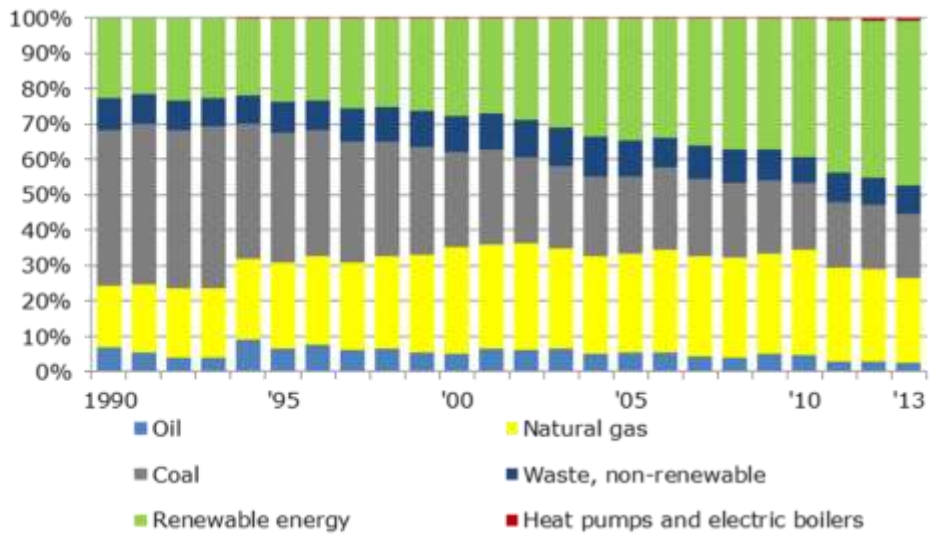

Figure 4: Fuel consumption for district heating in Denmark

Since the oil crises in the 1970'th, planning has been done in close cooperation between government, energy suppliers, private business and consumers. All major DH projects in Denmark must show socioeconomic feasibility. Without doubt, long term planning has been the main driver for development of District Heating in Denmark and in Copenhagen.

A parallel picture of the fuel mix for DH/CHP in Sweden is illustrated in figure 5 below.

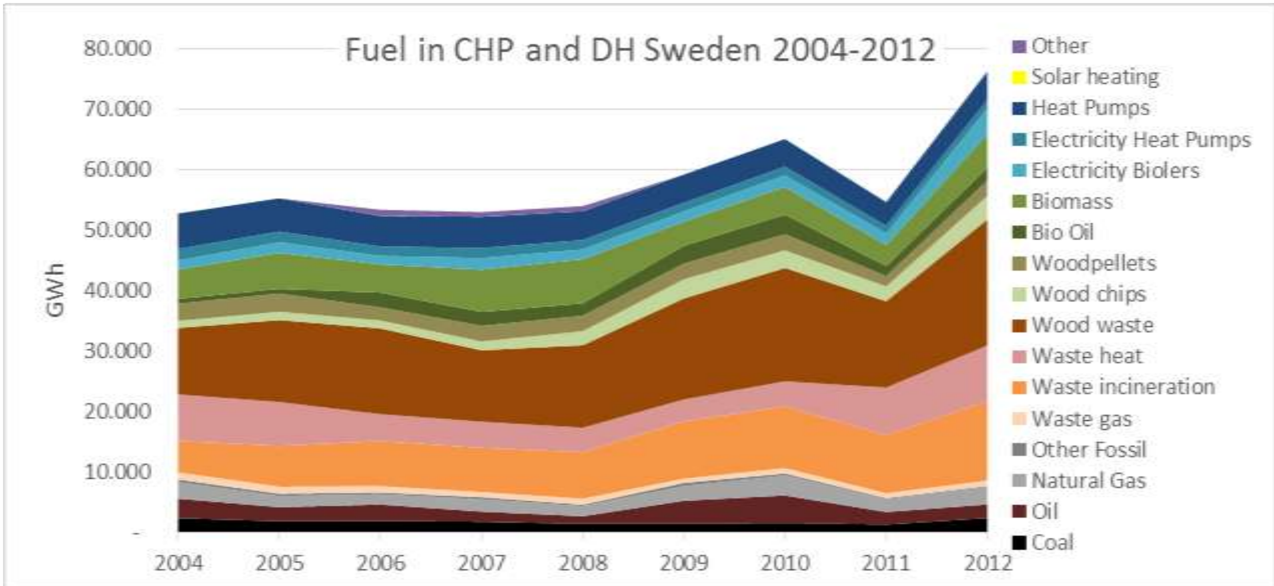

Figure 5: Fuel supply for CHP and DH in Sweden. Source: http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/

In Sweden, the development of DH is not a product of a national DH policy, but rather a result of energy optimization including CHP plants and in the later years a consistent energy and climate policy, where smart solutions in order to continue to deliver heat have been sought.

CHP technology is well proven, and over time it has turned out to be very flexible – it has adapted to different fuels and technologies following changing political priorities over the decades.

In the future, large amounts of fluctuating energy (especially wind) will require a dynamic new energy system with increased interaction between energy production and consumption and between electricity and heat.

New technologies, such as electric heat pumps, electric heaters, geothermal heat and heat storage will be developed with a view to becoming instrumental components of the district heating supply in the long term.

Heat pumps and CHP plant provides the connection between heat and power in the energy system. Just like heat produced in a CHP plant reduces the flexibility in the electricity grid, the heat production from large CHP connected to DH systems provides flexibility. With increasingly fluctuating electricity prices, the option to choose between heat from cheap electricity or to produce electricity sold to a higher price will drive variable heat prices down.

Some urban areas are advanced in applying long- and short term planning tools and procedures in parallel with procedures for daily operational optimisation of integrated energy supply systems. The future will require this for all urban areas. Different simulation tools as well as real time optimisation tools are needed and exchange of experiences, tools and best practice is very important.

Simulations tools, such as Balmorel (a short description included in the Copenhagen chapter), is used to perform cost-benefit analyses and to make system optimisation in larger energy systems with several energy production facilities. Balmorel is a model for analysing the electricity and combined heat and power sectors in an international perspective taking into account the interconnected electricity systems and Nordpool. The tool is highly versatile and may be applied for long range planning as well as shorter time operational analysis.

Also online network simulation tools like TERMIS (a short description included in Copenhagen chapter) are important and used in the larger cities to perform daily optimization, hydraulic analyses and heat predictions. TERMIS is used to evaluate how close to optimized operation the system reaches every day. Future temperature requirements in the district heating systems are very important for integration of new renewable sources and online monitoring of consumer behaviour and temperatures will be a main prerequisite for developing of the future smart cities systems.

