Avoided carbon dioxide emissions from the current global use of district heating and combined heat and power

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Abstract

Globally, district heating (DH) and combined heat and power (CHP), including all industrial CHP, reduce the existing global carbon emissions from fuel combustion by 3-4%. This avoided emissions corresponds to an annual reduction of 700-900 Mton compared to the global annual emissions of 22700 Mton. The lower estimate is based on IEA Energy Balances for 1998. The higher estimate considers the lack of adequate information about heat generation from industrial CHP in the EU and USA in the IEA Energy Balances. The highest carbon dioxide reductions from DH/CHP occur in Russia (15%), in the former USSR outside Russia (8%) and in the EU (5%).

This annual amount of avoided carbon dioxide emissions is impressive with respect to the low global market share for district heating. The total amount of the global central heat generation was 11500 PJ in 1998, which corresponds to only 3,5 % of the world energy demand for consumption. Hence, the current share of avoided carbon dioxide emissions from DH/CHP has the same magnitude as the market share for district heating.

Introduction

This article considers the recognition of the current amounts of avoided carbon dioxide emissions from all existing District Heating Systems (DH) and Combined Heat and Power (CHP) plants in the world.

Avoided emissions are defined as the difference between the replaced emissions from alternative electricity and heat generation and the current emissions from DH/CHP plants. This difference occurs since district heating gives the possibility to distribute heat derived from industrial processes, refuse incineration, geothermal sources, and CHP plants. Dual (or triple) use of energy supplied reduces the demand of fossil fuels for heating buildings, industrial processes, and electricity generation. District heating can be seen as a second hand business within the energy sector. CHP generation has also higher conversion efficiency than separate generation of heat and thermal power. DH/CHP also gives the possibility of a central fuel substitution from fossil fuels to non-fossil fuels, as biomass fuels. All these possibilities make DH/CHP a carbon lean technology.

The purpose of this article is mainly educational and aims at the identification of carbon dioxide mitigation methods already in use. The logical conclusion from this article should be: If mitigation methods are already operating today, they can be repeated and expanded for further reductions of carbon dioxide emissions tomorrow. In the analysis, only contributions from DH/CHP are considered. District Cooling (DC) is omitted from the analysis, due to a low market penetration and lack of relevant statistical information.

The main information sources for the analysis are the 2001 editions of the Energy Balances published by the International Energy Agency (IEA), [4] and [5]. They contain the appropriate information for the analysis. Calorific values for fuels used together with electricity and heat generated are available for CHP and DH plants on each national level. The magnitudes of the information gathered have also been checked against various other information sources.

The analysis is performed by presenting:

- Global heat demands connected to central heat generation
- Market penetration of central heat generation
- The energy supply composition for DH/CHP
- The conversion efficiencies for existing CHP plants
- The identification of statistical deficiencies
- Estimation of avoided emissions of carbon dioxide

Global heat demands connected to central heat generation

The total amount of the global central heat generation was 11500 PJ in 1998 and its distribution is presented in **Figure 1**. This volume corresponds to 3,5 % of the world energy demand for consumption. China and the former USSR have almost 80% of all central heat generation in the world. Russia alone has 56 %, since DH/CHP was promoted in the planned economy in the former USSR. The OECD countries have only 18 % of the total volume of central heat generation.

The final energy demand for central heat generation is divided between the industrial sector demands (39 %) and the heat demands in the residential, public, and commercial sectors (61 %). Most of the industrial demands occur in non-OECD countries.

Globally, the share of heat from CHP in central heat generation is only 48%. In many countries this share amounts to 60-90%. The averages for OECD countries and in the EU are 75 % and 81 %, respectively. Hence, more heat from CHP plants can be absorbed in heating systems supplied from central heat generation in non-OECD countries.

