The 11th International Symposium on District Heating and Cooling,
August 31 to September 2, 2008, Reykjavik, ICELAND

CHP and district heat in the Europe under an emission reduction regime

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ABSTRACT

The future development of the European energy market in the EU 27 is influenced by European targets on efficiency improvement, use of renewables in total or as a share of electricity generation, security of supply and emission reduction. Several measures have been initiated on the European or national levels to combat climate change, e.g. emission trading, promotion of renewables or discussion on national quotas or targets for electricity production from combined heat and power (CHP). In the context of these a large number of power plants in Europe have to be replaced within the next two decades. The economic option of building new and additional CHP capacities depends on the national situation and on the possible interaction with new district heat and cooling supply options.

In the context of efficiency improvements in industrial CHP, district heat and cooling systems, the use of waste heat becomes a topic of interest. On the other hand very often efficiency improvement in the residential or commercial sector is reduced on the topic energy saving. Without analysing the entire energy system the possible advantages of CHP and district heat and cooling couldn't taken into account.

INTRODUCTION

In order to stabilize of the carbondioxide concentration in the atmosphere at 450 ppm (see communication of the European Commission SEC(2007) 8) or to avoid the risk of a worldwide temperature increase of more than two degrees C° a strong climate policy in the EU27 will be necessary. Reduction of the CO_2 emissions in the EU27 by 70 %/Russ 2007/ in the year 2050 compared with the emissions in the year 1990 will be necessary. Using a regionalised PanEuropean TIMES energy system model, the impacts on CHP and district heat and cooling in Europe under such an emission reduction target will be analysed.

The PanEuopean TIMES model

The Pan European TIMES model is a technically oriented model which illustrates in detail the whole energy system of the member states of the EU27 for the period from 2000 to 2050. Additionally the countries Iceland, Norway and Switzerland are modelled. The model is based on the model generator “The Integrated MARKAL-EFOM System” (TIMES), developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA).

In the model, the following sectors and demand categories were implemented in the Reference Energy Systems (RES):

Transportation includes road and rail for passengers and freight, navigation and aviation. In road transport, there are five demand categories for passenger travel (cars – short distance, cars -long distance, buses – urban, buses - intercity, two and three-wheelers/off road), and one for freight (trucks). In rail transport, there are three demand categories (passengers – light trains (metros), passengers - heavy trains and rail freight). The aviation and navigation sectors are modelled using a single generic technology each and a single generic demand each that reproduces the energy consumption.

In Residential there are 11 end-uses (space heating, space cooling, water heating cooking, lighting, refrigeration, clothes washing, clothes drying, dish washing, other electric, other energy), and the first three are differentiated by building categories (single family house – rural, single family house - urban, multi family Apartment). Similarly, the RES structure of the Commercial and Tertiary sector has nine end-uses (space heating, space cooling, water heating, cooking, refrigeration, lighting, public lighting, other electric, other energy uses), with the first three being differentiated by building categories (small / large). Agriculture is modelled as a single generic technology with a mix of fuels as input and an aggregated useful energy demand as output.

Industry is divided in two different sets: energy intensive industries and other industries. For the energy intensive industries, a process-oriented RES was adopted, whereas for other industries a standard structure consisting in a mix of five main energy uses (Steam, Process heat, Machine drive, Electrochemical, Others processes) was chosen. The energy intensive sectors were further separated into sub-sectors (steel production, cement production, aluminium, etc). In order to start moving in the direction of LCA/I and ExternE, the material demands for some sectors (as such for example steel or limestone) were explicitly modelled.

Electricity and Heat production: this sector regroups public power plants, autoproducers of electricity and CHP. In the RES, three types of electricity (high voltage, medium voltage, and low voltage) and two separated (not connected) grids for long distance (high temperature) and short distance (low temperature) heat are distinguished.

Supply: each primary resource (crude oil, natural gas, hard coal, lignite) is modelled by a supply curve with several cost steps. There are three categories of sources: located reserves (or producing pools), reserves growth (or enhanced recovery), and new discovery. In addition, five types of biomass are modelled: wood products, biogas, municipal waste, industrial waste-sludge, and energy crops.

