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# Impact on carbon dioxide emissions from energy conservation within Swedish district heating networks

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**Abstract**

The 100 largest Swedish district heating (DH)-networks were studied on how DH conservation measures impacts $CO_2$-emission rates taking both direct and indirect (i.e. displaced electricity) emissions into account, applying six different methods for the indirect emissions assessment. When the marginal electricity approach is applied on low $CO_2$-emitting DH-networks with a high share of cogenerated electricity, it resulted in assessments that imply that DH conservation leads to higher $CO_2$ emissions. This was not the case with the efficiency method.


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*Keywords:* District heat, $CO_2$ emissions, marginal electrcity, efficiency method, energy conservation

## 1. Introduction

National and EU policies are pushing for lower energy consumption in the built environment. This will reduce the heat demand and could thereby cause decreased cogenerated electricity in CHP plants within DH networks. In low $CO_2$-emitting Swedish DH networks this reduced cogenerated electricity can be argued to be replaced by electricity production with higher $CO_2$-emssions. In this study six methods,

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categorized into four approaches, were used to assess these indirect emissions. To compare and contrast these methods, emission factors (EF) for the 100 largest Swedish DH-networks were calculated based on average fuel mixes, cogenerated electricity and delivered heat of 2012.

## 2. Methods

$EF_{DH\ total}$ (Eq. 1) denotes total $CO_2$ emission rate of the DH network, including direct and indirect emissions. $EF_{DH}$ is directly linked to fuel combustion, handling and transportation of fuels per delivered unit of DH, allocated by the energy content method [1]. Production of heat and electricity, fuel mixes and EF (including handling and transportation of fuels) for the studied DH networks were collected from the Swedish District Heating Association (SDHA) yearly publication on environmental assets for 2012 [2].

$$EF_{DH\ total} = EF_{DH} - \alpha_{system}(EF_{DE} - EF_{CHP}) \quad \text{Eq. 1}$$

The indirect emissions caused by the production of electricity is described by $\alpha_{system}(EF_{DE} - EF_{CHP})$ and derives from electricity production perceived as displaced by the cogenerated electricity. The electricity-to-heat output ratio of the system ($\alpha_{system}$) describes the quota of net coproduced electricity and total amount of delivered heat [3]. Wasted heat and electricity produced in condensing mode are to be excluded; in this study also operational electricity allocated to electricity cogeneration was subtracted. $EF_{CHP}$ denotes the emissions of the cogenerated electricity, based on the fuels mix allocated to electricity production. $EF_{DE}$ denotes emissions from displaced electricity production and varies depending on choice of method as seen in Table 1.

Table 1. Emission factors for displaced electricity utilized by the studied methods and approaches they are categorized by. The EM-method uses a resource efficiency approach, CC and NGCC uses a marginal electricity production approach, NM and SM uses average production as an approach and NRM is a market oriented approach

| Approach | Efficiency | Marginal production | | Market | Average production | |
|---|---|---|---|---|---|---|
| Abbreviation | **EM** | **CC** | **NGCC** | **NRM** | **NM** | **SM** |
| Method | Efficiency Method | Coal Condensing | Natural Gas Combine Cycle | Nordic Residual Mix | Nordic Mix | Swedish Mix |
| $EF_{DE}$ [$CO_2$ g/kWh] | - | 930 | 400 | 290 | 100 | 10 |

Nordic marginal electricity production of today was assumed consisting of CC while future marginal electricity production in the Nordic system was characterized by NGCC power plants. See [4] for more comprehensive information on the marginal electricity approach in the Nordics. NRM is a market oriented approach and represent the average of the residual when origin labeled electricity has been subtracted [2]. NM represent the average emission rate of the total Nordic electricity production [4,5] and SM represents the Swedish electricity production mix [4]. For the CC, NGCC, NM and SM methods EF of the respective method are applied on the DH-networks electricity consumption as well, while for the NRM method the EF reported by the companies (if they buy origin labeled electricity) were used and otherwise the NRM was used.

The EM is an allocation method recommended by the GHG Protocol Initiative [1]. It takes into account that there would be more fuel consumed if the electricity and heat would be produced separately and thereby allocates more of the fuel to the cogenerated electricity than the energy content method does.

Conversion efficiency values used for separate heat and electricity production are according to reference efficiency values set by the EU-commission [6] and varies depending on fuels used. For electricity used in DH production and plant operation NM was used. SDHA recommends its member to use the EM for allocation but for electricity they recommend the NRM method so the EF with the EM-method presented in this paper will differ somewhat from values published by the SDHA.