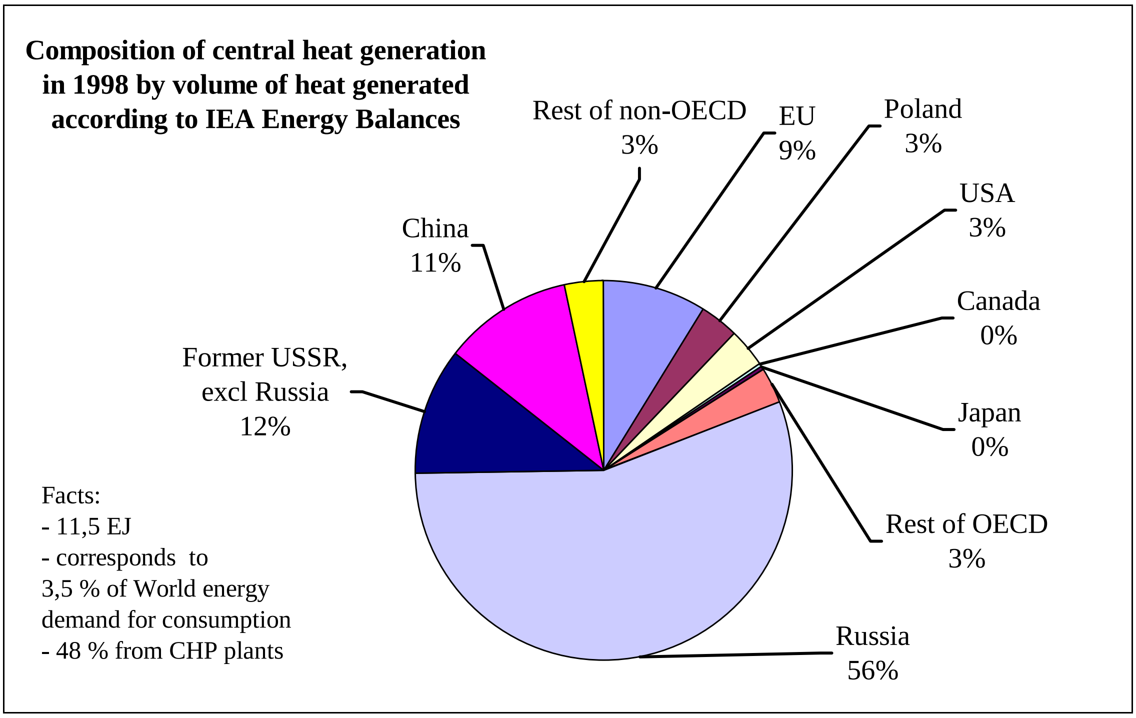

Figure 1. Composition of global central heat generation with respect to geographical distribution.

<u>Market penetration of central heat generation</u>

For the industrial sector, industrial processes dominate the energy demand. Central heat generation for industrial heat demands mainly appears in the former USSR, China, and Eastern Europe. However, in OECD countries, industrial CHP plants belong to the industrial sector in the energy statistics and not to the energy transformation sector.

For the residential, public, and commercial sectors, the energy demand in cold countries is dominated by the heat demand for heating buildings. Also for these sectors, the market penetration for central heat generation is high in the former USSR, China, and Eastern Europe. Some market penetration also occurs in the EU. However, this market penetration is irregular within the EU. High market shares occur in Finland, Sweden, and Denmark, while lower market shares appear in Germany, Austria, and the Netherlands. The other 9 EU countries have almost no central heat generation according to the IEA energy balances. But since Germany has a large population, it has the largest district heat market with 386 PJ/year. In size, it is followed by Sweden (167 PJ), Denmark (128 PJ), and Finland (118 PJ).

The conclusion is that the market penetration of central heat generation is low in the world. Only 4,2 % of the industrial energy demands and 5,5 % of the residential, public and commercial energy demands are globally met by central heat generation in district heating systems.

Energy supply composition

The energy supply composition for DH/CHP plants is presented in **Figure 2**. DH/CHP plants use more natural gas and combustion renewables than conventional thermal power generation. Hence, the fraction of coal in CHP plants is lower (38 %) than for conventional thermal power (67 %). Examples of countries that have high fractions of coal in the energy supply for both DH/CHP plants and conventional thermal power generation are Poland and China.

The global average carbon dioxide emission for energy supplied is 66 g CO_2 per MJ for DH/CHP plants. The corresponding global value for conventional thermal power generation is 83 g/MJ. The conclusion is that existing DH/CHP plants are more carbon lean in the energy supply than conventional thermal power generation.

