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Chapter 1

District Heating and Cooling Enable Efficient Energy Resource Utilisation

Dag Henning and Alemayehu Gebremedhin

Additional information is available at the end of the chapter

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1. Introduction

Economic development in transition countries, such as China and India, increase global energy use. Therefore, the demand for energy carriers grows, which should increase energy prices. Global energy supply is dominated by fossil fuels, such as coal, oil and natural gas, and this situation is likely to remain for many years even if the use of renewable energy sources (e.g., biomass, solar energy and wind energy) is expanding. Higher energy prices make certain changes of the energy system more profitable: use of *free* energy sources, such as sun and wind, efficiency improvements of energy supply, as well as energy conservation measures, which reduce energy use.

Several policies on various levels now promote increased utilisation of renewable energy sources and reduced energy end-use, for example in buildings. But there are also comprehensive systems that link energy resources with demand for energy. *District heating* is such a concept, which is common in many countries where space heating of buildings is required, for example Iceland, Latvia and Denmark. In a district heating system, heat is distributed through a network of hot-water pipes from heat-supplying plants to heat consumers in a single block or a whole city. The heat is mostly used for space heating and domestic hot water. District-heating systems range from a single development to city-wide networks. *District cooling* works in the corresponding way. *District energy* includes district heating and district cooling. District heating is sometimes called community heating, especially in the UK.

More than one-fourth of the primary energy supply in Europe becomes losses by energy conversion, mainly as heat that is wasted by electricity generation in condensing power plants. These losses are of the same magnitude as the European heat demand [1]. District heating is a means to utilise such losses, which otherwise are wasted, to cover demand for various kinds of heat and even cooling. District heating helps us utilising large amounts of heat that now are wasted in Europe.

Thus, district heating is not only a technology for energy distribution but it increases the amount of available energy resources. District heating can utilise energy sources that are difficult to use for individual buildings, such as unrefined biomass fuels, heat from waste incineration, heat from electricity generation in combined heat and power (CHP) plants and industrial surplus heat, for example heat from pulp and paper mills or production of automotive biofuel. Little of this energy could be utilised without district heating. Therefore, district-heating expansion may be beneficial for economy and environment.

District heating is used for heat supply to various kinds of buildings in villages and cities, primarily multi-family buildings and service premises, where the heat is used for preparation of domestic hot (tap) water and for space heating, normally, through a central waterborne heating system for the whole building.

District heating systems connect energy sources and energy users. District heating can provide affordable energy to consumers by using low-cost energy sources, such as surplus heat and waste. Many of these heat sources can be of local origin and promote local business and industry. What is the most suitable solution depends on the local conditions. By using various energy sources, district heating becomes a central component for waste management systems, forestry, power production and efficient energy use in industry.

1.1. Heat supply

Heat sources that cannot be used for separate houses can in a district-heating system be complemented by technologies that also are applicable at smaller scale, for example, fossil fuels, solar energy and electric heat pumps upgrading low-temperature heat. A small district-heating system can have one or two heating units, whereas a large system can host many different heat sources where, for example, a CHP plant fed with low-cost waste covers the base load throughout the year, a wood-fired heat-only boiler supplies most of the space-heating demand in winter and a boiler using expensive oil covers the peak load during the coldest days.

Base-load plants typically have a low heat production cost but require large investments. The low operation cost makes them suitable for being used during many hours a year. Benefitting from a lower heat cost than from other units pays back the heavy investment. Common base-load supply comes from CHP plants, waste incineration and industrial surplus heat. Oil-fired boilers, on the other hand, have low capacity costs but high operation costs, which make them suitable for covering short periods of peak heat demand.

Figure 1 shows how heat production can take place in a Swedish district heating system during a year. In summer, heat demand and production are low because there is primarily need for heating of domestic hot tap water only but in winter heat production is much larger due to high space heating demand. The base load is covered by industrial surplus heat throughout the year because it has the lowest cost. The higher load in winter is mainly covered by wood used in CHP plants and boilers but fossil CHP production and heat pumps are also used. Some oil is used in heat-only boilers when it is very cold. The units used at high demand have higher heat production costs and are generally more polluting than the plants used at lower demand. Therefore, the marginal cost for district heating production varies in a similar way as the heat demand during the year.