3 Planning and Integral Operation – Barriers and Competitive Solutions

Many initiatives exploring the road to a decarbonized energy supply in 2050 model generic solutions without investigating the possibilities and limits of their implementation in practice in an urban environment.

To ensure efficient utilisation throughout the development process, the interaction between the electricity and heat market are of upmost importance. A common recognition of this importance at local and regional level would support national strategies and create a sound basis for the necessary investments in the heat supply structure to ensure the overall efficiency of the integrated energy structure up to 2020 and between 2020 and 2050. After 2050 new technologies might be ready to take over.

The impact of CHP depends on both the technologies chosen and on the markets in which the technologies are applied. To evaluate the potential for energy efficiency improvements from combined cooling, heating and power system development, the product markets - cooling, heat and electricity - therefore should be considered in more detail. The structure of ownership of energy producers result in some conflict of interest. Especially the distribution of base load between grids and during the summer period is important.

In Finland, for instance, an analysis was performed how much the DH and CHP, both industrial and municipal CHP, have contributed to the CO_2 emission reduction compared to the fictive alternative without DH and CHP. In year 2013, for instance, the reduction has amounted to about 7 million ton of CO_2, being equivalent to about 1300 kg of CO_2 emissions less per capita in a country of 5,4 million population. The emission saving per capita of 1300 kg corresponds to a weight of a small car. The emission reduction is substantial even though we cannot visually recognise it.

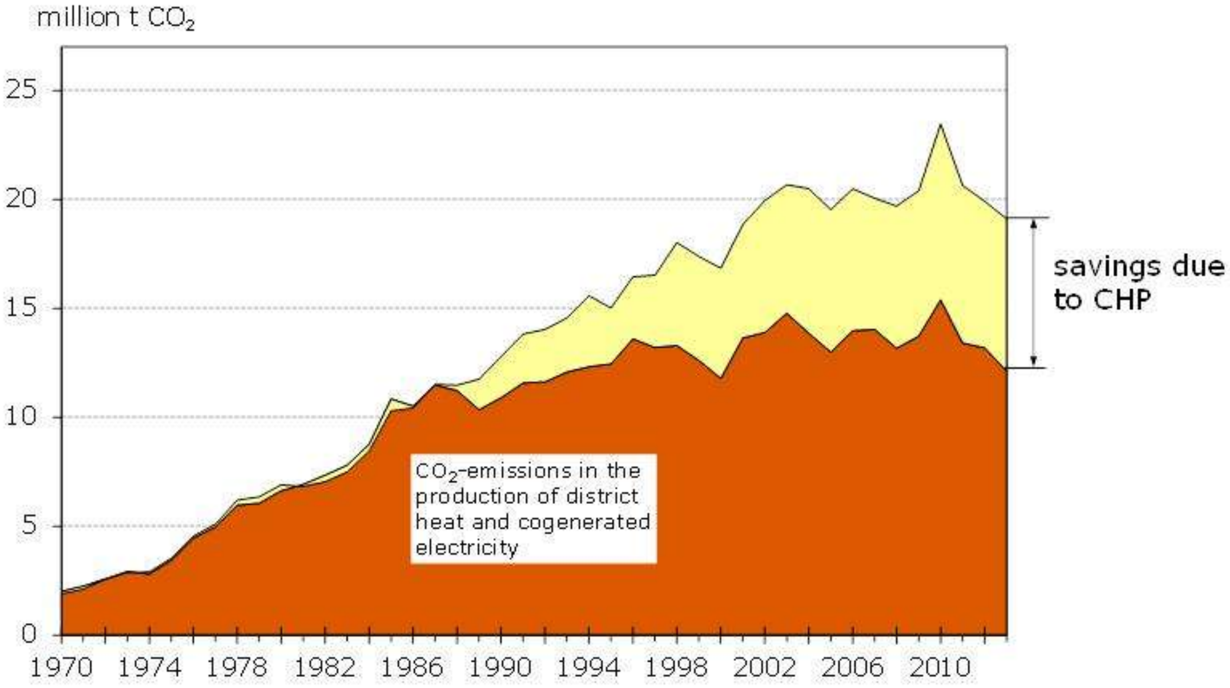

Figure 6: CO_2 savings due to DH and CHP in Finland (Source: Finnish Energy Industries association, www.energia.fi)

Physical and technical opportunities need to stand the test of economic feasibility. Here, many projects fail because of mismatching heat and power loads, disparate price evolutions of fuels and of heat and electricity, insufficient scales or utilisation times etc. Assessment of different options to increase the overall efficiency of the energy sector requires an integrated approach to demand sector initiatives and supply sector initiatives. The actual needs in respect of energy services and the consumer installations play an important role in the assessments.

EU Member States shall carry out a cost-benefit analysis covering their territory based on climate conditions, economic feasibility and technical suitability. The cost-benefit analysis shall be capable of facilitating the identification of the most resource-and cost-efficient solutions to meet heating and cooling needs.

The structure of the national and regional power market in which the cogeneration is to be cost efficient is important. The electricity supply system involves different production technologies with different characteristics. Typically, capital intensive production technologies like nuclear power plants and large hydro-power plants produce electricity at low marginal costs - actually the reason why they were established as the capital investments are paid off due to the low marginal costs. Thermal condensing power plants, on the other hand, produce at high marginal costs, but are less capital intensive. CHP plants are generally ranged between the capital intensive and the fuel intensive technologies and are thus competing between the base-load markets and the peak-load operators. This is a challenge to policy makers as well as to operators. Fuel costs influence the internal ranking between different CHP technologies.

To approach a realistic total potential market for electricity produced from cogeneration, the present electricity production structure as well as the future perspectives should therefore be analysed.

The feasibility of investing in a new plant (CHP, heat pumps, geothermal plants, solar plants and larger heat storages plant) should be analysed both for the specific national and for local market conditions. The environmental benefits of the production facility are to be involved. The feasibility of new CHP plants, heat pumps and storages depends very much on the future development in the electricity market. National development strategies should ensure flexible, but robust, framework conditions for investors and operators to be successful - i.e. to ensure that the overall development goals are achieved.

4 Examples from DH Market

The table below offers the main capacity indicators of the five DH/CHP systems in the BSR.

	Berlin	*Copenhagen*	*Helsinki*	*Stockholm*	*Warsaw*	*Unit*
Number of customers		31.300	15.000	15.200	19.000	#
Network length	1.775	1.500	1.400	1.350	1.700	km
Production	9.440	4.900	7.300	7.500	11.000	GWh
Sales to customers		3.842	6.800	7.100	10.000	GWh
DH design capacity	5.580	4.800	3.300			MW
CHP	Biomass Coal Natural gas Lignite	Biomass Coal Natural gas Oil	Coal Natural gas Biomass	Biomass Coal Natural gas Oil	Coal Biomass	MW
Waste to Energy		3 plants	1 in Helsinki region	1 plant	1 plant	

Table 1: Summary of DH in five Baltic capitals (2015).