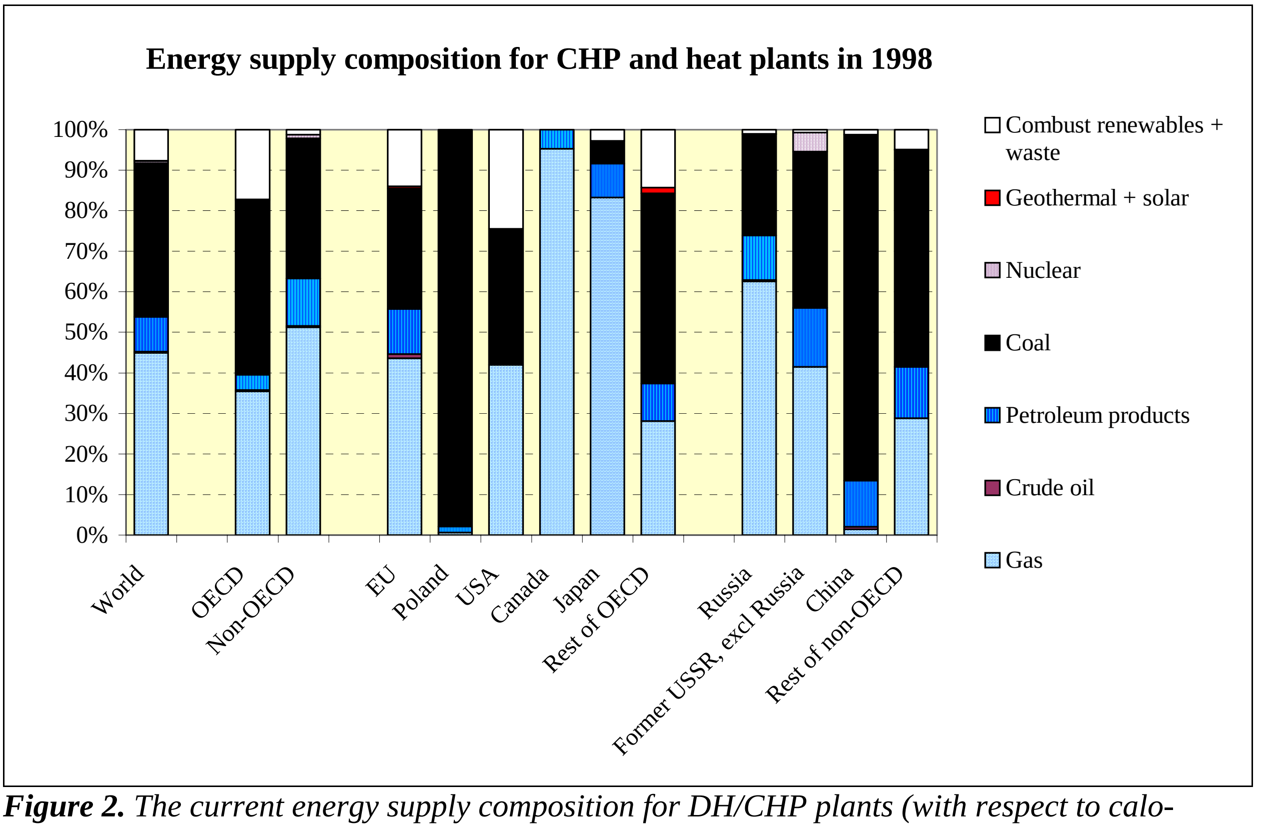

Figure 2. *The current energy supply composition for DH/CHP plants (with respect to calorific values of fuels used) for various parts of the world.*

Conversion efficiencies

The conversion efficiencies for CHP plants divided into the electricity and heat parts are presented in **Figure 3**. The global average is only 51 %. This implies that many CHP plants are also generating electricity in condensing mode without heat recovery. The highest conversion efficiencies are found in the EU (68 %) and Canada (67 %). Without any operation in condensing mode, total conversion efficiencies of 85-90% are possible for CHP plants.

It appears that the heat generated in the US CHP plants is underestimated, since the overall conversion efficiency is only 30 %. Since all thermal power plants are considered as CHP plants in Poland, the total conversion efficiency is also low. No information is available about CHP plants in China and Japan.

For conventional thermal generation, the conversion efficiencies are really low. The global average is only 33%. The highest conversion efficiencies occur in Japan, Canada, and in the EU.

The conclusions are that alternative generation of electricity is associated with low conversion efficiency and many CHP plants can probably deliver more heat since they also generate electricity in condensing mode.