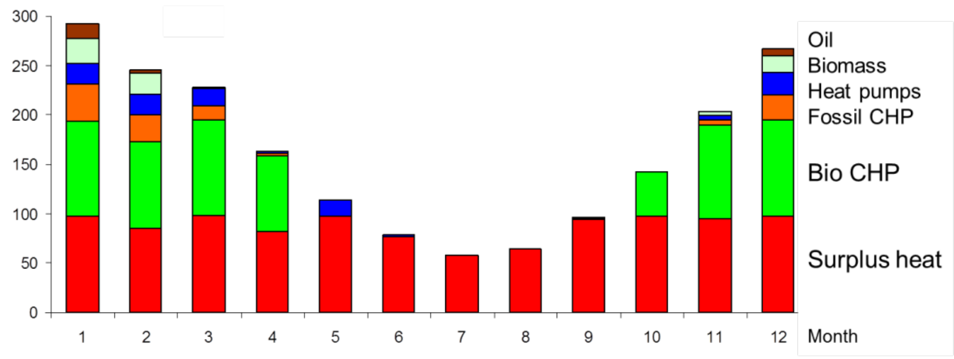

Figure 1. District heating production in a Swedish system (GWh)

The fossil-fuel-fired CHP plant and the heat pumps in the system in Fig. 1 were once built as plants covering the base load but later the wood-fired CHP plant was built, which could produce heat at lower cost and the annual utilisation times for the older plants were decreased. The introduction of industrial surplus heat reduced the use of all other plants to their present levels. District heating demand and production are often shown with a duration curve, which represents heat demand in descending order from the coldest winter days to the warmest summer nights (see e.g., [2]).

1.2. District heating in Sweden

District heating is used extensively in Sweden. Sweden has nine million inhabitants. Fifty annual TWh of district heating cover one-half of the heat market. There is a district heating system in every municipality with more than 10 000 inhabitants and in total there are more than 400 systems. One-half of Swedish district heating is supplied to multi-family houses, the rest mainly to premises, such as schools and offices, and small but growing fractions to industry and single-family houses [3]. House owners chose whether to connect to a district-heating grid or not.

Figure 2 shows the energy sources used for district-heating supply in Sweden since 1970 [4]. The total supply varies between cold and warm years. The last year (2009) was a very cold year. The fuel use for district-heating production in Sweden has switched from almost only using oil in the 1970s to a present mixture with many heat sources. Now, two-thirds of Swedish district heating is produced from wood and waste fuel. Sweden utilises much industrial surplus heat compared to most countries and heat pumps take heat from sewage water and lakes. Minor quantities of biogas and gas from ironworks are used but fossil fuels now produce less than 15% of the district heating (Fig. 2). The fossil carbon-dioxide emissions from district heating have been reduced significantly during the past decades because fossil fuels have produced a decreasing fraction of the heat. This transition has been facilitated by an early introduction of a carbon-dioxide tax and other policy measures [5].

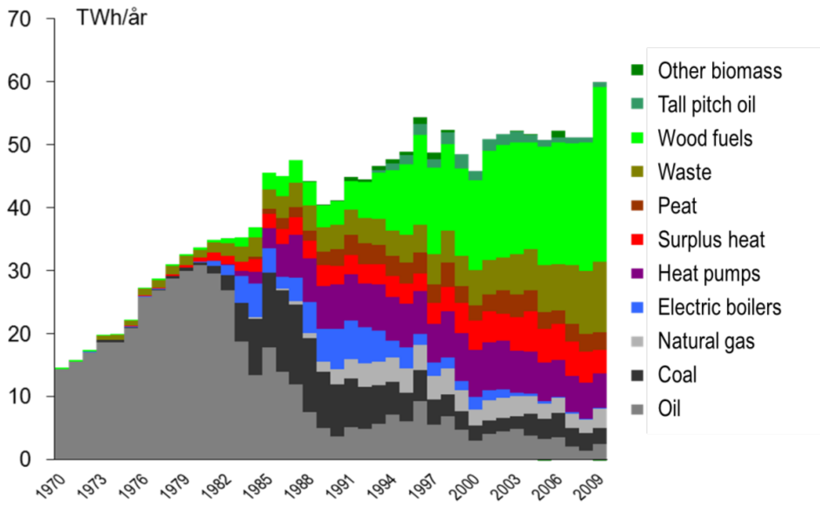

Figure 2. Fuels etc. used for district-heating production in Sweden (TWh/year)

Oil and coal use decreased during the 1980s (Fig. 2) due to increasing taxes. There has been a carbon-dioxide tax in Sweden since 1991, which now is 100 euro/ton. An energy tax was introduced even earlier. There is natural gas only in south-west Sweden. The use of electric boilers for district-heating production increased when nuclear power expanded during the 1980s but decreased when the electricity was taxed in the 1990s. Use of biomass (e.g., woodchips) was first promoted by the taxes on fossil fuels and later also by green electricity certificates and higher electricity prices that make biomass-fired CHP plants more profitable. Waste incineration increases (Fig. 2) because it is prohibited to dispose combustible fuel on a dump and district heating companies collect revenues for taking care of the waste. There have also been investment subsidies to some selected projects using local energy sources. The district-heating increase during the last decades reflects a political commitment to invest in infrastructure and reduce dependency on imported fossil fuels.