5 Best Practices on Planning and Integral Operation

5.1 Berlin

One major goal of the climate policy of the city of Berlin is the reduction of CO_2 emissions by 40 percent by the year 2020. The official Berlin Environmental Relief Program [SENGUV, 2011] focuses on the building stock and their heating energy demand, which has a share of up to 80% of the total energy consumption of a building and up to 40% of the total urban energy consumption in Berlin [AGEB, 2012].

Therefore, the aim is to increase the energy efficiency of buildings, and thus the reduction of CO_2 emissions as well, by comprehensive energy efficiency retrofitting measures. Furthermore, the efficiency of the electrical power and space heating production shall be increased by introducing renewable energy sources, in order to reduce the current CO_2 emissions.

Berlin is an outstanding example of the promotion of cogeneration by a city. The capital is an important location for research, and the production of innovative cogeneration technologies and Berlin also takes a leading position in the appliance of CHP.

The CHP has a long history in Berlin. When its western part was cut off from the rest of the Federal Republic from the late 1940s, it found itself fighting two forms of cold war simultaneously. With only limited primary energy available, the West Berlin authorities needed to make the most of what they had, and cogeneration was an obvious mechanism. The result was a huge system of district heating. Meanwhile, in the communist-run parts of the city, excess heat from factories was being used to heat surrounding apartment blocks.

With the fall of the wall in 1989, the two systems were linked up, creating one of western Europe's largest DH systems – some 1500 kilometres of pipes, connected to 10 CHP power plants, bringing heat to public and residential buildings.

A further development of the pipework is about to be realised, including the replacement of fossil fuels with biomass. Additionally, more than 300 cogeneration units are providing decentralized heating systems.

About 27% of all buildings in Berlin are connected to the DH grid.

Various technologies are used in Berlin to produce heat through CHP. The energy supply company Vattenfall combines gas with steam turbines in its five combined cycle gas turbine (CCGT) power stations.

Operation of the power station is controlled by the heat demand, i.e. the station is 'heat-led'. In the coming years, the Vattenfall group will invest more than €1000 million to build new power stations or modernise the existing ones in Berlin. At the same time, these activities of Vattenfall support the government of Berlin in its effort to reduce carbon dioxide emissions in the city by more than 40% by 2020.

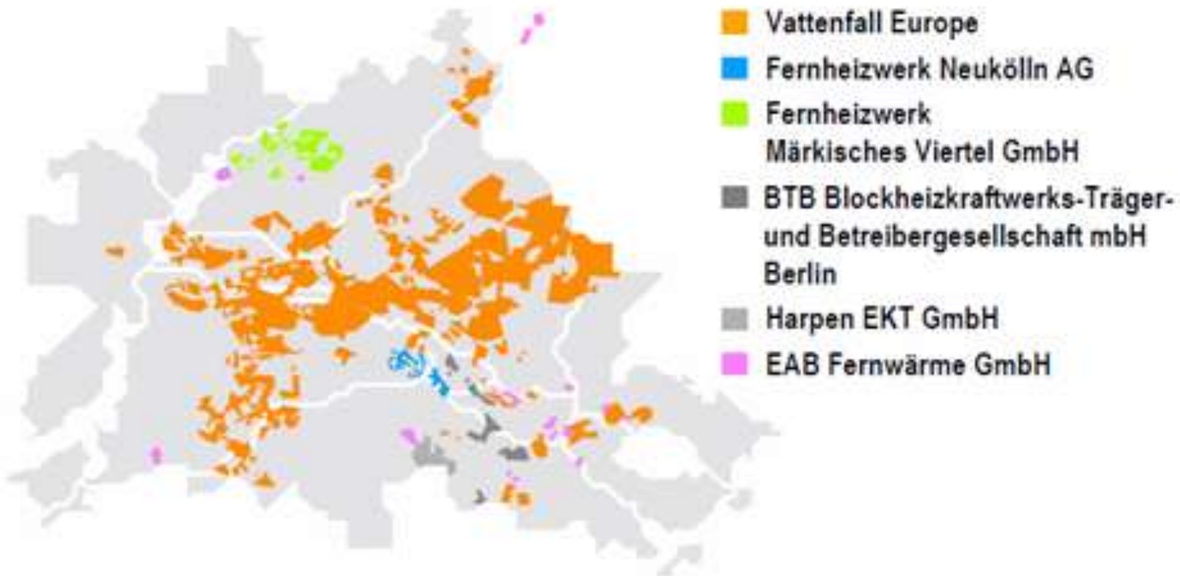

Figure 7: District heating areas in Berlin. In addition to large-scale, central CHP stations, decentralized CHP is becoming ever more important in Berlin. Due to special support programmes by the federal government, 50 new cogeneration units have already been added since 2009. Decentralized CHP is a versatile, flexible and environmentally friendly solution for intra-urban areas.

Apart from Vattenfall, BTB Blockheizkraftswerks-Träger and Betreibergesellschaft mbH Berlin, Fernheizwerk Märkisches Viertel GmbH and RWE are also operating CHP plants in Berlin.

The decentralized plants, some with trigeneration, are operated by Berliner Energieagentur (BEA), a modern energy service company located in Berlin and aiming to promote the efficient use of energy with innovative projects to reduce energy costs and CO_2 emissions.

Together with the cooperation partners Gasag, Vattenfall and the senate department for health, the environment and consumer protection of Berlin, the Berliner Energieagentur initiated the campaign 'KWK Modellstadt Berlin' (CHP Pilot City Berlin; www.kwk-modellstadt-berlin.de). The initiative defines CHP as a key technology for a climate-conscious future. The initiative aims to inform people living in Berlin about the technology and its advantages and make a substantial contribution to extending the share of CHP. Berlin is systematically positioned as a CHP pilot city for other regions as well, not only in Germany.

5.2 Copenhagen

In the City of Copenhagen, 98% of the heat demand is covered by District Heating (DH). The DH system in Copenhagen was established in 1925 and has been developed and expanded since then, so that today the 1,500 km double-piped network provides heat for more than 30,000 customers – approx. 562,000 inhabitants.

The City of Copenhagen in 2009 issued an ambitious Climate Plan for combating climate change for reducing CO_2 emissions by an additional 20% between 2005 and 2015. This target has been reached as the recent climate account from 2014 show a reduction since 2005 of 31%. In 2012 CHP2025 was adopted. The new climate plan shows the way to carbon neutrality by 2025.The energy sector is responsible for approx.75 % of this goal.

