Part IV:

Environmental Benefits by DH&DC compared to Local Heating and Cooling Plants

By

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4. Environmental benefits by DH&DC compared to local heating and cooling plants (Part IV)

A comparison between the environmental effects of different energy production systems is problematic. Extensive studies are needed to clarify environmental effects profoundly, e.g. detailed life cycle assessment (LCA) of every studied system. Principles and framework of the LCA is standardised /1/, but the whole method is still under development work. Because of the complexity of LCA studies, in this chapter only general aspects of environmental effects of district heating and cooling systems are presented. The comparison between local and district heating and cooling systems are based on information collected from references and on a few calculated examples of flue gas emissions.

4.1 Environmental effects

Energy production for heating and cooling systems has several environmental effects. Figure 4.1 shows an example of a formation chain of environmental effects in the energy production. If environmental effects between different energy production systems are compared, some kind of determined index for valuation of effects is needed. In the LCA studies, the index can be based on evaluated costs of different effects, for example.

The most influential air pollutants are heating or electricity production systems, which require the combustion of fossil fuels. Nuclear power and also hydroelectric power production systems don't have flue gas emissions at all, but they do have environmental effects such as radioactive wastes from the nuclear power production. Hydroelectric power production systems have more effects on nature's aesthetics than producing actual pollutants /2/.

Not only the energy production, but also the energy conversion and distribution systems have environmental effects, too. Especially in the conventional cooling plants conversion of the primary energy to the cooling energy have strong environmental effects.

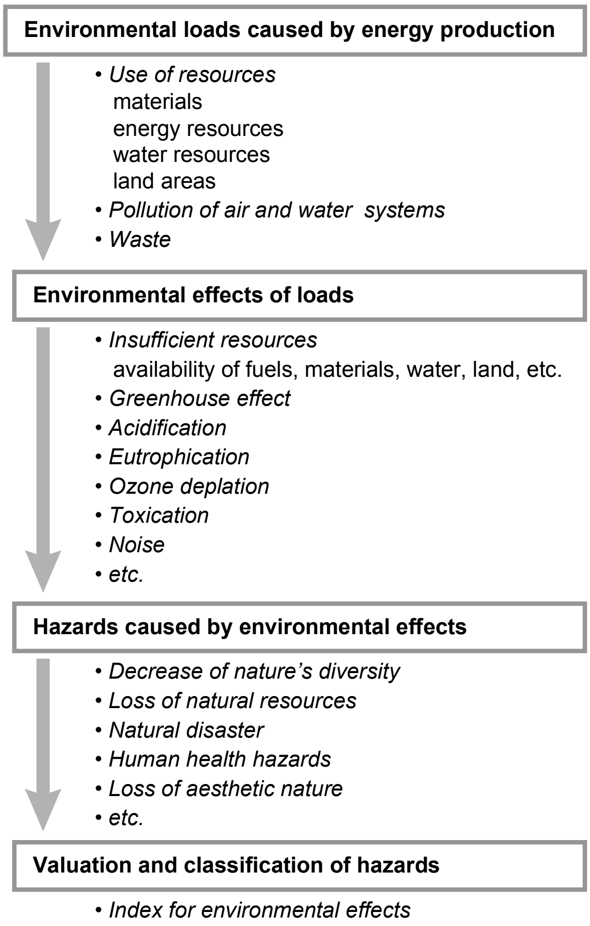

Figure 4.1. An example of a formation chain of environmental effects /3/.

For example electrically driven compressors of the cooling systems require refrigerants. Before the Montreal protocol was signed in 1988, adapted refrigerants were usually chlorofluorocarbons (CFCs). These chemicals are thought to be the primary contributor to the ozone layer depletion in the upper atmosphere /2/. In the Montreal protocol, timetables for ending the production and use of CFCs were established. Later the protocol was revised a few times and the timetables were strengthened, as were done at the meetings in London and Copenhagen.