## 3. Result

Fig. 1 shows EF result for 100 Swedish DH networks for the six different methods studied. Results and characteristics for 5 DH-networks are shown in more detail in Fig. 2 and Table 2. These DH networks were selected to highlight dependencies between choice of method and the outcome on the characteristics of the DH network.

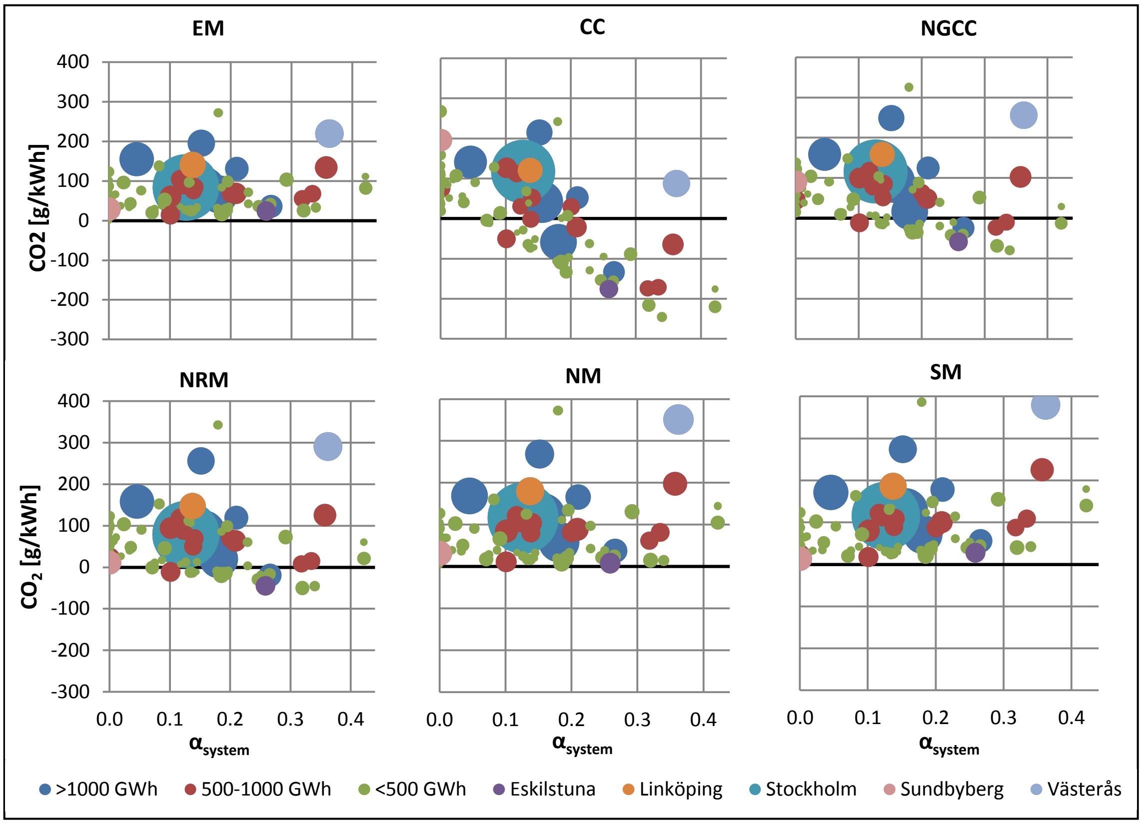


Fig. 1. $CO_2$ emission factors for 100 largest Swedish DH networks, x-axis shows quota of net coproduced electricity and delivered heat. Size and color of bubbles indicates amount of DH delivered.

In a DH network like Stockholm, having both cogeneration of electricity and electricity consumed in heat pumps for DH production, will obtain a similar EF regardless of the selection of assessment method (see Fig. 2). However, they benefit from the market oriented approach (NRM method) as the bought origin labeled electricity is considered having zero $CO_2$-emissions (see Table 2). The city of Linköping obtains similar results, but benefits somewhat more from the marginal electricity approach as there are no heat pumps in the DH production. Areas with high share of electricity for heat pumps and no CHP plants, like Sundbyberg, benefits most from the NRM method (bought electricity origin labeled with zero $CO_2$ emissions), while a marginal electricity approach gives much higher EF. Eskilstuna city that has a relative high $\alpha_{system}$ value in combination with a high share of biomass fuel will act as a coal sink if assessed with the CC, NGCC or NRM methods, and also obtains low values with NM, SM and the EM methods. Västerås city that also has a relative high $\alpha_{system}$ value obtains about four times lower EF with the CC method compared with the SM method, However, it will still be a value above zero due to high share of fossil fuels in the fuel mix. Västerås is also the only district heating network of the included ones that doesn't buy origin labeled electricity, this results in being the only DH network having a more favorable outcome when using the EM assessment rather than the SDHA method (see Fig. 2).