The Copenhagen DH system is highly flexible in terms of switching between production plants and fuels. The heat and electricity production on CHP plants is optimized hourly at the lowest possible cost, including energy taxes and CO_2-quota costs.

The Copenhagen DH system is operated as a part of the very large coherent DH system in greater Copenhagen, covering Copenhagen and 15 minor municipalities. Copenhagen is supplied with heat from four cogeneration plants, and four waste incineration plants placed in the city. The yearly heat consumption is approximately 33,000 TJ in the total system, 55% of which is in the City of Copenhagen. Two large heat transmission companies, CTR and VEKS, transport heat from the large CHP plants to the local distribution system. Below, the greater Copenhagen DH system is shown.

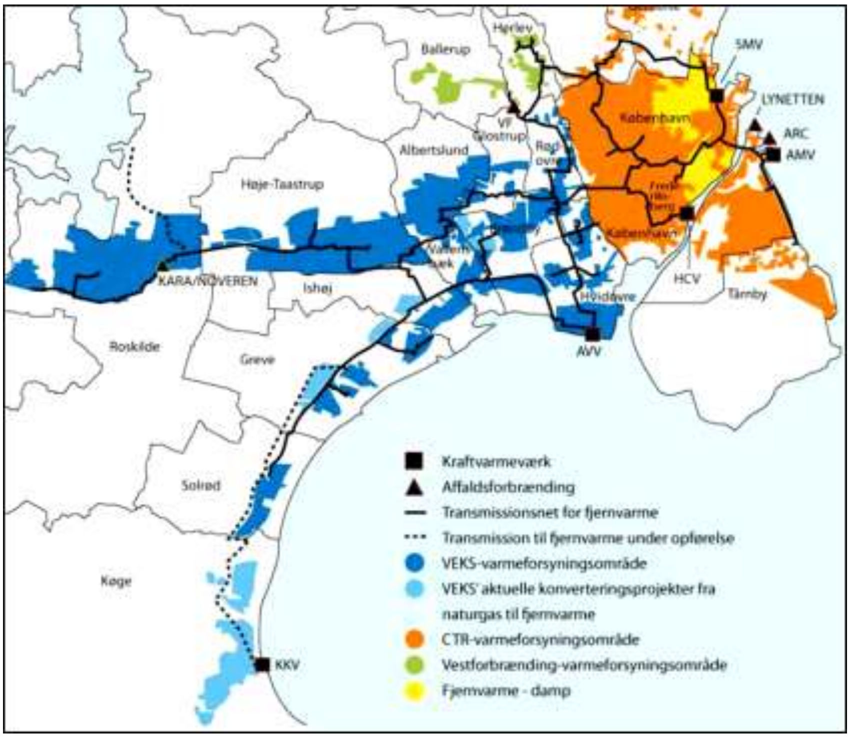

Figure 8: The DH system for the Greater Copenhagen Area.

The DH system in Copenhagen receives its heat supply from many different units with different technical data and using different fuels. Because of this, the system is very flexible, has a high level of security of supply and is less vulnerable to fluctuating world-market prices. The energy system (heat and power) is operated in a manner that gives the best economic performance through a common optimization of production of heat and electricity. Based on a forecast for every day, it is estimated which CHP stations should be in operation, reflecting the estimated heat demand, fuel prices and electricity prices.

The Copenhagen example demonstrates that DH is a very versatile, adaptable form of heat supply. The extensive DH system in Copenhagen enables optimal utilization of the city's waste and today, approximately 1/3 of the heat in the district heating system of Copenhagen is based on biomass and waste incineration, and 2/3 are fossil fuels.

The main actors on the DH market in Copenhagen are also some of the main drivers to establish a voluntary certification scheme for biomass.

The total heat production capacity is higher than the base load. The structure of ownership of energy producers results in some conflict of interest. Especially the distribution of the base load between the grids and during the summer period may be reasons to conflict. In Copenhagen several waste incineration plants are connected to the DH system.
The supply company prepare development plans in close cooperation with the municipality of Copenhagen. The municipality is the approving authority for all development projects and the heat law and administrative regulations set up common assumptions for the socioeconomic analysis to be carried out as basis for approval of projects. Such assumptions are generally published on annual basis.

Simulations tools, such as **Balmorel,** is used to perform cost-benefit analyses and to make system optimisation in larger energy systems with several energy production facilities. Balmorel is a model for analysing the electricity and combined heat and power sectors in an international perspective taking into account the interconnected electricity systems and Nordpool.

The purpose of the Balmorel project is to support modelling and analyses of the energy sector with emphasis on the electricity and CHP sectors. Such analyses typically cover a number of countries, and include aspects of energy, environment and economy. Balmorel is a model for analysing the electricity and CHP sectors in an international perspective over several years with an hourly resolution. Balmorel is a modelling tool that can be used by energy system experts, energy companies, authorities, transmission system operators, researchers and others for the analyses of future developments of a regional energy sector.

The Balmorel model has been applied in several projects in BSR i.e in Denmark, Norway, Estonia, Latvia, Lithuania, Poland and Germany.

District heating companies are bound by law to be achieve economically equilibrium i.e. no profit is made. This ensures stability and predictability in a market that automatically achieves a natural monopoly. This stability contributes to making planning around a DH grid easier, and DH might be included in an extended manner.

In 2014, 53% of the DH production in Copenhagen was based on CO_2-neutral energy sources and the emissions were 98 gram CO_2 per kWh heat.

The Copenhagen Climate Plan outlines a number of specific initiatives – supported by HOFOR – in order to attain the goals, including:

- Biomass to replace coal at the Amagerværket CHP plant and Avedøre CHP plant
- Large electricity based on heat pumps. The potential is estimated to 285 MW heat production
- The plan estimates 20.000 MWh heat storage
- Some peak load and reserve plants to be converted to CO_2 neutral fuel
- 360 MW wind turbines are to be established in and outside Copenhagen by 2025. The City Council and HOFOR will give Copenhageners the possibility of directly investing in the wind turbines

- The district heating networks are to be continuously modernised in order to reduce heat losses from the pipes

- In the coming years, the role of geothermal energy in the energy system in Copenhagen will be determined. The plan estimates a new 65 MW geothermal facility before 2025

- Plastic is to be separated in waste treatment. Plastic contributes substantially to CO_2 emissions when incinerated. Hence, substantial CO_2 reductions will follow if plastic is recycled rather than burned

The future energy system based on fluctuating renewables will rely on capacities based on biomass CHP, so it is expected that the marginal heat price in DH will be closely correlated to fuel prices of biomass. Today the marginal price of DH based on biomass is on the same level as heat production prices from waste incineration.