2. Methods

Favourable comprehensive solutions can be elucidated through system analysis and optimisation models. These methods can show the best way to use resources to satisfy aims. Common aims are low costs and low environmental impact, which often can be conflicting. The essential features of an issue under study for a system can be represented in a model. Models often help system understanding and reveal relations among components, such as between district-heating production, solar energy extraction and wall insulation. The best solution according to a criterion and under certain conditions can be shown by an optimisation model. For energy issues, an energy system optimisation model can be used to find the best design and operation of a system. In such models, many technical components can be described [6].

Examples of energy system optimisation models are MARKAL (e.g., [7]) and TIMES (e.g., [8]). These models were primarily developed for national energy-system analyses, whereas the model MODEST was originally made for optimising district-heating supply under consideration of heat-demand fluctuations.

MODEST is an energy system optimisation model, which uses the optimisation method linear programming to find the minimum cost for satisfying energy demand and presents the system design and operation that achieves the lowest cost. A large number of options for energy supply and conservation can be considered with this model framework. The user can make a comprehensive representation of the energy system under study with chosen level of detail. Many different energy systems can be analysed as long as the important properties of the system can be described by linear relations. An almost arbitrary set of parameter values may be attributed to each component and energy flow in a system. A flexible time division makes it possible to reflect diurnal, weekly, monthly, seasonal and long-term variations of, for example, costs, capacities and demand. The modelling result presents the optimal investments and the optimal operation of existing and new units as well as emissions and costs [6].

MODEST has been most used for optimisation of electricity and district-heating production. MODEST has been applied to more than 50 district-heating systems, some regional energy systems and a few national power systems. Studied issues include introduction of waste incineration and combined heat and power production and connections between industrial and municipal energy systems [6], for example, how large CHP plant should be built, is waste or biomass the best fuel and should industrial surplus heat be utilised? The model has been used a lot to study impact of energy prices and policy instruments on investments and operations in energy conversion, for example, how emissions allowances influence combined heat and power production.

3. Favourable energy sources and plants

District heating can use heat resources that are more or less impossible to supply to and convert to heat in single houses. Such energy sources include surplus heat from industries, heat produced through combustion of waste and unrefined biomass, as well as heat from larger combined heat and power plants.

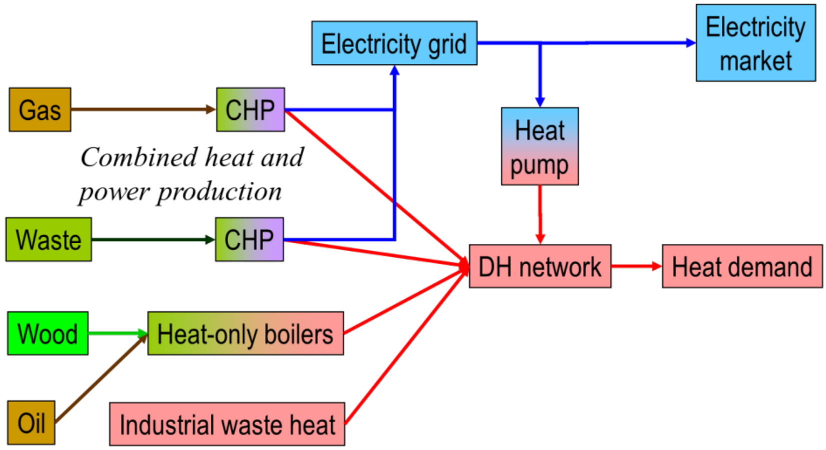

Figure 3. Common plant types and energy flows for district-heating supply at a local Swedish energy company

Figure 3 shows the district heating system in the second largest Swedish city Göteborg (Gothenburg). There is a large city-wide district-heating network with a large heat demand, which means that the system can host many different forms of heat supply. There are two combined heat and power plants, which produce electricity and heat; a natural-gas-fired combined-cycle unit and a waste-fired steam-cycle plant. Industrial surplus heat is bought from two oil refineries. Wood and oil-fired boilers, as well as electric heat pumps produce heat only. The heat is distributed through the district-heating network to the consumers to the right in Fig. 3. This is one example of how district heating enables efficient energy utilisation, but the system also includes components that may be considered less sustainable, such as fossil fuels.