Scenario analysis of the EU27 energy system

Framework data - EU demographic and economic Development

The long-term demographic development, the overall economic and sectoral growth of production, the development of living areas, the transportation capacity both for transportation of persons as well as of goods and the development of the prices for imported fossil energy carriers are given for the scenario analyses. It is assumed that the population in the EU27 decreases over time (Table 1). The resident population will slightly decline from about 488 million today to about 472 million people by the year 2050. In the same period, the gross domestic product (GDP) increases by about 188.5 %, if a growth rate between 2.2 %/a and 1.2 %/a is assumed.

Table -1: Socio-economic framework data for the scenarios

		2005	2010	2015	2020
Population	[%]		0.3%	0.2%	0.1%
	Mio.	488	493	495	496
GDP	[%]		2.2%	2.1%	2.1%
	Bio. €2000	10.2	11.5	12.9	14.5
Private Consumption	[%]		1.9%	1.8%	1.8%
Industrial activity (energy intensive)	[%]		2.3%	2.2%	2.0%
Other industrial activity	[%]		2.2%	2.1%	2.0%
Transport activity	[%]		2.2%	2.1%	1.9%
Service sector activity	[%]		2.0%	2.0%	2.0%
		2025	2030	2040	2050
Population	[%]	0.0%	0.0%	-0.1%	-0.3%
	Mio.	496	495	487	472
GDP	[%]	1.8%	1.7%	1.5%	1.2%
	Bio. €2000	16.3	18.3	23.16	28.83
Private Consumption	[%]	1.7%	1.6%	1.6%	1.4%
Industrial activity (energy intensive)	[%]	1.6%	1.4%	1.0%	0.4%
Other industrial activity	[%]	1.6%	1.5%	1.2%	0.8%
Transport activity	[%]	1.5%	1.4%	1.0%	0.6%
Service sector activity	[%]	1.9%	1.8%	1.7%	1.6%

The development of the economic structure is characterized by the continued tendency of the expansion of the tertiary sector. The share of the service sector to the entire gross value rises from over two thirds by the year 2000 to 72.5 % by the year 2020.

Important input data for the model are also the mid- and long-term development (real) of the import prices of oil, natural gas and hard coal. It is assumed that the prices increase continuously and according to the recent situation of resources. For oil and natural gas, the averaged increase is assumed to be 1.7 and/or 1.9 % per year which is about twice as high as the price rise for hard coal (0.9 %/a).

Space heat and cooling demand in Europe today and in future

The demand for space heating and cooling differs among the countries in Europe based on the differences in climate conditions, and in the short term on differences in living standards (e.q. square meters per capita) and different building standards.

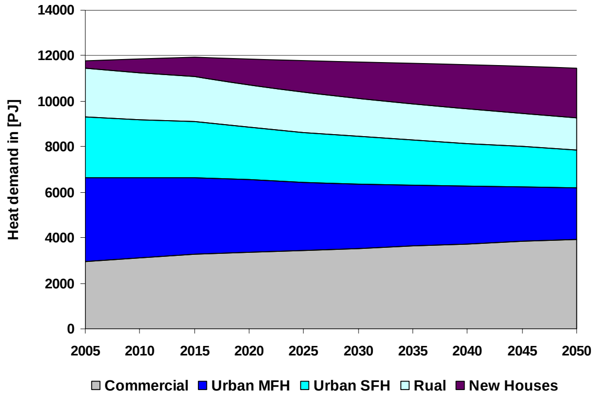

Figure 1: Demand for space heating and hot water in the EU27

The useful demand of cooling was in the year 2000 lower unless than 5 % of the useful demand of space heating and hot water. In the long term, the cooling demand will be dominated by the commercial sector. The increase of cooling demand in the EU27 up to 2050 will reach approx. 1120 PJ in the residential and commercial sector (see figure 2).

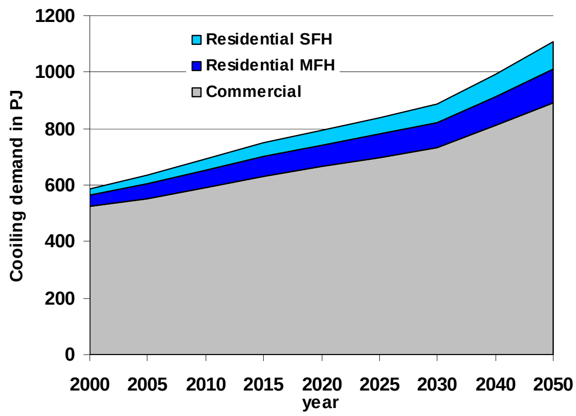

Figure 2: Cooling demand in the EU27

Scenario analysis of the European energy system

In the business as usual scenario (BAU), no climate policy is implemented in the member states of the European Union. The scenario includes a minimum of energy generated from renewable energy carriers, depicting current renewable schemes in the states of the EU27. In contrast to the BAU scenario, the CO_2 scenario reflects a strong climate policy in the EU27, aiming the stabilisation of the CO_2 concentration in the atmosphere at 450 ppm (see communication of the European Commission SEC(2007) 8). For the CO_2 scenario