During the past 10 years, massive work has been undertaken to develop alternative refrigerants for CFCs, because of the Montreal protocol. Every compound of CFC (or HCFC) refrigerant has an individual ending timetable, which vary from 1996 to 2030 /4/.

Maybe the confused situation of conventional refrigerants is one reason for the recent development of district cooling systems. Recently developed district cooling systems don't include refrigerants like CFCs. This kind of systems are e.g. absorption chillers, which are operated by district heating, and sea water cooling systems.

4.2 Flue gas emissions of energy production

The main pollutants released from the combustion of fossil fuels are:

- carbon dioxide CO_2
- carbon monoxide CO
- sulphur dioxide SO_2
- nitrogen oxides NO_X
- unburned hydrocarbons

Carbon dioxide forms the largest component of the products of combustion, and rising concentrations in the earth's atmosphere are a major cause of the greenhouse effect and risk of climate change. It's production is directly proportional to the quantity and composition of fuel burnt /5/.

Carbon monoxide is a poisonous gas, which is produced through incomplete combustion. It can be reduced to negligible levels simply through satisfactory air/fuel control /5/.

Sulphur dioxide is an acidic gas, which is released when burning sulphur-containing fuels such as oil, coal or bio-gas, but not e.g. from natural gas. SO_2 emission is a cause of acid rain and, if allowed to condense, it causes corrosion damage to steel for example in heat recovery systems /5/.

Nitrogen oxides are produced by burning any fuel in air. NO_X formation is strongly influenced by combustion conditions, such as temperature, residence time and air/fuel ratio. In the atmosphere, nitrogen oxides undergo various chemical reactions, which result in ozone formation and smog. NO_X also contributes to acid rain and is one of the major urban pollutants /5/.

Unburned hydrocarbons are largely produced by the reciprocating engines of motor vehicles where poorly controlled combustion leads to small quantities of partially burnt fuel passing through the engine. Unburned hydrocarbons are a major cause of smog and contribute to the greenhouse effect /5/.

4.3 Development of emissions

Emissions vary according to national circumstances, but the average specific CO_2 emissions per unit of primary energy consumption have been slowly decreasing during the past 20 years in almost all western countries (figure 4.2).

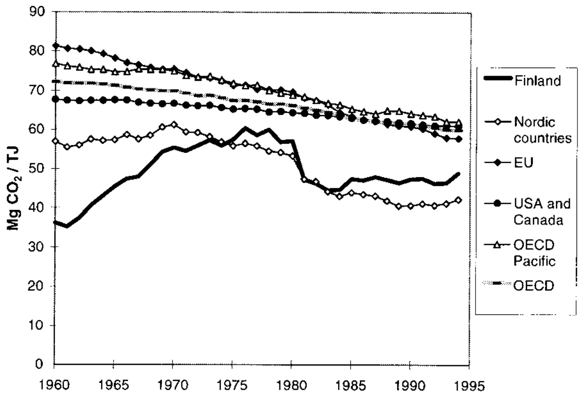

Figure 4.2. CO_2 emissions per unit of primary energy in selected countries /6/.

The trend of average CO_2 emissions have been decreasing for example in OECD countries, in Europe, in USA and in Canada. The average emissions of the Nordic countries are lower than the average in Central or Southern Europe, in USA and Canada or in OECD countries /6/. Table 4.1 shows emissions from electricity production in some European countries according to the reference /7/.

	CO_2 g/kWh$_e$	SO_2 mg/ kWh$_e$	NO_X mg/ kWh$_e$
Norway	0	0	0
Switzerland	16	7	25
Sweden	50	51	44
Austria	218	207	188
Netherlands	459	207	523
Finland	272	423	492
France	71	485	239
Germany	543	1368	438
Italy	546	2711	1592
Denmark	743	2747	2150
Great Britain	485	4398	1441

Table 4.1. Emissions from electricity production in different European countries /7/.

Many countries have a national energy strategy, which contains objectives for the reduction of flue gas emissions, especially CO_2 emissions. The international agreements, like the Kyoto agreement, commit to do measures, so that promised reductions of emissions will be achieved.