CHP plants offer better fuel use. In condensing power plants, most of the fuel energy is normally wasted. Electricity produced in CHP plants, which produce district heating, can displace electricity from condensing power plants. Due to higher efficiency, less fuel is needed for the electricity generation in CHP plants than condensing power plants because the major fraction of the fuel yields district heating. Therefore, the carbon-dioxide emissions caused by the power production are lower for a CHP plant even if it is fed with fossil fuel. But the environmental benefit is of course even larger if renewable fuels are used for the CHP production.

3.1. Using local renewable energy resources

Available local renewable energy supplies influence the suitability of various solutions at a location. In some places, solar energy may contribute to district-heating supply. But most useful for district heating are biomass fuels and combustible waste.

Biomass fuels can be derived from forestry and agriculture. Use of biomass fuels can initiate local biomass industry and promote local business and development. The demand for biomass fuel from a district-heating plant can make entrepreneurs develop supply systems for, for example, wood fuels, such as tree branches from forests.

Today, much waste is landfilled. Using the waste as fuel or for energy extraction in other ways reduces the landfilling. Waste is a resource and various waste fractions should be separate to make it possible to use them in the most suitable way. The separation can take place at the source, that is, in households and firms, etc. For example, biodegradable waste can yield biogas, which can be used as automotive fuel, whereas other combustible waste (e.g. from households or building demolition) can be used as fuel for electricity and district-heating production.

Utilisation of local renewable energy resources means higher security of energy supply and lower dependency on fuels from other regions and countries. Use of local fuels and generation of electricity reduce the energy bought from other places and increases the money that can create wealth locally. Switching from fossil to renewable fuels also reduces emissions of fossil carbon dioxide and decreases the local contribution to global warming.

However, biomass may be a too valuable resource for producing only heat, which is an energy form of lower value than electricity and automotive fuel. Biomass could rather produce combinations of different energy carriers, such as heat, steam, electricity, automotive fuel and cooling (Sect. 6). Biomass certainly is a renewable energy source but its extraction must anyhow be carried out in a sustainable way. Land also produces food and raw material and a dilemma is that the wealthy can pay more for fuel than the poor can pay for food.

Waste is of renewable, as well as fossil origin. Waste volumes are normally increasing with economic growth but less waste than now should be generated in a sustainable society. Waste incineration may therefore partly be seen as a transition technology rather than being a basis to the present extent in a long-term system.

4. Utilising industrial surplus heat

There is today a huge amount of surplus heat within the energy and industry sectors. In many cases, this surplus heat is not utilised as it should be. This situation is not good since the industrial sector accounts for more than 30% of the world total final energy consumption [9]. This should also be seen in connection to the fact that the total primary energy supply is highly dominated by fossil fuels. Thus, utilising surplus heat is an essential measure to achieve an overall sustainable energy system in a community or region.

Heat can be recovered for repeated utilisation at decreasing temperature levels in industry and finally for space heating. Although it is known that there is surplus heat in certain facilities, in some cases little is known concerning the volume and the quality of the heat. Identifying and measuring surplus heat resources would therefore be necessary before any evaluation can be made. For instance, a study based on energy auditing showed that as much as 500 GWh/year heat energy of different quality is wasted in a single pulp and paper mill [10]. However, knowing heat quantity and quality does not automatically mean that the surplus of heat can be used. Other factors, such as time of availability, heat demand, infrastructure, technology and costs, play decisive roles in determining if the surplus heat can be utilised or not.

District heating offers an outstanding opportunity to utilise surplus heat which otherwise would be wasted. Though the share differs from country to country, the Nordic district heating systems are good examples of using surplus heat [11]. From a consumer's perspective, district heating systems with significant share of surplus heat in its fuel mix offer relatively low heating costs to their consumers. In some municipalities in Sweden, the rather low heat costs can be attributed to surplus heat supply from industries. Availability of surplus heat during summer when the heat demand is low opens an opportunity to produce district-heating-driven cooling for buildings during summertime (Sect. 5).

Utilising surplus heat in district-heating applications is not quite easy since such an endeavour has different issues that need to be resolved. One of the main issues is how to bring about a co-operation platform between players where the use of industrial surplus heat is understood in the light of a broader system perspective. In this case, a municipality, or a region with several municipalities, can be the system boundary when considering energy co-operation. In regions where district heating is well established and where there is relatively high concentration of industrial activities, there might be a need to develop a regional heat market to encourage efficient utilisation of energy resources. Though the core business of an industry is not selling surplus heat, such a market could be a driving force which in turn enables players to take measures that might promote the use of surplus heat. This would mean that industries with substantial amounts of surplus heat can play significant roles as heat suppliers in local or regional markets. This is also important when considering investments in new generation facilities for electricity, steam and heat. In this case, regional energy system optimisation would be valuable to maximise the efficiency of resource utilisation.