(450ppm), this target means an EU27 wide reduction of CO_2 emissions by 70 % in 2050 compared to 1990. The BAU scenario as well as the 450ppm scenario contains the decisions on the nuclear phase out in the corresponding member states (e.g. Germany, Sweden, Spain, The Netherlands and Belgium). Moreover, commissioning of new power plants in the model is only allowed in those countries which still have nuclear power plants in the base year (2000).
The base value of the CO_2 emissions for 2000 of the EU27 has been determined by means of model calculations and an alignment with available statistics, and amounts to 3975 Mio. t. In the reference scenario the CO_2 emissions increase until 2050 up to a level of up to 4750 Mio. t. This is around 3.7 % higher than in the Kyoto base year 1990. In the 450 ppm scenario the given target of 1310 Mio t CO_2 will be achieved. This represents more or less the emission level from electricity and district heating production in the EU27 of today. Until the year 2020 the reduction target (37.8 % compared with 1990 or 25 % compared with 2005) in the 450ppm scenario will be achieved by the reduction in the conversion sector. Further reduction will be made in the industry sector, followed by the residential and commercial sector and finally by the transport sector.

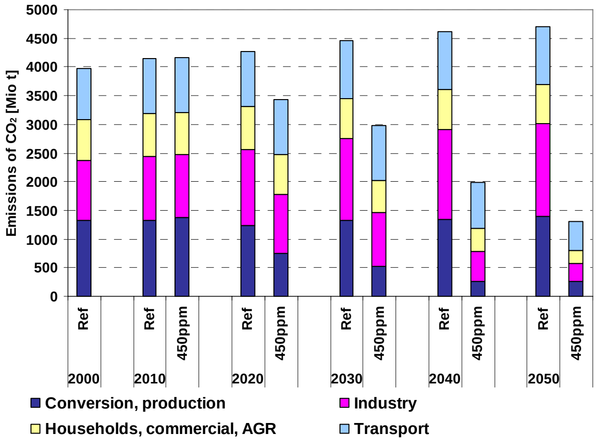

Figure 3: CO_2 emission by sector in the different scenarios

Due to the assumptions made for the development of the population and the economy as described before, the final energy consumption of the EU27 rises first from about 47085 PJ by the year 2000 to about 57610 PJ by the year 2020 and reaches 64994 PJ by 2050 in the reference case.
By the year 2020, the consumption of final energy in households increases by about 5.7 % relative to the year 2000 and stays more or less at this level until the year 2050. The development of the final energy demand takes into account improved new insulation standards for new buildings in the future and continued renovation measures combined with energy improvements in existing houses. On the other hand the electrical consumption for information and communication technologies and other appliances will increase.
The specific consumption of final energy in the industry rises by about 57 % until 2050 compared to the year 2000 with the energy use of the tertiary sector increasing by 85% by 2050. This growth in the BAU scenario already includes on the one hand side an efficient improvement and on the other hand is related to the strong economic growth of the new member states of the EU27.
In the transport sector the consumption of final energy rises until 2020, by about 22% even though a high increase in the transportation capacity is assumed. Beyond 2020 a smaller increase of the transportation capacity and further reduction of the specific fuel consumption are assumed. This will amount to a final energy consumption of 18750 PJ by 2050 compared to 14130 PJ in 2000.
In the case of the 450ppm scenario the final energy consumption will be additional reduced by efficiency improvements and the activation of additional energy saving measures by 8 % in 2050. The additional saving potentials which are used in the residential sector, are about 1200 PJ and 1600 PJ in the industry sector compared to the BAU scenario.
The use of petroleum products decreases in absolute terms in the BAU scenario. The share of petroleum products in the end energy consumption goes down from 42 % in the year 2000 by about 5 % to 38 % by the year 2020 and to 35% by 2050. This change includes increasing fuel consumption in the transportation section as well as oil consumption in the industry sector especially in the new member states of the EU27. The oil consumption decrease in private households and the commercial sector is related to the new efficiency standards for buildings. The share of gas rises from about 26 % (2000) to about 28.5 % by 2020. The importance of coal decreases in all sections; by 2020 coal has a share of somewhat more than 4 % of total end energy consumption.
The end energy consumption of electricity shows already in the BAU case a rise by 2020 of + 35 % and + 67 % until 2050 compared to 2000. The increase in electricity consumption is based mainly on the industrial, tertiary and transportation sectors with increasing shares of railway transportation as well as the use of electricity in alternative drives. In the residential sector, the increase in electricity consumption is related to the higher penetration of electrical heating systems as well as electrical appliances.
In the case of the 450ppm scenario a switch in the demand sectors from the use of fossils energy to electricity can be observed, since the demand sectors only have limited economic and technological possibilities for reducing CO_2 emissions.
Local and district heat cannot increase its share further in order to cover the demand of final energy in the BAU scenario it remains more or less at the level of 3.4 % of total final energy demand in the EU27. In contrast to the year 2000 the distribution of local and district heat to the sectors households, commerce and industry changes by the year 2050. Thus the demand of district heat in industry rises on the one hand, remains constant in the residential sector and decreases in the industry sector in the reference scenario (see figure 5).