In the national energy strategies of many countries combined heat and power production (CHP) is taken up as one solution to achieve international commitments and CHP capacity is growing throughout many European countries all the time. High efficiencies of CHP lead to a reduction in CO_2 emissions compared to conventional separate generation because of more efficient use of fuel /5/.

Below are shown a few examples concerning national energy policies or strategies and environmental protection according to the reference /8/. These examples show that district heating systems and especially CHP production play an important role in national energy and environmental protection strategies.

<u>Finland /8/</u>

The Finnish energy policy has three major goals;

- security
- economy and effectiveness
- safety and environmental acceptability

The protection of the environment, as well as encouraging competition in the energy field, have become more important.

District heating has been an important tool in advancing the realisation of the Finnish energy policy. CHP production has made a significant contribution to the energy saving efforts. The government and local authorities have taken a positive attitude toward district heating.

The regulations for maximum emissions of particles, sulphur dioxide and nitrogen oxides have affected large investments for power plants and bigger boilers. These investments and other measures have weakened the competitiveness of district heating towards individual gas heating or light fuel oil heating. The CO_2 tax has also affected some extra costs for district heating.

<u>Norway /8/</u>

The Norwegian Parliament endorsed the objectives concerning emission restrictions on sulphur dioxide and nitrogen oxides. Regarding the carbon dioxide emissions, a majority of the government advocated a reduction of the emissions to reach a stable level by the year 2000 at the latest. As a result of the environmental requirements, a reduction in the rate of growth in total energy consumption may be necessary, aiming at a levelling out towards the turn of the century. To obtain these goals, an energy price and tax policy allowing for a reflection of the environmental costs is being prepared. This mainly applies to the prices of fossil fuels.

The use of renewable energy sources is encouraged by the government, and may increase the future use of district heating as biomass may be most efficiently used in such centralised plants.

Germany /8/

To have a sufficient and reliable supply of cost efficient energy, a political conception with the following focal points has been fixed:

- priority for energy saving and efficient use of energy
- improvement in the structure of energy demand by reducing the share of fuel oil and increasing the share of coal, natural gas, nuclear energy and - if available on economical conditions - of new and renewable energy sources
- optimal use of domestic energy resources
- broad spread of sources of primary energy imports
- national and international supply on the international energy market in case of disturbance of the energy supply

The district heating - in particular the CHP production - has an important meaning on that occasion. By its intensified use an important part of the total energy consumption will be saved. Because of the high no-polluting energy source and its large effect on energy saving, district heating has a very positive image in the Federal Republic of Germany.

In the frame of environmental protection, large amounts of money have been spent in power stations, in particular in CHP plants.

Denmark /8/

The Danish energy policy has three major goals:

- energy savings
- utilization of domestic energy sources
- safety of the energy supply

In addition, the protection of the environment, as well as encouraging competition in the energy field, has become more important.

District heating has been an important tool in advancing the realization of the Danish energy policy. CHP production has made a significant contribution to energy saving efforts.

District heating has no doubt contributed to an improvement in the environment situation in Danish towns and cities. Through changed methods of producing district heat and installation of exhaust gas cleaning, the outdoor air in Denmark is much better today than it was one or two decades ago.

The Netherlands /8, 9/

The main goals for the Dutch government are:

- reduction of emission of carbon dioxide, according to the Kyoto conference
- introduction of sustainable energy up to 10 % of the total use in the year 2010.
- increase of the energy efficiency
- liberalisation of the energy-market

The long-term policy is to increase the use of sustainable energy (wind, biomass, en photo-voltaic-cells). Especially the electricity-sector has to participate in the sustainable energy development.

Development of CHP and DH still play an important role in the increase of energy-efficiency.

To reach the Kyoto goals the Dutch government started a subvention program 1997 to realise their goals. A lot of new D/H-schemes are as part of this program developed. An important part of these projects contain D/H-connection of greenhouses.