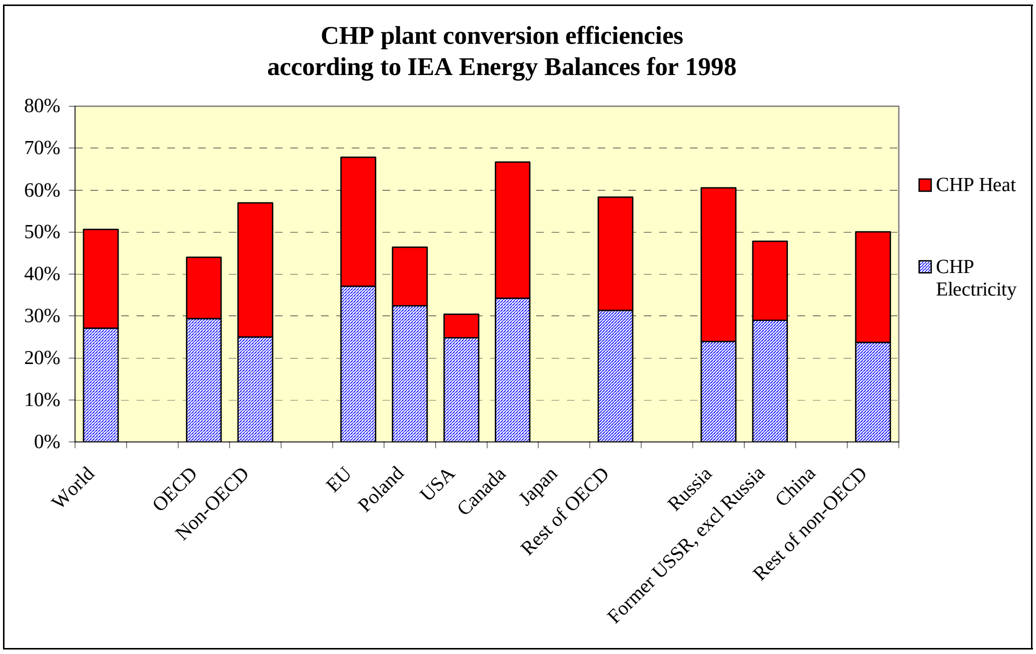

Figure 3. *Current average conversion efficiencies for CHP plants.*

Identification of statistical deficiencies

The quality of international energy balances published by the IEA has improved considerably during the recent years with respect to heat and CHP generation. However, due to different national statistical gathering routines, some deficiencies have been identified in the IEA Energy Balances. As a summary, the following statistical deficiencies are relevant to this analysis:

- EU: Heat generated in industrial CHP plants is not included. This is evident from a comparison with the heat amounts from CHP published in [2]. It appears that fuels allocated for electricity are included in the CHP statistics, while fuels allocated for heat generation are included in the industrial heat demands. For UK, both heat generation from CHP and heat plants are missing.
- Poland: All thermal power plants are considered to be CHP plants.
- USA: Low heat output from CHP plants. It appears that only fuel consumption and electricity generation are reported for many CHP plants.
- Canada: Information about heat plants is not available.
- Japan: No CHP statistics are available, only heat plants are reported.
- Russia: Almost all thermal power plants are considered as CHP plants.

- China: No CHP statistics are available, only heat plants are reported.

It appears that the most suitable statistical routines for gathering information about DH/CHP are found in the former USSR and Eastern Europe. In the former planned economy, the CHP plants were often built and operated separately from industrial enterprises and district heating systems. Hence, the routines for gathering statistical information seems still follow this traditional organisation. In the EU and USA, industrial CHP plants are integrated within the industrial enterprises. These countries have then no tradition of gathering CHP heat generation information from the industrial sector.

Avoided emissions of carbon dioxide

Avoided emissions are defined as the difference between the replaced emissions from alternative electricity and heat generation and the current emissions from DH/CHP plants.

The estimations of avoided carbon dioxide emissions are based on the following calculation procedure:

- The current emissions from DH/CHP plants: Total calorific values for fuels used have been multiplied with following emission factors: Coal – 92 g/MJ, oil products – 75 g/MJ, and gas - 56 g/MJ. No carbon dioxide emission is allocated from other energy supplied.
- Fuels avoided for electricity generation: Assumed conversion efficiency of 33 %. Replaced fuel has been assumed to be coal, according to the analysis performed in [6]. The calculation presumes central alternative electricity generation, since distribution losses are not deducted.
- Fuels avoided for heat generation: Assumed conversion efficiency of 80 % and average emission factor for country or region, dependent on fuels locally used. Average emission factor was 70 g/MJ. Highest factor for China (87 g/MJ) and lowest for Canada and Russia (65 g/MJ). The calculation presumes local alternative heat generation, since distribution losses are deducted from the central heat generation in DH/CHP plants.