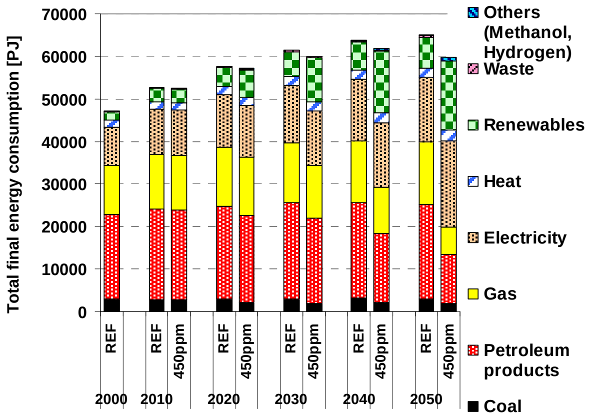

Figure 4: Final energy consumption in the EU27

In the case of the 450ppm scenario an additional 320 PJ district heat will be consumed in the year 2050. In contrast to the reference scenario the share of district heat demand in industry and the residential sector increase and decrease in the commercial sector.

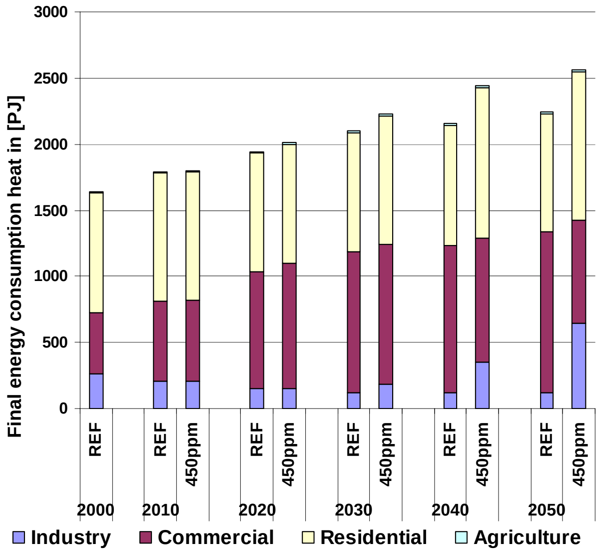

Figure 5: Final energy consumption of district heat by sectors

Driven by the growing demand for energy over the forthcoming decades, the total electricity production in the BAU scenario in the EU27 increases from 2843 TWh in 2000 to 4569 TWh in 2050 (see figure 6). The share of electricity generated from fossil fuels grows by 7.9 % to 55.6 % of total generation, whereas coal and lignite dominate fossil energy production. Electricity production from hard coal increases considerably by a factor 2.5 to 1213 TWh in 2050. The share of natural gas in the BAU scenario (16.3 % in the base year) remains nearly constant, although absolute quantities almost double to 853 TWh in 2050. Electricity generated in nuclear power plants changes increases slightly by 100 TWh to 1011 TWh in 2050. In the BAU scenario the use of renewable energies develops according to national policy schemes. Hereby wind power plants (onshore and, especially in the second half of the model time, offshore) as well as biomass and biogas fuelled power plants gain more and more importance among renewable energy producers.