Thorough studies that focused on this subject are given in [12,13]. In both studies, several district-heating systems and industrial energy systems of a region are considered and the MODEST model is applied (Sect. 2). The second study [13] was more in detail and it includes several scenarios where measures, such as investment in new facilities, process integration and energy efficiency measures, are considered. In general, both studies indicate an overall system benefit of connecting the various energy systems in forms of reduced total cost, efficient use of plants and reduced carbon-dioxide emissions, but the latter depends strongly on the carbon accounting method applied. Interesting to note is that an enlarged system boundary, encompassing all the district-heating systems and industrial energy systems, enables efficient utilisation of surplus heat that is available within the system. Depending on the prevailing conditions, utilisation of surplus heat can be in conflict with the use of CHP. A widened system boundary with a possible heat market may enable the use of both surplus heat and CHP.

Utilising surplus heat should be promoted in similar way as renewable energy where policy instruments are deployed to encourage power production based on renewable sources. Furthermore, a suitable co-operation platform needs to be created where different issues concerning the utilisation of surplus heat in district heating systems can be resolved. However, surplus heat supplies available for district-heating systems may be somewhat reduced by increased heat reuse within industries.

5. Cooling

Cooling of rooms now increases due to higher comfort requirements in, for example, countries in Northern Europe, as well as from the middle class in transitions countries where the living standard is rapidly rising. The desire to cool the rooms is also enhanced by the global warming and the growing number of electric appliances that supply waste heat in the rooms [14].

Normally, electricity-driven refrigeration machines are used to produce cooling. But district-heating sources can also produce cooling for indoor climatisation in absorption cooling machines, either in central plants (e.g., waste incineration plants) supplying a district cooling network or in distributed units situated in the buildings that are to be cooled, which are fed from the district-heating network (Fig. 4). Such solutions mean that electricity is not required for the cooling. It increases the low heat demand during summer and also the electricity generation in CHP plants if the heat is produced there. Thus, cooling can become a basis for electricity generation instead of consuming electricity [2]. Absorption cooling is most suitable when a low-cost fuel, such as waste, can be used.

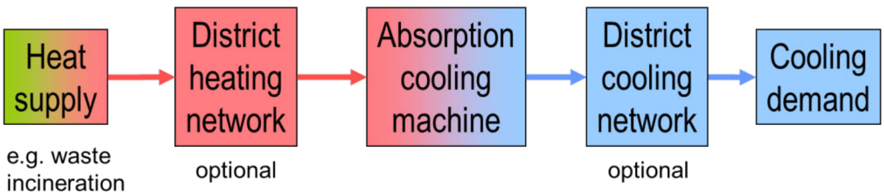

Figure 4. Cooling with heat through absorption cooling. One of the networks is required.

6. Poly-generation of several energy forms

European polices aim at increasing the use of automotive biofuel. Such fuels can be favourably produced in poly-generation plants that can turn various forms of biomass into automotive biofuel, electricity, steam, heat and cooling, which partly is used within the processes but largely is output from the plant. Similar arrangements can be made for other types of industry. A combined heat and power plant can produce district heating, electricity and district cooling as well as steam, which is supplied to an industry. The joint generation of several energy carriers increases the utilisation of installed capacity, increases revenues from delivered energy and may make plant investment more profitable.

The deployment of combined heat and power production in district heating systems connects the heat and power sectors in such a way that the overall production efficiency will be improved substantially. Poly-generation plants that produce automotive fuel connect the stationary energy system with transportation, like electric cars and trains do, and increase the number of options for biomass utilisation and transport provision. The linkage with the transport sector is especially important since the electricity, heat and transport sectors cause more than 60% of globally generated carbon-dioxide emissions from fuel combustion [9]. A combined action within these three sectors will definitely reduce emissions. In this aspect, biomass is a vital resource to meet energy and environmental targets. Using biomass just for heating purposes could be a step toward sustainable development particularly in areas where non-renewable sources are used now. However, other technologies, such as co-generation (CHP), tri-generation (CHP + cooling), and poly-generation, should be considered to maximise the benefit of using biomass. This is especially important in areas where the deployment of CHP is difficult due to barriers, such as insufficient heat load, unfavourable power prices, high investment costs, lack of infrastructure etc. Furthermore, low heat-demand periods are a challenge in district-heating systems with CHP as base load production. This situation can possibly worsen with increasing efficiency within the residence sector where lower heat demand is expected (Sect. 8.1). There is also a desire to cut heat production costs through additional revenues from sales of electricity and automotive fuel since district heating is not always the cheapest alternative in some places. With this background, the poly-generation concept can be helpful for tackling the mentioned issues.