The national government published a new law on 15 December 1995, which prescribes a required "Energy Performance Standard" when a new building is designed and built. The "Energy Performance Standard" is the energy-paragraph in the building code. At review in 1998 has increased the energy performance of CHP and other heat-sources in this standard. A house with a DH-connection reaches a 10 to 20% better value than a house with an individual boiler.

Bulgaria /8/

The national energy policy follows three fundamentals:

- maximum use of indigenous energy sources (mainly lignite) in conjunction with measures necessary for environmental protection
- thrifty use of energy, especially in relation to heat and electricity
- the furtherance of district heating systems, particularly the installation of CHP plants
- the extension of nuclear power plants due to the lack of indigenous energy carriers

To achieve more energy savings, measures have been set in motion to introduce individual heat cost accounting.

CHP production plays a significant role in Bulgaria, especially over the past 20 to 25 years. However, the restructuring of the country from a planned to a market economy has strongly inhibited the growth of district heating systems, although it is known that CHP systems contribute to reducing fuel consumption and thereby cutting pollutants.

Bulgaria has had comparatively stringent environmental legislation for some time. In preparation are also measures for controlling flue gas losses in relation to fuels used and installed boiler output, as well as the introduction of ecological waste disposal systems using modern, environment-friendly technologies.

4.4 Calculated examples of emissions

A great number of factors have to be chosen when emissions of different kind of energy production systems are compared by the help of calculations. These factors are the properties of available fuels, characteristics of burners and boiler plants, energy distribution losses, share of combined heat and power production, etc. And every chosen factor has an effect on a calculated result.

Flue gas emissions from local heating plants can be defined when characteristics of the fuel and boiler plant are known. In the case of district heating or electricity production, the definition of emissions is not so clear. Distribution losses and shares of fuels in production have to been taken account, too. In the case of CHP production, the definition of emissions will become more complicated.

Allocation of emissions to the electricity and district heating production is problematic. Several methods to allocate emissions have been introduced, but none of these methods are standardised.

One method is to allocate emissions to the district heating and to the electricity in the share of their production or sale. Another method is to decrease emissions of the district heating production with a reduction of emissions, which is achieved when condensing power production is replaced by the CHP production. This method is used in the calculated examples shown below. The calculations were done by the Emission calculation application of the Excel worksheet, which was developed at the VTT Building Technology in 1993.

Structures of electricity and district heating production systems, and shares of fuels in Finland have been chosen for a basic case of calculations (fig. 4.3 and 4.4).

These factors have been varied in six fictional cases, and their effects on CO_2, SO_2 and NO_X emissions are defined. Seven calculated example cases are:

- case 1, a reference case
- case 2, all district heating from CHP production
- case 3, all district heating from separated production
- case 4, all heating energy from local light oil heating boilers
- case 5, all heating energy from local natural gas heating boilers
- case 6, all heating with direct electric heating produced by condensing power
- case 7, all heating with direct electric heating produced by nuclear or hydropower

In all cases, specific emission factors of fuels consist of production, transportation, storage and combustion of the fuel. The calculated CO_2 -equivalent emission factor is based on the total emissions of carbon dioxide CO_2, methane CH_4 and nitrous oxide N_2O. Table 4.2 shows the emission factors.

Release of emissions mainly depends on the composition of fuels, but it also depends on the quality and property of the fuel. The quality and property of the fuel likely varies significantly, which of course affects the calculated emissions.

Cleaning of flue gas emissions is not included in the calculations, which have to be taken into account when calculated results are studied. Because of this the calculated SO_2 and NO_X emissions are higher than in reality, but it doesn't affect the CO_2 emissions.

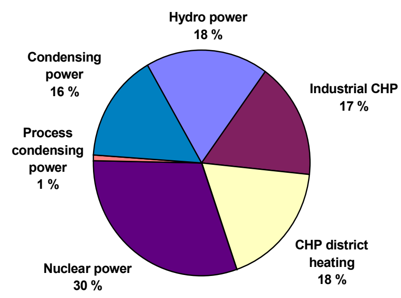

Figure 4.3. The structure of electricity production in Finland /10/.