The first set of estimations of avoided emissions was obtained using the original IEA Energy Balances. In total, 667 Mton of carbon dioxide emissions are avoided due to the existing use of DH/CHP. This corresponds to a reduction of 2,8 % of the global emissions from fuel combustion of 22700 Mton obtained from [3].

A second set of estimations is presented in **Table 1**. In this set, corrections have been made for inadequate information about the EU, USA, and China in the IEA Energy Balances. The following corrections were made:

- EU: Information about CHP plants (fuels used and heat generated) from [2] are used instead of information from IEA Energy Balances. By this change, also industrial CHP plants in the EU will be included in the analysis.
- USA: A total conversion efficiency of 60 % is assumed. No change in fuel supplied occurs since only the total conversion efficiency has been changed.
- China: A national power-to-heat-ratio of 0,3 is assumed in relation to total heat generated, giving 9,1 Mtoe (106 TWh) of electricity generated in CHP plants. The fuel supplied has been increased proportionally.

In total, 892 Mton of carbon dioxide emissions are avoided due to the existing use of DH/CHP according to this second set of estimations. This corresponds to a reduction of 3,8 % of the global emissions from fuel combustion.

The Euroheat & Power Committee of Ecology has in [1] estimated the avoided carbon dioxide emissions for the EU. Their estimation was 186 Mton for 1997. This value should be compared to the estimation for the EU in **Table 1**, which is 182 Mton for 1998.

Table 1. *Calculation of avoided carbon dioxide emission due to DH/CHP plants with estimated corrections for inadequate information for the EU, USA and China.*

Corrections made for inadequate information in the IEA Energy Balances

Mton	CO2 emissions from DH/CHP plants	CO2 emissions replaced by electricity generated	CO2 emissions replaced by heat generated	**Avoided CO2 emissions**	Total CO2 emission in 1998	Relative reduction of CO2 from DH/CHP
World	2136	1859	1169	**892**	22726	3,8%
OECD	834	921	421	**507**	12017	4,0%
Non-OECD	1302	938	749	**385**	9989	3,7%
EU	260	271	172	**182**	3171	5,4%
Poland	160	139	33	**12**	320	3,6%
USA	335	421	176	**262**	5410	4,6%
Canada	5	9	2	**6**	477	1,2%
Japan	1	-1	2	**0**	1128	0,0%
Rest of OECD	73	82	35	**45**	1511	2,9%
Russia	809	561	497	**249**	1416	14,9%
Former USSR, excl Russia	223	207	83	**67**	790	7,8%
China	185	106	137	**58**	2893	2,0%
Rest of non-OECD	85	64	32	**11**	4890	0,2%

Corrections made (shaded cells: EU 260 and 172; USA 176; China 185 and 106)

The extended position map

The position map for various heating options was presented as figure 6 in [6]. The position map presents the carbon dioxide emissions for two dimensions: The current and the future situation. The purport of the current situation is that alternative electricity generation is performed in coal condensing plants. In the future situation, alternative electricity is generated in natural gas combined cycle condensing plants giving more carbon lean electricity.

The information from **Table 1** can be integrated with the position map from [6]. This integration is presented in *Figure 4*. This new extended position map reveals that most regions in the world have DH/CHP systems with low net emissions in the current situation. However, the existing DH/CHP systems will receive very high net emissions in the future situation. The future competition, with respect to low carbon dioxide emissions, will be very stiff from local natural gas boilers and heat pumps. Hence, the existing DH/CHP systems must become more carbon lean in the future in order to survive this competition.

District heating systems in Sweden has a unique position compared to other countries since the current use of fossil CHP is low, [6]. Instead, a high fraction of biomass is used, mostly in heat-only-boilers. This gives Sweden a position near the zero-zero interconnection. The district heating systems in Sweden have then a better initial position for the competition in the future situation. The current net emission of about 110 kg/MWh is slightly lower than the future net emissions for heat pumps.