Studies indicate that there are economic and environmental benefits of applying poly-generation concepts. For instance, increased power production from CHP plants can be achieved by integrating lignocellulosic ethanol plants with district heating [15]. Another similar study uses the MODEST model (Sect. 2) to show that a poly-generation configuration would result in lower production cost for heat and reduced emissions as a result of integration [16]. There are also other poly-generation applications where products, such as steam, electricity, heat and wood pellets are generated simultaneously. Such plants are already available, for instance, in Sweden and Norway. Revenues obtained from sales of, primarily, power and vehicle fuel together with renewable incentives seem to encourage the use of biomass resources efficiently and thereby create a favourable condition for the competitiveness of district heating and biomass-based power production.

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7. A valuable infrastructure

District heating plants and networks have low operation costs when using low-grade energy resources but they require large initial investments. The cash flow is negative for some years during the establishment of a new district-heating system and the payback time can be rather long, which makes financing more difficult. A long-term perspective on profitability and business models with low risks are essential for the deployment and modernisation of district heating systems. Prevailing public policy support may also be needed to facilitate the development of district heating infrastructure, like for other large-scale systems. Due to the heavy investments made, existing district heating systems are valuable assets, but some systems may require substantial improvements [17].

The district-heating value chain goes from fuel through heat production and distribution to consumer. Most Swedish district heating companies encompass all central parts of this chain, that is, heat production, distribution and sales, which enables utilisation of operational synergies. This arrangement can be favourable because if many actors are involved, a series of agreements are required, which increase business risks, which in turn makes financing more expensive, which may make investments unprofitable [17].

Heavy investments, such as waste-incineration and CHP plants, require a certain size to be profitable and therefore they also need a large district heating system to be suitable. Such a district-heating network may sometimes be achieved through connection of smaller systems.

8. Heat demand

District heating demand may be seen as a valuable resource itself because it enables the utilisation of energy resources that without this demand would be difficult to use. The district-heating demand also makes combined heat and power production possible.

District heating is more suitable the larger the heat load density is (i.e., heat demand per ground area, e.g. [18]) because more heat can be delivered per meter of pipe buried in the ground and network costs can be spread on a larger energy amount. Therefore, district heating is primarily used in larger buildings, for example multi-family residences and service premises, such as hospitals, schools and larger office buildings. But the heat load density that is required for district heating to be economically favourable depends on the heat production cost [2]. If the *heat sink* that district-heating users constitute enables power production or waste reception that yield revenues, it is profitable to build district-heating grids in areas with lower heat load density than if biomass or oil is used to produce the district heat separately.

In some places, heat prices vary in a similar way as the heat production cost during the year (Sect. 1.1) to give consumers a signal on when it is most desirable that they reduce their heat demand. Houses with district heating may, for example, be less suitable for solar heating because district heating often comes from surplus resources, such as waste or waste heat, when there is most solar radiation.

8.1. Lower demand

Now, heat demand is decreasing due to higher outdoor temperatures caused by the enhanced greenhouse effect, as well as policies that promote low-energy houses, which makes district heating a less suitable form of heat supply. All new buildings in the European Union are supposed to be *nearly-zero-energy* buildings in 2020 [19]. Low-energy houses often have thick wall and attic insulation, windows transmitting little heat, ventilation with heat recovery and solar heating. These more advanced installations cause higher investment costs but the lower energy use reduces operation costs.

Lower heat demand should reduce the use of natural resources, such as fossil fuels, and enable biomass to be used for other purposes than space heating, such as production of automotive fuel. But the heat demand reductions are a challenge for district heating and therefore also for the possibilities to utilise energy sources that need district heating to be used, such as industrial surplus heat. Therefore it is important to analyse the interplay between energy supply and energy conservation and between district-heating companies and buildings.

Energy-efficiency measures, such as improved wall insulation and better windows, primarily reduce heat demand in winter and, hence, decrease seasonal demand variations. This may be favourable from a heat-production viewpoint because high-load plants are needed less but base-load plants (Sect 1.1) may be used more, which would reduce operation costs and environmental impact. But base-load plants would also be affected, which could decrease efficient electricity generation in combined heat and power plants.