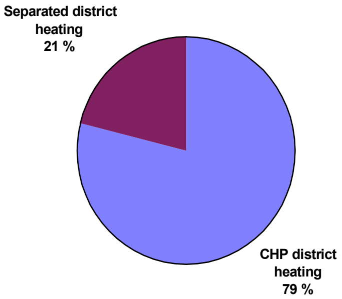

Figure 4.4. The structure of district heating production in Finland /11/.

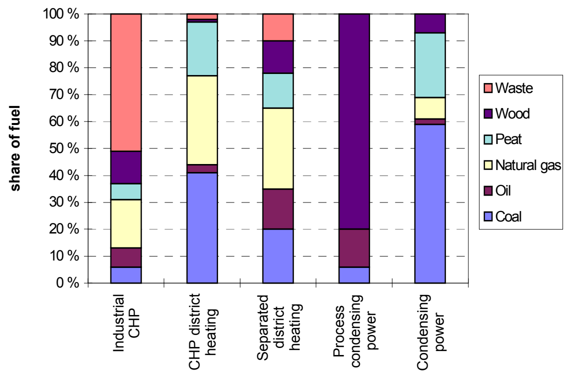

Figure 4.5. Shares of waste and fossil fuels in the electricity and in the district heating production in Finland /10, 11/.

Fuel	CO_2-eq g/MJ	SO_2 mg/MJ	NO_X mg/MJ
Coal	121	479	349
Peat	113	191	272
Natural gas	88	2	245
Heavy oil	94	1079	308
Light oil	90	176	146
Wood	122	2	132
Waste soda-lye	3	132	115
Bark & waste wood	9	2	182

Table 4.2. Emission factors of fuels /12/.

Case 1

Structures of the electricity and the district heating production are from the year 1997 in Finland (fig. 4.3 and 4.4). The production of electricity is 66,1 TWh and district heating is 28,2 TWh. The shares of fuels are also from the year 1997 in Finland (fig. 4.5).

Case 2

CHP plants produce the entire district heating. The shares of fuels in the district heating production are the average of total district heating production in case 1. The shares of fuels in the electricity production are identical with case 1. Compared to case 1, the condensing power production is reduced because of the additional CHP electricity production.

Case 3

No CHP production, which is replaced by condensing power production. The shares of fuels in the district heating production are the average of total district heating production in case 1. The shares of fuels in the electricity production are identical with case 1. All the CHP electricity production is replaced by condensing power production.

Case 4

No district heating production, which is replaced by the production of local light oil heating boilers. The shares of fuels in the electricity production are identical with case 1. The CHP electricity production is replaced by condensing power production.

Case 5

No district heating production, which is replaced by the production of local natural gas heating boilers. The shares of fuels in the electricity production are identical with case 1. The CHP electricity production is replaced by condensing power production.

Case 6

No district heating production, which is replaced by electric heating. The shares of fuels in the electricity production are identical with case 1. Condensing power produces the additional electricity production.

Case 7

No district heating production, which is replaced by electric heating. The shares of fuels in the electricity production are identical with case 1, except that coal in the condensing power production is replaced by nuclear or hydropower (fig. 4.5). Also the additional electricity production is produced by nuclear or hydropower.

Results

The calculated examples give trendsetting results about released emissions in different kind of fictional heating and electricity production systems. As was mentioned above, cleaning of flue gas emissions are not included in the calculations, which have to be taken into account.

Figure 4.6 shows relative CO_2 emissions, figure 4.7 shows relative SO_2 emissions and figure 4.8 shows relative NO_X emissions. The ratio of the emissions in the reference case is one. The emissions in other cases are compared to the reference case 1.