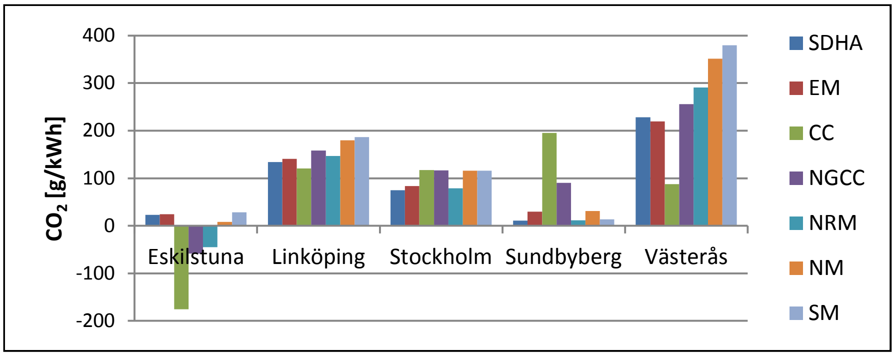


Fig. 2. Resulting $CO_2$ emission factors for selected DH networks and the 6 studied methods (see Table 1). Also the emission factors reported to the SDHA by the companies are shown (a combination of EM and NRM methods).

Table 2. Characteristics of selected DH networks [2]. *1 EF for labeled electricity bought by DH network, if no label then NRM is used. *2 Allocation with the efficiency method, applying labeled electricity as recommended by the SDHA. *3 100 g $CO_2$/kWh for Stockholm, 0 g $CO_2$/kWh for Sundbyberg

| | Eskilstuna | Linköping | Stockholm | Sundbyberg | Västerås |
|---|---|---|---|---|---|
| Delivered DH [GWh] | 712 | 1320 | 8430 | 1050 | 1540 |
| Produced electricity [GWh] | 195 | 208 | 1216 | - | 612 |
| Labeled electricity*1 [g $CO_2$/kWh] | 0 | 0 | 0 | 0 | 290 |
| Reported EF*2 [g CO2/kWh] | 23 | 134 | 75 | 11 | 228 |
| **Fuels for DH-production [GWh]** | **924** | **2270** | **9630** | **1150** | **2110** |
| Biomass [%] | 77 | 22 | 23 | 39 | 38 |
| Fossil [%] | 3 | 15 | 12 | 1 | 22 |
| Waste [%] | - | 46 | 17 | - | - |
| Peat [%] | - | - | - | - | 26 |
| Heat pumps (gained heat) [%] | - | - | 18 | 32 | 1 |
| Electricity [%] | 3 | 5 | 11 | 18 | 4 |
| Flue gas condensation [%] | 18 | 13 | 7 | - | 9 |
| Bought DH*3 [%] | - | - | 11 | 9 | - |

## 4. Discussions and conclusions

If the marginal electricity approach is applied on DH networks with high share of biomass fuels and a high $\alpha_{system}$ value (e.g. in Eskilstuna) it implies that reducing heat demand by energy conversation measures will lead to higher total $CO_2$-emission release. The EM method will benefit DH networks with large share cogenerated electricity on the merit that fuels are used more efficiently than with separate heat and power production. As the method merely shift emissions from heat to electricity production negative EF will not occur and all emissions origin from used fuels will be accounted for. In 2012 less than 1 % of the electricity generated in CHP plants within DH networks was reported being produced in condensing mode, so it can be argued that in today's market situation reduced cogenerated electricity actually is replaced by less clean marginal electricity production. When using a market oriented approach, such as the NRM method, makes it hard to compere DH networks from a system perspective since DH networks with high electricity consumption (e.g. trough heat pumps) that buys origin labeled electricity receive a totally different assessment than a DH network that doesn't.

This study was made with annual average values but DH conservations within mature DH-networks will normally affect the fuel mix on the margin (top load) more than the base load as has been shown in articles [3,7]. However, using annual average data provides a good indication on the impact from heat savings in different DH network. In summary, energy conservation within low emitting DH networks does not contribute, or might even have negative impact (with the marginal electricity approach), to $CO_2$-emission reduction goals. However, there are other reasons for saving heat in district heating areas, such as resource conservation, energy security and cost savings.

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