Varmelast.dk prepares the daily heating plan. The heating plan is based on the district heating forecasts disclosed by the district heating companies. The heating plan is prepared considering:

- Fuel prices
- Operating and maintenance costs
- Energy taxes on heat production
- CO_2 quota costs
- Income from the power market

Moreover the most important hydraulic bottlenecks in the transmission network are considered. In Copenhagen, the online simulation tool **TERMIS** is used to perform daily optimization, hydraulic analyses and heat predictions. TERMIS is tool used to solve complicated hydraulic applications, both in the DH and DC. Operational optimization and reliability are paramount. TERMIS is used for numerous tasks, such as temperature optimization, real-time calculations, pump optimization and renovation. TERMIS continuously optimizes the required flow temperature and leads to substantial savings on heat losses of the DH network.

The TERMIS model receives on-line data from the SCADA (supervisory control and data acquisition) as well as forecast information about weather conditions through the data interface,

Based on these data TERMIS runs a simulation for the entire network, allowing the operator to see exactly how his DH distribution network is operating – right now – and up to 3 days from now.

Operation of the heat supply is based on cost of heat. Every morning the heat optimisation unit - *"Varmelast"* sends a prognosis for the heat demand based on the weather forecast. Based on this, the heat suppliers may bid a heat capacity to the marked based on their marginal cost taking the electricity market price into consideration.

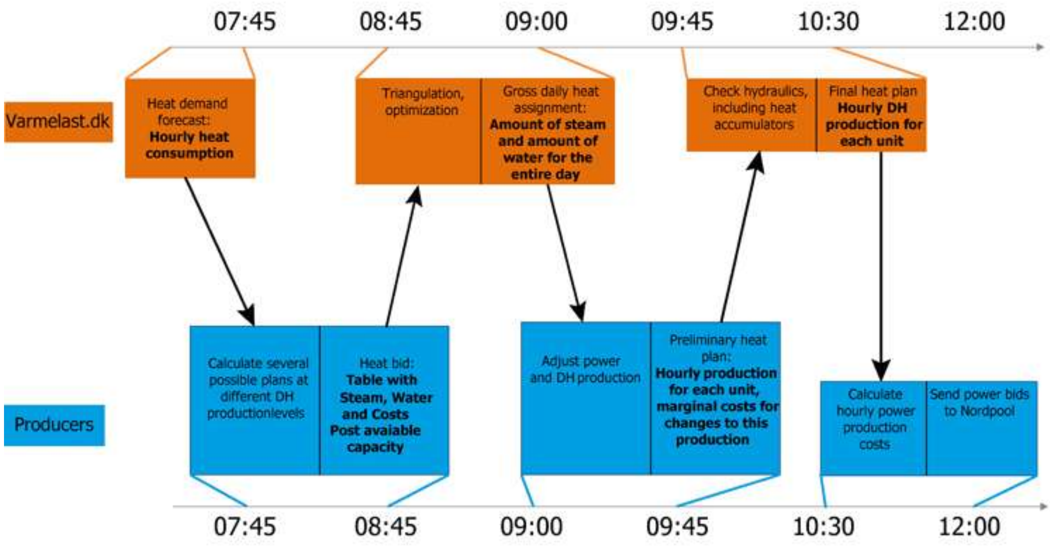

Figure 9: Illustration of how Varmelast.dk transforms heat requirements to district heating consumption 365 days a year. Source: http://www.varmelast.dk/en/heat-plans/heating-plans

Then *"Varmelast"* makes a prognosis which is sent back to the heat producers for a last bidding round timed with bids placed for the day ahead spot marked for electricity (*Nordpool*). Heat from waste incineration plants is presently always given first priority. TERMIS is used to evaluate how close to optimized operation the system reaches every day. Pricing is subsequently based on production actual heat production expenses. In the DH system in Copenhagen, buffer tanks are mainly used to optimize electricity production patterns.

5.3 Helsinki

In Helsinki, as everywhere in Finland,

- The heat customers are buildings or building groups, but never individual apartments
- Real estate ownership is concentrated in the hands of major real estate owners
- Voluntary connections to DHC as neither the company nor any authority can force the customer to connect DHC
- No obligation for the energy company to connect any building to DHC prevails.
- No specific DHC legislation exists in Finland but normal customer protection and energy market legislation, the latter due to dominant market position of DH, as for any commercial product is available.

The specific heat consumption comprising both DH and DHW of the customers has been constantly declining, and has reached the value of 38 kWh/m^3 in year 2014.

Helsinki is a frontrunner in flexible, eco-efficient and sustainable energy production. The story of smart energy solutions continues: HELEN Ltd, the successor of Helsingin Energia, has set the target for a carbon neutral Helsinki in 2050. To achieve this, HELEN is continuously developing new technologies and innovations to continue its several times internationally awarded policies and activities. The success of HELEN is several times awarded by international institutions such as, for instance, the United Nations (UN), the International Energy Agency (IEA), Euroheat&Power association and the International District Energy Association (IDEA).

Initially, the decisions of CHP and DH were made in 1953 by City Council of Helsinki. Since then the DH system has constantly expanded geographically and by introducing CHP in 1957 and the new product DC in 1998. The basic arguments to start DH were:

- Economical as there was the need to minimize the costs of imported fuels after the World War II
- Ecological as the previous heating based on individual wood boilers in buildings was highly polluting
- Supply reliability as the cold and long winter requires a reliable heating system
- Energy political as energy imports had to be minimized under restricted financial resources

From the very beginning DHC have been an economical success and it has been market driven: responding to the actual heating and cooling needs of the customers in a competitive and sustainable way. At all times, the DH, and now DC as well, have run on commercial basis without regulatory enforcement and operation subsidies. In the first decades DH had to be competitive to oil heating, in 1980's to electric heating as four nuclear power units were commissioned in a few years period, and today competitive to individual heat pumps. As there has always been competition on the heat market, DH innovative solutions had to be used. At all times the DH company had to be aware of costs and benefits and to develop a customer oriented attitude to win and maintain customers.

Today, the DHC/CHP operation of Helsinki can be characterized by 90 / 90 / 90 meaning:

- Market share of DH is 93 %
- Share of CHP is more than 90 % of the annual DH production
- Annual heat production efficiency is higher than 90 %.