Åberg and Henning [20] studied the impact of a potential heat-demand reduction due to extensive energy-efficiency measures in existing buildings on district-heating and electricity production by using the energy system optimisation model MODEST (Sect. 2). In the Swedish city under study, the heat-demand reductions would primarily decrease heat-only production, whereas CHP production would be less reduced. The *electricity-to-heat output ratio* for the system would even increase, that is, generated electricity per unit of delivered district heating would increase. Local carbon-dioxide emissions would be lowered by the energy-efficiency measures because less fossil fuel would be used. Global carbon-dioxide emissions would also be reduced though less efficient coal-fired condensing power plants would need to replace the electricity that can no longer be produced in the CHP plants due to reduced heat sink in the buildings. However, only the existing electricity and district-heating production plants are considered in this study [20], whereas a process of gradual heat-demand reduction in present houses would run in parallel with a restructuring of the heat supply system probably including a transition to even larger use of renewable fuels. In such a future system, energy-efficiency measures might not reduce carbon-dioxide emissions.

In a similar study of another city [21], the combined effect of energy-efficiency improvements in existing multi-family buildings and the connection of new low-energy multi-family houses to the district-heating grid was studied with MODEST. These changes would not affect global carbon-dioxide emissions if there is interplay with coal-fired condensing power plants. But heat production plants and fuels used have crucial importance for the environmental impact of district heating. In this case, the heat demand changes would, for example, decrease the use of a CHP plant fuelled with carbon-rich peat, which cause similar carbon-dioxide emissions as coal. The larger impact on CHP production compared to the previously mentioned study is also shown by an electricity-to-heat output ratio for the system that declines with heat demand [21].

8.2. Using district heating at low demand

To make it favourable to use district heating in areas with low heat demand and, thus, to enable utilisation of the energy sources that can only be used through a district-heating system, as much district heating as possible should be used in such an area while still using the heat efficiently.

Besides the traditional purposes domestic hot water and space heating, district heating can be used for industrial processes and all heat supply to household appliances (e.g. dish washers, washing machines, tumble dryers and towel dryers), which now often, at least partly, use electricity for heating. Solar rooftop energy extraction could yield electricity instead of heat, because the latter would reduce the demand for district heating supply.

Henning [22] outlined scenarios for more sustainable energy supply for a development in a Swedish town. In two cases, the buildings were supplied by district heating. In one of these scenarios, district heating was used only in the traditional way for domestic hot water and space heating in normal, but not inefficient, houses. In the other scenario, there were low-energy buildings where district heating also was used for household appliances. Energy that in the first case only disappeared out of the buildings was in the other case utilised for heat supply to dish washers, washing machines, tumble dryers and towel dryers. The first scenario meant more climate-dependent space-heating demand partly covered by expensive high-load fuels (mainly forest wood chips in this town), whereas the latter scenario included more base load in the household appliances, which could be covered by fuels with lower costs (wood waste, [22]).

Many industrial processes have heat demand that partly or wholly can be covered by district heating but now is supplied through fuel or electricity. When required, district heating can be supplemented by boilers to obtain desired high temperatures. Heat demand in industrial manufacturing processes is often more or less independent on outdoor temperature and only has little seasonal variations (besides holidays) in the same manner as domestic hot water. Industrial processes can, therefore, constitute a base demand, which favourably could be covered by base-load plants, such as waste incineration or CHP plants [23].

With lower heat demand, the temperature in district-heating networks can be lower, which means that surplus heat of lower temperature can be utilised. Also, more electricity can be produced in CHP plants because the heat that is extracted after electricity generation can be of lower temperature. A larger fraction of fuel energy can yield high-quality electricity instead of low-quality heat.

9. Useful electricity use

Electricity is widely used for purposes there district heating or cooling could be used instead. Electric heating is used extensively in Norway (Fig. 5) but also in several other countries. Electricity is also generally used for air conditioning. Switching from electric heating or cooling to district heating or cooling naturally reduces the electricity consumption but if the district energy comes from a CHP plant the switching may also enable a larger electricity production there and less other electricity production is needed, which often is coal-fired condensing power plants. Thus, such energy-carrier switching influences the power system twofold through reduced demand and changed generation, which can lower fuel consumption and carbon-dioxide emissions. In Sweden, the use of district heating could be increased by 25% if all electric heating in non-rural areas was replaced by district heating [14].