As depicted in figure 7 the electricity generation structure in Europe changes considerably under the impact of a climate change policy. The total generation increases in the CO_2 scenario to 6177 TWh at the end of the time horizon. Compared to the BAU scenario this means an additional 1608 TWh annually in 2050. The energy savings applied in the residential, commercial and industrial sectors lead to a reduced electricity consumption in the middle section of the period modeled. Especially in the periods 2020 to 2030 the electricity production in the 450ppm scenario falls below BAU production level. But in later periods the stringent climate target with its emission reductions are realized in the energy production sector. Here the 450ppm scenario shows an increased use of natural gas in the power sector, contributing to 42 % (2592 TWh) of total electricity production in 2050. Compared to the BAU scenario electricity from natural gas tripled in the 450ppm scenario. The opposite is the case in the development of coal / lignite electricity generation, which declines drastically to 355 TWh in 2050. Under this climate constraint almost no lignite is used after 2030. The contribution of Nuclear power plants at electricity generation increases in the 450ppm scenario compared to the BAU scenario and reaches a total production volume of 1488 TWh in 2050. Furthermore the share of renewable energies is expected to grow under climate protection conditions to 28 % (1731 TWh) in 2050. Hydro energy potentials are almost depleted, meaning no significant energy quantities from hydro. The main source of renewable energy comes from biomass (609 TWh) and wind (427 TWh) and to a minor extract from solar energy (59 TWh).

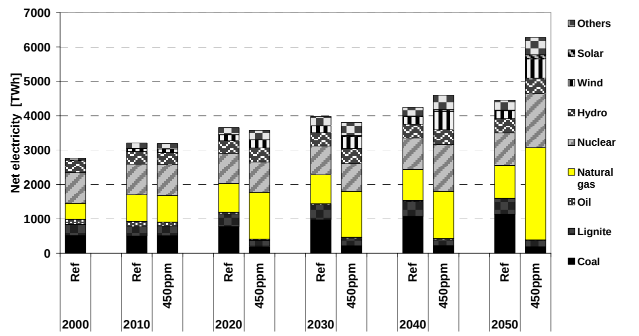

Figure 6: Net electricity generation in the EU27 by energy carriers in different cases

As stated before, the 450ppm scenario shows under the BAU scenario shows an increased electricity consumption of 1608 TWh in 2050. This implies an additional 400 GW installed capacity in 2050 (see Figure 7). The majority of the fossil generated electricity is produced in power plants with carbon capture and storage (CCS) technology, of which 360 GW gas combined cycle and 116 GW internal gasification combined cycle plants (IGCC) are installed in 2050. Among natural gas technologies a trend towards the commissioning of combined cycle units without CCS can be observed for less restrictive climate targets (here indicative of the middle periods of the 450ppm scenario).

Due to their high efficiency accompanied with low carbon emissions they fulfill the climate target cost efficiently. However under very stringent emission limitations, combined cycle units alone are not sufficient to reach the target. Concerning the assumed nuclear phase out in the corresponding member states, CCS technologies gain advantage competitive and represent a low carbon production opportunity. Figure 7 also depicts significant capacity commissioned in renewable units. Since these power plants are characterised by a lower annual availability, higher capacity is necessary to gain the corresponding output quantities.

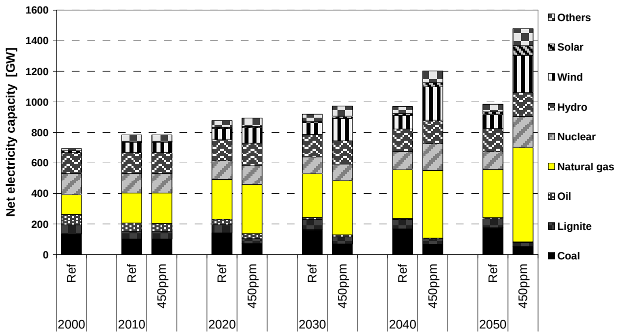

Figure 7: Installed net capacity in the EU27 by energy carriers in different cases

The electricity generation of CHP plants in the EU27 increases by 79 % from about 423 TWh in the year 2000 to 840 TWh by the year 2020 in the BAU scenario (see Figure 8). The extension of the electricity generation of CHP plants is essentially supported by gas-fired and biomass- based CHP plants. Additionally, existing public CHP plants with an extraction condensing turbine are substituted by CHP plants with higher power-to-heat ratio and there is also an extension of industrial CHP plants which are often used in cooperation of communal facilities. Until the year 2050 the electricity production by CHP plants in the reference scenario further increases up to a level of 1190 TWh.