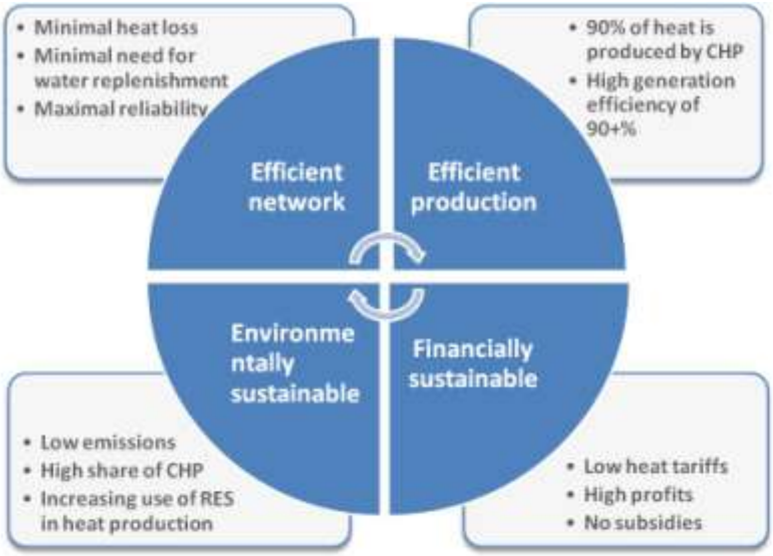

Figure 10: Four cornerstones of sustainable DH and CHP used in Helsinki.

The four cornerstones illustrated above show the basic components of sustainable DH, for instance, as:

- The minimal heat losses are achieved by optimal supply and return water temperatures as well as tight and well insulated network. At present the annual network heat losses range only from 6 to 7% of the produced heat energy.

- The water losses are low amounting to 0.08% of the circulation water flow, equivalent only to one network water replenishment a year.

- The high reliability is equivalent to 2,5 hours heat supply break on average per customer a year. Most often the customer does not even recognize the heat was cut off as such works requiring temporary disconnection are often done during the night time.

In Figure 11, the DH and CHP of Helsinki are illustrated. The heat only boilers plants (HoB) having more than half of the production capacity generate only 8% of the heat energy whereas the heat pumps and CHP 92% of heat energy.

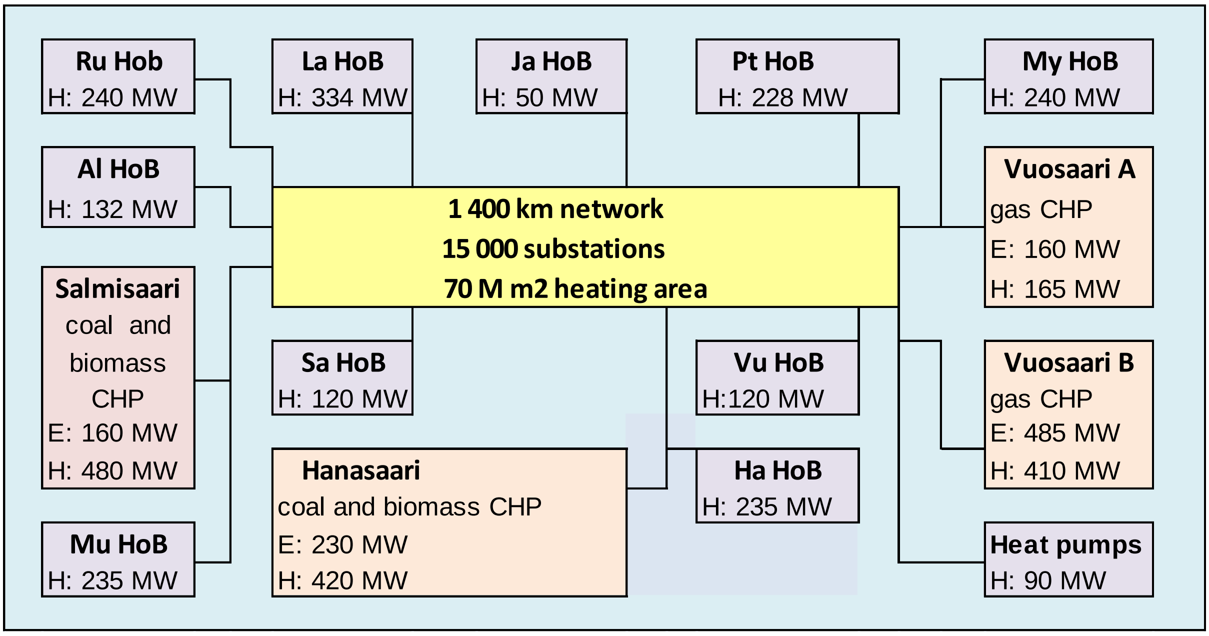

Figure 11: DH and CHP system of Helsinki excluding DC which is described in Booklet 3.

In addition to Figure 11, there is heat trading between the neighboring cities, Vantaa and Espoo, through three heat exchanger stations located on the city borders. In this way all three DH companies on the sides of the city borders benefit from lower heat supply costs even though the trading volumes are relatively small.

Integration of DC in the large scale to the existing DH/CHP has been introduced in Booklet 3.

All 14 heat production plants in Figure 11 except ”Ja” (Jakomäki) are interconnected by means of trunk lines built in underground rock tunnels, which enables transmission of large energy volumes in the entire city area, thus maximising both economy and security of heat supply. The total length of the rock tunnels, in which main water pipes and electricity lines are located as well, amounts to 60 km in Helsinki.

The DH system of Helsinki is highly flexible in terms of switching between production plants and fuels. The DH system of Helsinki receives its heat supply from many different units with different technical data and using different fuels. Because of this, the system is very flexible, has a high level of security of supply and is less vulnerable to fluctuating world-market prices of fuels.

Based on a forecast for every day and week, a computerized optimization software developed by VTT, the Technical Research Center in Finland, optimizes which CHP and heat only boiler plants should be in operation and how their operation is economized using the heat and cold accumulators, electric boilers, and heat pumps based on the predicted outdoor temperature and electricity prices of Nordpool.

The DHC and CHP system is operated in a manner that gives the best economic performance through a common optimization of production of heat, cold and electricity. As evidence, despite of competitive prices of

DH on the local heat market and the electricity on the Nordpool, HELEN has been highly profitable in the past years. Since year 2008, for instance, the annual profit has ranged from €200 to €300 million while the annual turnover from €800 to €900 million. The profit has been taken by the city of Helsinki as the sole owner of HELEN.

The long-term target of HELEN is to have the DHC and CHP carbon neutral by year 2050 latest. At the moment, both coal fired CHP plants, Hanasaari and Salmisaari, have started to use wood up to 5% of their fuel capacity. Later in 2015, a decision will be taken whether the share will be increased to 25-40% or a new multifuel HoB plant designed to 100% capability of using wood will be commissioned around year 2020. The HoB is preferred to CHP as the predicted Nordic power pool (Nordpool) prices indicate too low price levels to justify CHP.