The calculated emissions of the reference case in electricity and heating production are, respectively:

- 294 g/kWh_e and 168 g/kWh_h for CO_2
- 949 mg/kWh_e and 193 mg/kWh_h for SO_2
- 906 mg/kWh_e and 456 mg/kWh_h for NO_X

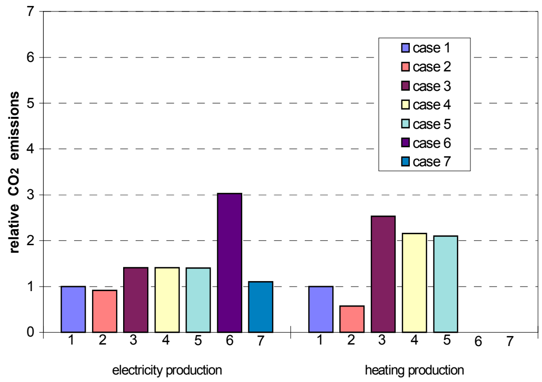

Figure 4.6. The ratio of CO_2 emissions in different cases.

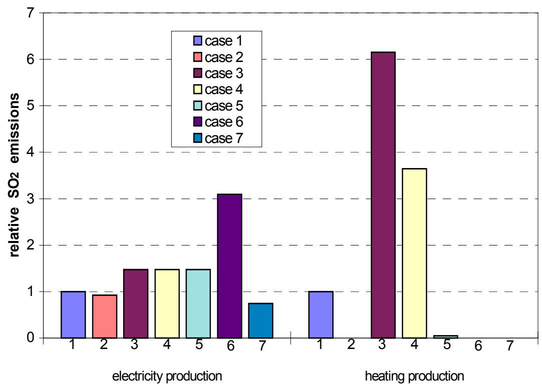

Figure 4.7. The ratio of SO_2 emissions in different cases.

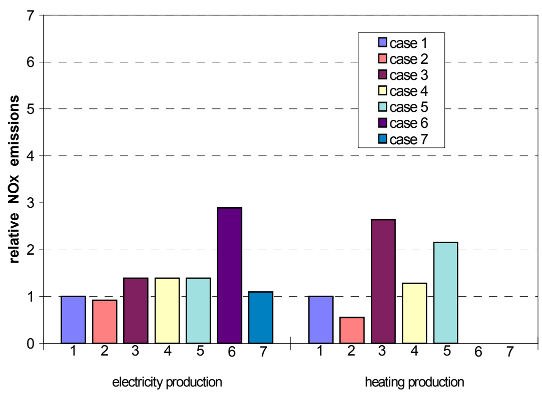

Figure 4.8. The ratio of NO_X emissions in different cases.

In the reference case, the share of CHP production in district heating production is already high, but a reduction of emissions is still possible by increasing the share of the CHP production (case 2). If the CHP production would be replaced by condensing power, emissions will be increased significantly, especially SO_2 emissions (case 3).

Emissions in the local oil heating case 4 are higher than in the reference case 1, but smaller than in the case 3, which does not include any CHP production. In the local natural gas heating case 5, SO_2 emissions are almost zero, but CO_2 and NO_X emissions are higher than in the reference case 1.

In the electric heating cases 6 and 7, emissions of the heating energy production are zero, and all emissions are released from the electricity production. If the additional electricity production for heating purposes is produced by condensing power, emissions are higher than emissions of heating and electricity production together in the reference case 1. If the condensing power is replaced by nuclear or hydropower, emissions of electric heating are decreased significantly.

If the calculated emissions in the case 1 are compared to the emissions in Finland in table 4.1, it can be seen that the calculated CO_2 emissions are in the same level, but the calculated SO_2 and NO_X emissions are about two times greater, than the emissions in table 4.1. This is partly due to the fact that cleaning of flue gas emissions is not included in the calculations. Another possible reason is that in reference /8/ the profitable reduction of emissions in the CHP production has been allocated mainly to the electricity production and not to the district heating production as was done in the calculations.