In the case of the 450ppm scenario the development of electricity by CHP plants turns out to be different. Based on the lower specific emissions of natural gas compared to coal the electricity generation by gas increases. Additionally the total electricity generation by CHP is 300 TWh higher. The fraction of autoproducer CHP will increase especially in the future in both scenarios.

The electricity generation based on biomass CHP plants is around 65 TWh higher in 2020 as in the reference scenario. Based on the higher heat to power ratio from biomass CHP compared to gas and coal CHP the district heat generation is higher than in the 450ppm scenario than in the BAU scenario.

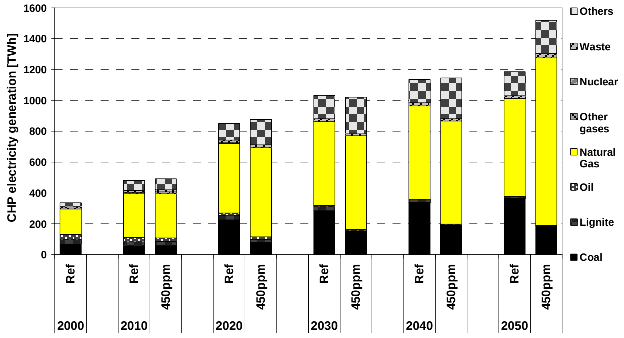

Figure 8: Net electricity generation of CHP plants in the EU27 by energy carriers in different cases

In the reference scenario the district heat generation increases from approximately 1980 PJ in the year 2000 to 2310 PJ in the year 2020. The extension of district heat happens independently of an increasing efficiency in the distribution and operation system and the extension of energy saving measures in the residential sector. In the case of reduction targets for public electricity and heat generation, the increase in the year 2020 will be 140 PJ higher.

The development of DH generation in the different regions within the EU27 during the past and in the future was and will be different based on varying economic and social starting points.

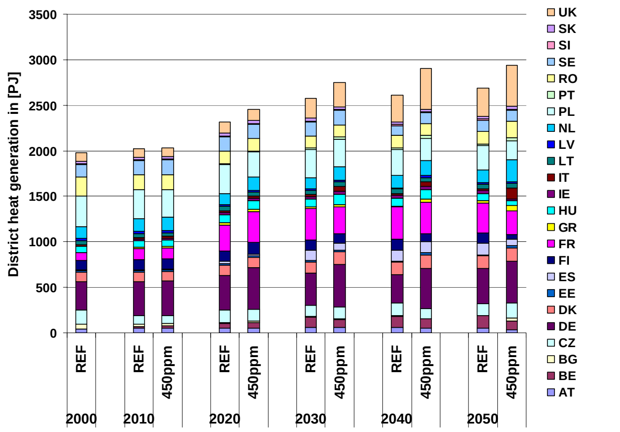

Figure 9: District heat generation in the EU27 by aggregated regions

In the Scandinavian countries (Sweden, Finland and Denmark) during recent years the share of district heat in the heat market has been increasing. Today, the contribution of district heat to the heat market in Sweden is 50 %. The situation in Finland and Denmark is nearly similar. In future times the growth of district heat will be slower because the main parts of the economic district heat areas are still connected.

In the UK during the last 10 years the utilisation of CHP has remained at 7% of total electricity supply. Today, the total capacity of CHP for district heat is lower than 100 MWel. The future increase of DH generation is represented by gas fired CHP plants and will be even higher under the 450ppm scenarios than in the reference or renewable scenario.