5.4 Stockholm

Figure 12: District heating systems in Stockholm.

In the north-western part of Stockholm, Norr Energi produces heat based on biomass and treated wastewater from the treatment plant in Bromma. Norr Energi's mix of biofuels consists of wood powder (pellets and briquettes), tall oil and bio-oil. In some periods of the year, Norr Energi purchases heat from Fortum. In central Stockholm one of the largest systems for heating and cooling is located. The production also includes electricity and occurs mainly at Värtaverket - a well-known part of the city of Stockholm's profile.

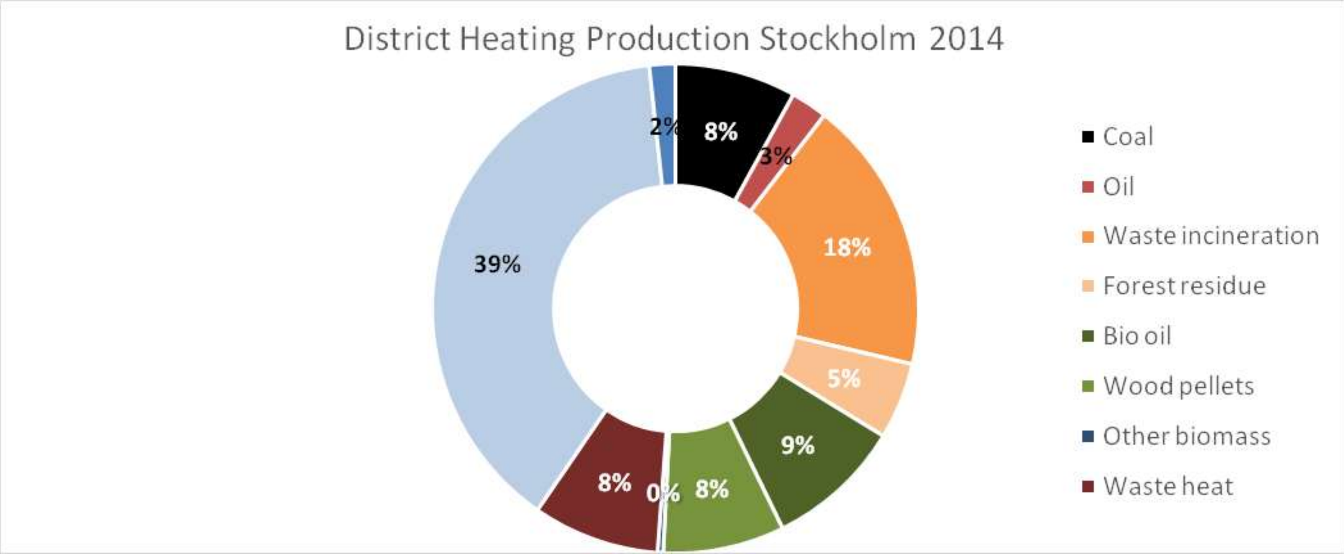

Figure 13: Production mix DH in Stockholm 2014. Source http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/

South of the city the heat is produced at Fortums electrical heat pumps in Hammarby and the waste incineration plant in Högdalen, which has the first priority and thereby covers the base load. Söder Energi produces heat on three biomass units and sell their surplus heat of ca. 500 GWh to Fortum. In 2014, Fortum produced 918 GWh from the heat pumps based on waste heat in treated wastewater from Stockholm.

In 2015, the DH prices were for the first time lowered – though marginally. The reduced prices are said to be due to production and grid optimization. TERMIS is used to make hydraulic optimizations.

Fortum Värme is the first company in the world to offer a marketplace for surplus heat. Open DH is a concept, which among other things allows data centres to sell their surplus heat at the market price, makes Stockholm a unique place to base a business. The company is now aiming to attract more data centres to set up a shop in Stockholm so that the surplus heat they generate can actually be used by people rather than simply being extracted by fans.

5.5 Warsaw

The DH system of Warsaw has passed through a comprehensive rehabilitation in the past quarter century.

The DH system operated by Veolia Energia Warszawa S.A. is one of the largest DH systems in the European Union (See Table 1). That's over 1 700 km network, supplies heat to 19 000 buildings in Warsaw, covering 65% of the needs of the capital.

Today, about 90% of the DH is produced by CHP, the efficiency of which is about 90% in the year. About 80% of the population of 1,7 million is covered by the DH.

The DH network is owned and operated by Veolia Energia Warszawa S.A. The CHP plants 1 and 2 and the HoBs 3 and 4 are owned by PGNiG Termika S.A. and the CHP number 5 is owned by the municipal company of the City of Warsaw - Miejskie Przedsiębiorstwo Oczyszczania w m. st. Warszawie (MPO).