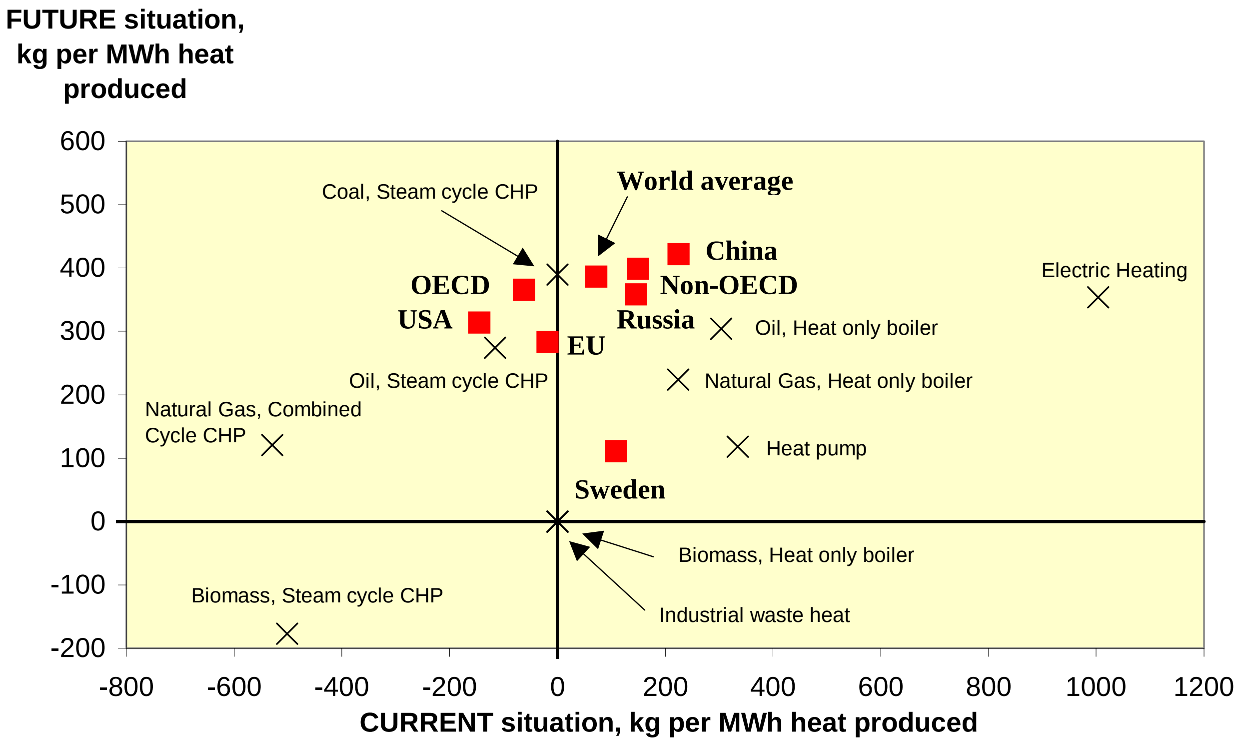

Figure 4.Net emissions of carbon dioxide from District Heating systems and CHP in various countries compared with various technical options for heating buildings. The purport of the current situation is that alternative electricity generation is performed in coal condensing plants. In the future situation, alternative electricity is generated in natural gas combined cycle condensing plants giving more carbon lean electricity.

Conclusions

The major conclusion is that the avoided carbon dioxide emissions from the global use of DH/CHP are significant and is about half of the magnitude of carbon dioxide reduction presumed in the Kyoto protocol.

Globally avoided carbon dioxide emission from DH/CHP can be increased by

- increasing the market penetration of central heat generation by introducing new and expanding existing district heating systems.
- increasing the heat utilisation in existing CHP plants by expanding the local heat sales.
- increasing the share of CHP in existing central heat generation, since only 48% is generated in existing CHP plants. The possibility is higher in non-OECD countries, since the share of CHP is 75 % in OECD countries.
- fuel substitution in existing DH/CHP plants, since coal constitutes 38% of fuel supplied.

Globally avoided carbon dioxide emission from DH/CHP will decrease when the carbon dioxide emissions from alternative generation of electricity and heat will be reduced. However, this is not a unique situation for DH/CHP; it will apply to all carbon lean technologies, since the future competition will not come from carbon rich technologies, but from other carbon lean technologies.

Acknowledgement

This work has been financed by Annex VI of the IEA implementing agreement of District Heating and Cooling, including the integration of Combined Heat and Power, within the project *Promotion and Recognition of DHC and CHP Benefits in Greenhouse Gas Policy and Trading Programs.* This article is a short version of appendix 3 from the final report, [7].

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