The generation of DH in Austria has been increasing within the last years. The amount of installed capacity is mainly represented by CHP with a size of less than 20 MWel. In the future there still exists a potential of 7.5 GWel to extend and build up new public district heating systems. Depending on the particular scenario, part of this potential will be based on biomass CHP plants.
The DH production has been decreasing significantly in several of the EU10 countries between 1990 and 2000 due to the reduction of heat consumption both in industrial and residential sectors. High district heating prices, energy savings on the demand side especially in the residential sector, modernisation and refurbishment of the DH schemes are among the reasons for this reduction of demand. A second important point is that a lot of residential heating was switched from district heat to gas because of the cross-subsidies between large and small gas customers and the political interference in tariffs. However, in relative terms the DH share in the residential market in the EU10 (2004) maintained its level of the year 2000 which means that certain stability was registered in these last four years in this segment.
Some particularities also should be mentioned: in the Czech Republic, one of the countries with the largest DH production and share in the residential heat market, there is a tendency towards increasing the DH share in large urban areas. In Slovakia the trend was similar to the Czech Republic. The increase compared to the Czech Republic was lower because temporary cross-subsidies of gas simultaneously promoted the use of gas in the residential sector. In the future, both countries have an additional district heat potential which will be partly used.
In Hungary, the decrease in the residential sector is to a certain extent compensated by an increase of DH supply to the tertiary sector (services). In the future the prevention of subsidies for natural gas and the obstructions for households to turn away from the DH system will lead to a growing share of CHP in heat production and hence, reverse the current trend of declining DH.

Impact on the reduction for CO_2

In order to explain the CO_2 reduction in the 450ppm scenario compared with the reference scenario it is possible to split up the reduction of CO_2 by cause. In figure 10 the driving forces are the higher share of nuclear in electricity generation (nuclear), the use of CCS (in public heat and electricity, by autoproducer or in the energy conversion sector), the fossil fuel switch (fossil) and the use of larger amounts of renewables in all sectors. The point efficiency includes efficiency improvements and energy savings in all end use sectors as well as in the conversion sector.
Based on the emission reduction target after 2010 fossil fuel switching and a higher penetration of renewable energy use in all sectors will be the first options to achieve the target. Based on the availability after 2015 and the building time, CCS will come after 2020 with a not negligible part in the solution. After 2030 efficiency improvement becomes more and more important. In 2040 electricity generation by nuclear and the increase of electricity consumption will be additional reasons for the achievement of the reduction target.

In the year 2050 the highest impact of CO_2 emission reductions of over 1000 Mio. t of CO_2 will be related to renewables followed by the use of CCS and fuel switching. Around 370 Mio. t will be related to efficiency improvement, 250 Mio. t because of the increase of electricity consumption in the end use sectors and approximately 200 Mio. t of additional nuclear power generation.

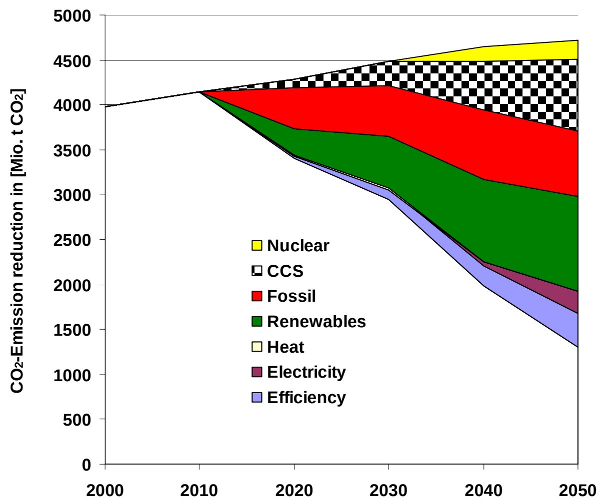

Figure 10: Attribution of CO_2 emission reduction in the EU27

The distribution of CO_2 reduction by effect does not match the reduction by sector because changes in supply quantise or the flexibility to account for reduction effects influences the result. For example the increase of final electricity and heat demand on the one hand side reduce the CO_2 reduction in the end use sectors; on the other hand higher emissions in the electricity supply sector might occur. The relation ship between technologies and CO_2 reduction depends on the efficiency of the technology, the carbon contents of the fuel and the possibility of CCS. The comparison of the impact on the CO_2 reduction between CHP, power plants and end use technologies for the years 2020 and 2050 is made in figure 11 and figure 12.
In 2020 the CO_2 emission reduction related to CHP plants is 30 % or 260 Mio. t CO_2. It is mainly caused by fuel switching (from coal to gas and to renewables; see also figure 8) and with only a small share due to efficiency improvement. If CCS is available, the share of the power plants to achieve the reduction target will be 35% or 304 Mio. t CO_2. 85 Mio. t CO_2 of this reduction will be connected with the fact that CCS is available and installed.