4.5 Environmental benefits of district heating and cooling

In the earlier study of the IEA's District heating - program potential environmental benefits of district heating and cooling systems compared to non-district systems are shown /2/. These benefits are relevant also today. The benefits are:

- higher efficiency of partial loads
- utilisation of CHP production
- biomass combustion
- limited number of emission sources
- superior operating and maintenance of plants
- technical upgrades
- higher design efficiencies of compressors
- easier to install effective noise control
- easier to supervise condition of fuel storage
- easier to use alternative fuels

- better chance to use alternative heating or cooling energy resources as waste energy
- conversion from one refrigerant to another is simpler

In general, district heating and cooling plants operate at higher efficiencies under partial load conditions, compared to non-district systems /2/. The higher efficiency means more efficient use of fuel and less emission per produced energy unit.

Especially in the CHP production the efficiency is significantly better than in the separated production of electricity and heating. Because of more efficient use of fuel in the CHP production, reductions in CO_2 emissions are achieved compared to the conventional separate district or local heating systems.

In the case of separated heating plants' efficiency and peak load conditions, there is not so great a difference between district heating and local heating systems, if the same fuel is used. The efficiency of district heating systems is decreased because of longer distribution networks.

The efficiency of electrically operated compressors of cooling plants is better in big than in small scale plants (part II fig. 2.1), which is an environmental benefit of the electrically operated district cooling plants compared to the small scale cooling plants.

The district cooling systems, which are not based on electrically operated compressors, have valuable benefit compared to the electrically operated compressors of local or district plants. The electric compressors are not needed for example in cooling plants, which are based on the absorption processes and which are operated by district heating, or in the district cooling systems based on sea water. These kinds of cooling systems don't need refrigerants, which is a clear environmental benefit compared to the conventional cooling plants using CFC refrigerants.

In biomass or wood combustion, CO_2 emissions are considered to be zero, because the CO_2 balance doesn't change. The combustion of biomass or wood releases the same amount of CO_2 as is absorbed in the growth of the burned material /2/. In the future, biomass and wood can be alternative fuels in small-scale plants, too. Utilisation of wood chips in small scale heating plants has been developed recently, and active plants already exist.

The district heating and cooling plants mean a reduced number of emission sources in a community /2/. This is an environmental benefit compared to local individual energy production plants such as local oil heating boilers. Compared to the individual small-scale plants, the installation of facilities to clean emissions from the centralised plants' flue gases are technically and economically more effective.

The district heating and cooling plants also cut down problems associated with fuel delivery, which is also an environmental benefit. The logistics of the centralised plants are more effective than in the decentralised plants. Some central heating and cooling plants have even oil or gas pipelines to facilitate fuel delivery.

Operating and maintenance practices are usually more effective in the centralised plants than in the individual small scale plants. The centralised plants have trained staff, sophisticated monitoring and control systems for operation of the plant. New technical improvements, for example in low NO_X burners and heat recovery scrubber systems, are simpler to install to the large systems than to the small scale systems /2/. All these matters are beneficial for the environment.

4.6 Conclusions

Comparison between environmental effects of different energy production systems is problematic, because various effects occur. If the comparison were done profoundly, extensive studies such as the life cycle assessment of every studied system would be needed. Because of the complexity of environmental effects, the above shown comparisons between local and district heating and cooling systems are mainly based on general aspects collected from different references.

The released emissions are strongly dependent on the available fuels and structure of production, which can be seen from the calculated examples, too. Among the input values of the calculations there are also many other assumptions, which certainly have impacts to the results.

The calculated examples give trendsetting results about released emissions in different fictional heating and electricity production systems, when the cleaning of flue gas emissions are not taken into account. One obvious result is that the CHP production is very beneficial for environment.

Also without any calculations it is well known, that district heating and cooling systems have certain environmental benefits compared to local systems. Many of these benefits are mentioned above. The most significant benefit is the reduction of different emissions. Compared to local systems, this benefit can be achieved, among other things, by the help of

- CHP production,
- higher efficiency of partial loads,
- effective cleaning techniques of flue gas emissions

and
- utilising alternative heating or cooling energy resources.

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