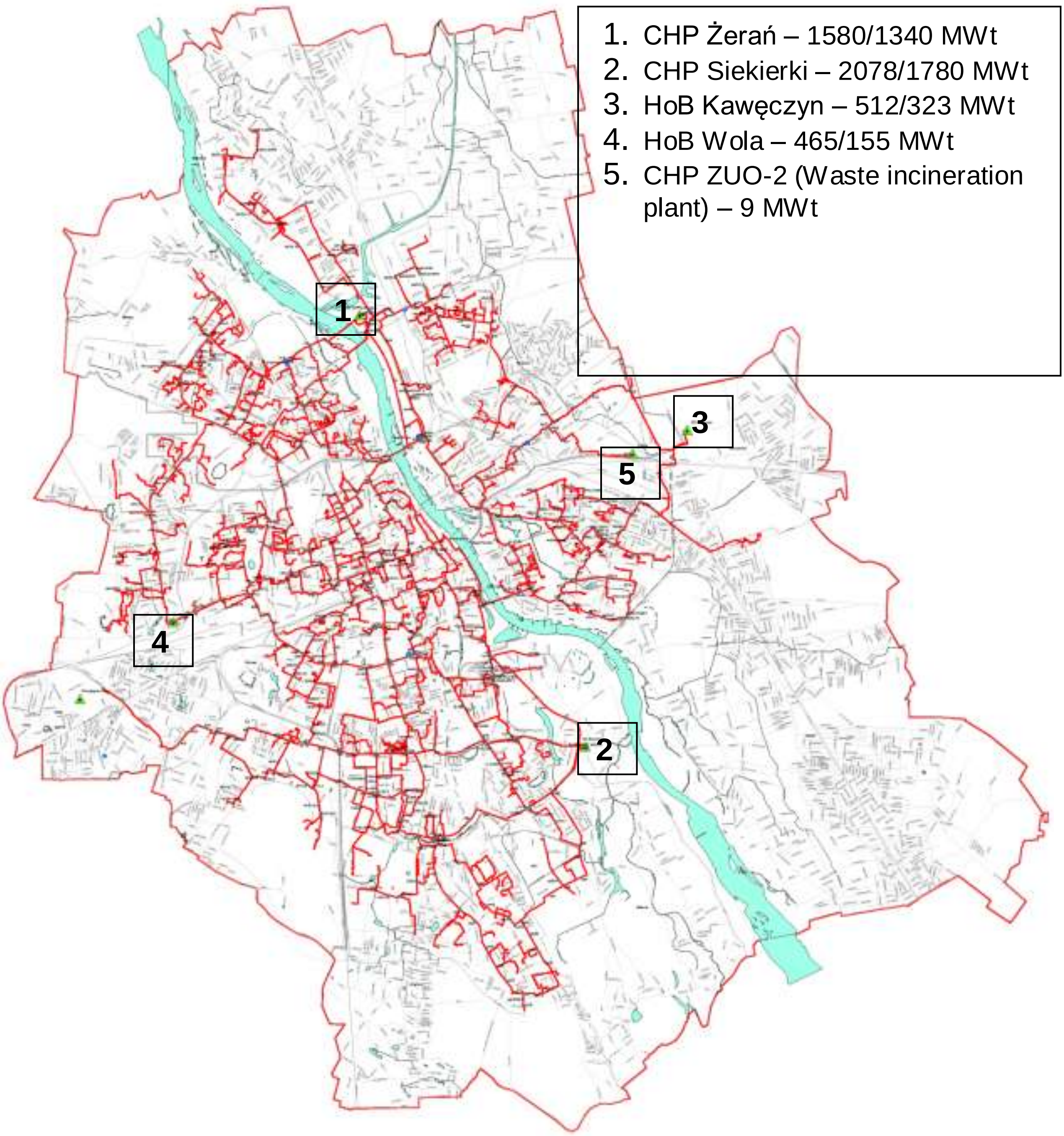

Figure 14: The main CHP plants and DH network pipelines in Warsaw . As to 4 plants owned by PGNiG Termika S.A. - Żerań, Siekierki, Kawęczyn and Wola – the first cited value of heat power refers to their production capacity, while the second – to power purchased from them by Veolia Energia Warszawa S.A.

The Warsaw DH system is supplied by five heat sources, which are working in one hydraulically connected heating network. Three main power plants CHP Siekierki, CHP Żerań and CHP ZUO-2 are working as base load power plants and two boiler plants HoB Kawęczyn and HoB Wola are peak load plants.

Companies are enhancing their R&D efficiency. The "open innovation" paradigm has paved the way for new labs, shared data and joint research, offering a breath of fresh air for firms seeking solutions that can let them focus on bringing their products and services to market.

Open innovation embraces a more collaborative approach, backed by a network of partners inside and outside the company, including universities, public organizations, SMEs and start-ups. Action is the modus operandi; synergy and cooperation are the guiding principles.

Open innovation is also the watchword of the five global tech centers set up by Veolia Environment and dedicated to enhancing the efficiency of energy systems for both municipal and industrial customers.

In 2012, the Heat-Tech Center (HTC) joined the Veolia folder following the acquisition of a Polish company managing heating networks in Warsaw – another addition to the "network of excellence."

The existence of the Heat-Tech Center in Warsaw, one of the world's very first centers for excellence and research in heating networks, can be explained by the fact that one of the Europe's largest heating network has been installed in the Polish capital since the 1960s.

Its current size speaks for itself: it heats an urban area of 136 square km and covers 65% of the city's needs. With approximately 19,000 delivery points (substations) supplying 11,000 GWh of thermal energy per year, it is easy to understand why intelligent management of the entire system is needed. Management is based on a loop of excellence combining engineering and maintenance operations within a continuous technical improvement process.

Working hand in hand with Veolia Environment research and innovation teams and researchers at Warsaw University of Technology, the HTC focuses on developing one of the largest heating networks in Europe and plays a key part in promoting best practices and selecting the best technology.

Intelligence and reliability

Based on two pillars (R&D for over 80% and the rest supported by Veolia's technical support functions), the Heat-Tech Center is currently developing two complementary research projects: one focuses on the intelligent management of the network and the other on its reliability.

On the program: improved network performance for greater energy efficiency and improved ability to capture low carbon emission energy sources, the use of artificial intelligence for optimized steering and a data management system compatible with the gradual installation of sensors and probes at key points of the infrastructure.

Deployment of real-time data management became possible through the mass of data acquired and processed, The user is informed not only of the condition of the network, but also of any maintenance, emergency or scheduled operations almost instantaneously. HTC aspires to become the leader in heating network research and innovation. By regularly inviting students to come and develop their final year projects and doctoral theses, this world-renowned center has become a major player in the city, making each day a little smarter.

6 Conclusions

DH can be highly flexible in terms of switching between production plants and fuels, and the CHP technology is well proven, and has over time turned out to be very flexible – it has adapted to different fuels and technologies following changing political priorities over the decades.

In the future, large amounts of fluctuating energy (especially wind) will require a dynamic new energy system with increased interaction between energy production and consumption and between electricity and heat. New technologies, such as electric heat pumps, electric heaters, geothermal heat and heat storage will be developed with a view to becoming instrumental components of the DH supply in the long term.

The application of long- and short term planning tools and procedures in parallel with procedures for daily operational optimisation of integrated energy supply systems is important to the future development of all urban areas,

Cooperation between all involved public and private stakeholders is important to ensure implementation of development plans in accordance with agreed development goals. Monitoring and evaluation should be an integral part of each development plan. The success stories are found where the process has been planned and implemented in an interactive and not in a counteractive way.

The competition amongst the energy companies has resulted in less transparency between companies who have become more closed and do not publish performance indicators as they used to, thus hiding operation information from their competitors. Moreover, private ownership of DH companies has set a new barrier for co-operation with the municipality: often information exchange has been restricted, co-planning has been put aside, energy efficiency is not promoted. The DH company protects and extends heat sales as core business. Who is to pay the bill (if any) for sustainability and long term objectives? A new barrier to optimal development, benchmarking to the benefit of efficiency and sustainability as well as exchange of good experiences has become more difficult.

In the complex future it is important to keep focus on integrated system optimization and to avoid sub optimization due to short term business development strategies. An integrated top-down and bottom-up development process is the way forward. ***The top-down process*** is needed as basis for decisions regarding long-term development strategies to achieve national and local goals and commitments in respect of environmental sustainability, security of supply and economy. A ***bottom-up process*** initiated in parallel with the top-down process define specific actions to analyse and demonstrate options and implementation steps related to specific projects mainly at local level.