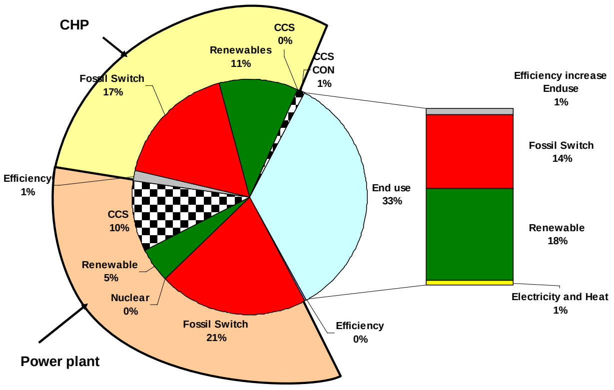

Figure 11: Attributes of CO_2 emissions reductions in the EU27 in 2020

The reduction in the end use sectors is 33 %. This illustrates that in the short term the reduction will happen in the conversion sector much more easily because of the central options. In the short term the share of CHP is higher than in the long term because the realizations of a reduction reason have immediate impacts on the specific CO_2 emissions of electricity generation and of heat generation. In the long term the CO_2 contents of the heat supply for the end use sectors will be reduced from 130 kg CO_2/MWh to 122 kg CO_2/MWh in 2020 and from 113 kg CO_2/MWh to 36 kg CO_2/MWh in the year 2050. This is one explanation for the strength of the CO_2 reduction target in the topic of heat issues on the one hand. On the other hand the possibility to use CO_2 neutral fuels or to install CCS influences the penetration of CHP more and more.

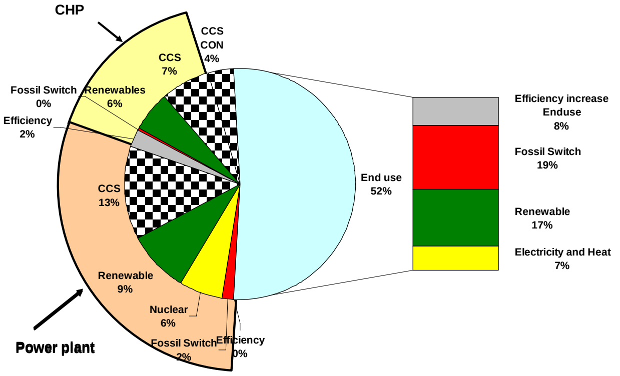

Figure 12: Attributes of CO_2 emission reduction in the EU27 in 2050

For small scale CHP a cost efficient combination with CCS is not possible. This is one reason why a reduction of local heat production happens in the 450ppm scenario and related the impact of CHP for CO_2 reduction becomes limited.

Overall the contribution of CHP to achieve the reduction target in 2050 (see figure 12) will be 15 %. Fossil fuel switch more or less is not a reason for CO_2 reduction because the fossil fuel switch will be used in nearly every case in combination with CCS. CHP in combination with CCS will reduce 235 mio. t CO_2. This is followed by 195 mio. t CO_2 reduction based on by the higher quantity of renewables used in CHP. It might be that biomass CHP is a cost efficient option to reduce GHG emissions in the electricity and CHP generation sector but as long as a strong reduction target is to be achieved the use of alternative becomes more and more competitive. Because of the limitations of other possibilities biomass or biofuels achieves a higher penetration in the transport sector. The main reason for the increase of efficiency improvement in 2050 compared with 2020 is a high share of CHP autoproducer in the industry sector.

Conclusions

District heating generation offers an economic potential for extension in the future. Depending on the regions or countries the development will be different because the starting point is of economic growth, existing national laws or cross-subsidies for competitor's energy carriers. In addition, it is necessary to take into account that the climate conditions within Europe differ substantially.
Moreover, the additional co-generated electric power to be produced tendency is for the out of natural gas and biomass. The efficiency of the whole district heat system is main issue in the long term. With or without it is an issue to become or to remain competitive with other energy carriers. Here already in the reference scenario efficiency improvements will be achieved.
The scenarios show that the power-to-heat ratio of CHP plants increases and that the share of district heat from CHP plants gradually rises instead from heating plants.
In general the progression of district heat crucially depends on the costs of opening up new district heating supply areas in the future. Provided that the costs of the extension of supply areas and the costs of starting losses reduce significantly, new district heating supply areas can be opened up economically.

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