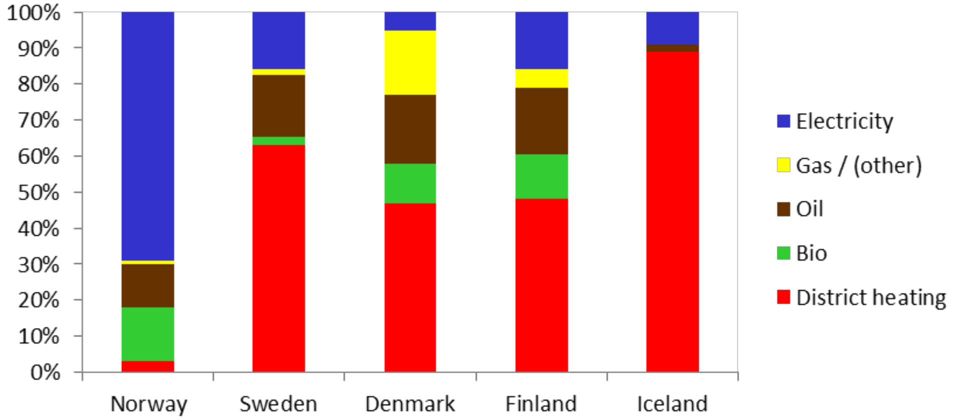

Figure 5. Nordic heat market (Source: Norsk Bioenergiforening (NoBio)

Seen from an exergy point of view, electricity should not be used for heating purposes. This is particularly obvious if electricity is generated with low efficiency and with fuels that are both costly and not environmentally friendly. On the other hand, it could be more difficult to argue against using electricity if the power is generated through hydropower with low production cost and without emissions. This is also one of the main reasons for the rather high share of electricity in some of the heat markets shown in Fig. 5. There are different reasons why there is a widespread use of electricity-based heating in some places but a shift to district heating or other forms of heating where renewable sources are used should be seen as a necessary measure to achieve energy and environmental targets. From a Nordic perspective, where the share of renewables in power production is high, a shift from electricity-based heating would offer tremendous opportunity to meet national and international policy targets through letting the not used electricity displace less environmentally benign power production. The transport sector, now being one of the main carbon-diode emitters, might alternatively benefit from energy-carrier switching to electricity. However, this depends on the maturity and the efficiency of the technology for electric vehicles.

10. Conclusions

District heating is a comprehensive concept for heat supply from fuel through heat production and distribution to consumers. District heating systems are valuable assets, which enable efficient resource utilisation.

The main advantages with district heating are low primary energy demand due to high energy efficiency, high security of supply through utilisation of domestic renewable energy resources, if available, as well as small carbon-dioxide emissions thanks to low fossil fuel use and the high conversion efficiency.

District heating enables utilisation of energy resources that are difficult to use in single buildings and that otherwise may be wasted, such as industrial surplus heat, municipal waste and heat from generation of electricity in combined heat and power plants.

Incineration of waste with heat recovery to district heating may be used at very low cost. Surplus heat from industries can, instead of being wasted to air or water, be utilised in district-heating systems. District heating also gives opportunity for cogeneration of power and heat with high efficiency. District heating, thus, enables profitable heat supply with less environmental impact.

District cooling from, for example, absorption-cooling devices saves electricity and may increase power production in CHP plants. To efficiently utilise biomass for energy purposes, it could be supplied to poly-generation plants where it yields, heat, steam, electricity, cooling and automotive fuel.

The use of, for example, biomass fuel decreases the dependency on imported fossil fuels. Efficient plants need less fuel, which decreases the vulnerability of energy supply. Global warming and better houses reduce heat demand. Using district heating for additional purposes enables increased utilisation of energy resources that otherwise may be wasted.

11. Outlook

Companies and organisations in well-developed district-heating countries have much knowledge that can facilitate district-heating development elsewhere. Such actors could help establishing district-heating systems from fuel supply, via heat production plants and networks to customer contracts. It would promote industrial prosperity for all parties and help building sustainable energy systems in Europe [17].

Government on all levels should recognise district heating as means for increased efficiency of energy utilisation, higher security of supply and decreased environmental impact and their policies should facilitate district heating development.

District heating and cooling can be keys to sustainable local energy systems, which connect energy surplus and energy demand at various temperatures. Regional heating and cooling networks could be supplied by a variety of heat and cooling sources. In such systems, energy supply and demand could be matched, for example, industrial surplus heat, hot water for dishwashers and cooling of rooms, food and water.

European district heating industry has a vision of metering and control of heat sources and consumers that match and optimize energy sources and demand. The vision envisages that IT, real-time smart metering devices and intelligent substations for individual customers, in the future will allow energy inputs and outputs to be identified, matched and regulated in order to optimize the interaction between sources of energy supply and the various temperature demands of customers [24].

Introduction of new district heating systems and modernisation of old ones can result in optimal energy systems from forest to living room.

Author details

Dag Henning[1*] and Alemayehu Gebremedhin[2]

*Address all correspondence to: dag.henning@optensys.se

1 Optensys Energianalys AB, Linköping, Sweden

2 Department of Technology, Economy and Management, Gjøvik University College, Gjøvik, Norway

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