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Modelling the impact of policy instruments on district heating operations - experiences from Sweden

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Modelling the impact of policy instruments on district heating operations – experiences from Sweden

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Abstract

Emission allowances aim at reducing carbon dioxide emissions in the European Union. Feed-in tariffs and green certificates increase renewable electricity generation in some countries. Undesired energy carriers, such as fossil fuels, can be taxed to decrease consumption. In Sweden, monetary policy instruments have been used for many years, which has influenced district-heating utilities' operations and investments.

The energy system optimisation model MODEST may help elucidating the impact of policy instruments on choices of fuels and plants. The model can minimise operation and investment costs for satisfying district heating demand, considering revenues from electricity sales and waste reception. It has been used to analyse heat and electricity production for 50 local Swedish utilities. This paper shows how some plants, systems and policy instruments have been modelled and results from some case studies. It may help analysts who face policy instruments, which probably will have a growing influence on district heating operations.

Policy instruments should reflect external costs and induce behaviour that is beneficial from an overall viewpoint. Swedish fossil-fuel taxes hampered cogeneration during many years. Earlier, fuel input could be freely allocated to output energy forms and wood was often used for heat production and coal for electricity generation to minimise taxes. Now, lower taxes promote fossil cogeneration but green certificates make it more profitable to invest in renewable electricity generation.

Carbon dioxide emission allowances can reduce local emissions due to district-heating and electricity production significantly at current price levels but the impact depends on allowance price. With emission trading, investment in a natural-gas-fired cogeneration plant may be beneficial for some utilities due to high electricity prices in the European electricity market, partly caused by emission allowances.

District-heating demand can enable utilisation of resources that otherwise would be of no value. A landfill ban now increases waste incineration, which may reduce industrial waste heat utilisation and heat disposal from cogeneration plants and thereby decrease electricity production. A tax on incinerated waste may reduce the profitability of investing in waste incineration.

Keywords Energy policy, taxes, green certificates, emission allowances, CHP

1 Introduction

This paper shows how heating plants, combined heat and power (CHP) plants, district heating (DH) systems and policy instruments have been modelled and the results from some case studies. The impact of taxes, electricity certificates and emission allowances are considered for local utilities in the Swedish towns Stockholm, Göteborg, Linköping, Skövde and Örnsköldsvik. The experiences may help DH analysts who face various policy instruments, which probably will have a growing influence on DH operations.

As a means of elucidating impact of policy instruments (initially taxes) on district heating production, the energy system optimisation model MODEST was developed (Henning 1994, Gebremedhin 2003, Henning et al 2006). The model uses linear programming to minimise operation and investment costs for satisfying a DH demand under consideration of revenues from waste reception and electricity sales. The model has been used to analyse heat and electricity production for 50 local Swedish utilities (e.g. Henning et al 2006, Holmgren 2006). The model has also been applied to regional biofuel utilisation and national electricity supply and conservation (cf. Henning et al 2006).

In many countries, energy utilities have little experience of monetary policy instruments, but in Sweden, policy measures have attached costs to energy carriers for many years, which has influenced operations and investments for district heating companies. Complicated and fluctuating taxation called for methods that showed favourable choices of fuels and plants. MODEST has been used for many such analyses.

2 Taxes

Actors' choices can be influenced through taxation of undesired energy carriers, such as fossil fuels, which enhance the carbon dioxide (CO_2) concentration in the atmosphere. In Sweden, there is energy tax, CO_2 tax and sulphur tax. They are added to fuel prices for oil, coal, LPG and natural gas in the models. Wood fuel is not taxed. There are no energy and CO_2 taxes on fuels that produce electricity because there is a tax on electricity consumption. Fuels in CHP plants partly produce electricity and partly heat and the fuel fractions are taxed accordingly. If a CHP plant's power-to-heat output ratio is approximated as constant (e.g. Z in Fig. 1), the total fuel cost is decided by the costs for and the sizes of the two fractions, and this cost is normally given as input to a model. For example, a MODEST model of the Göteborg DH system includes natural-gas-fired plants that always are run in cogeneration mode (Sect. 4, Holmgren 2006).

To support industry, fuel that is used to produce heat that is used for manufacturing has no energy tax and lower CO_2 tax. Fuel supplies that correspond to the district heating delivery to industries can be modelled as a limited amount of fuel with lower cost (e.g. L in Fig. 1). The sulphur tax concerns oil, coal and peat and is the same irrespective of how the fuel is used. Taxes contribute to the fiscal budget, whereas a fee can redistribute money among actors. There is a fee on Swedish nitrogen oxide (NO_x) emissions, which also can be added to fuel costs. But plants with low NO_x emissions can expect revenues from the NO_x fee system, which can lower fuel costs in a model.

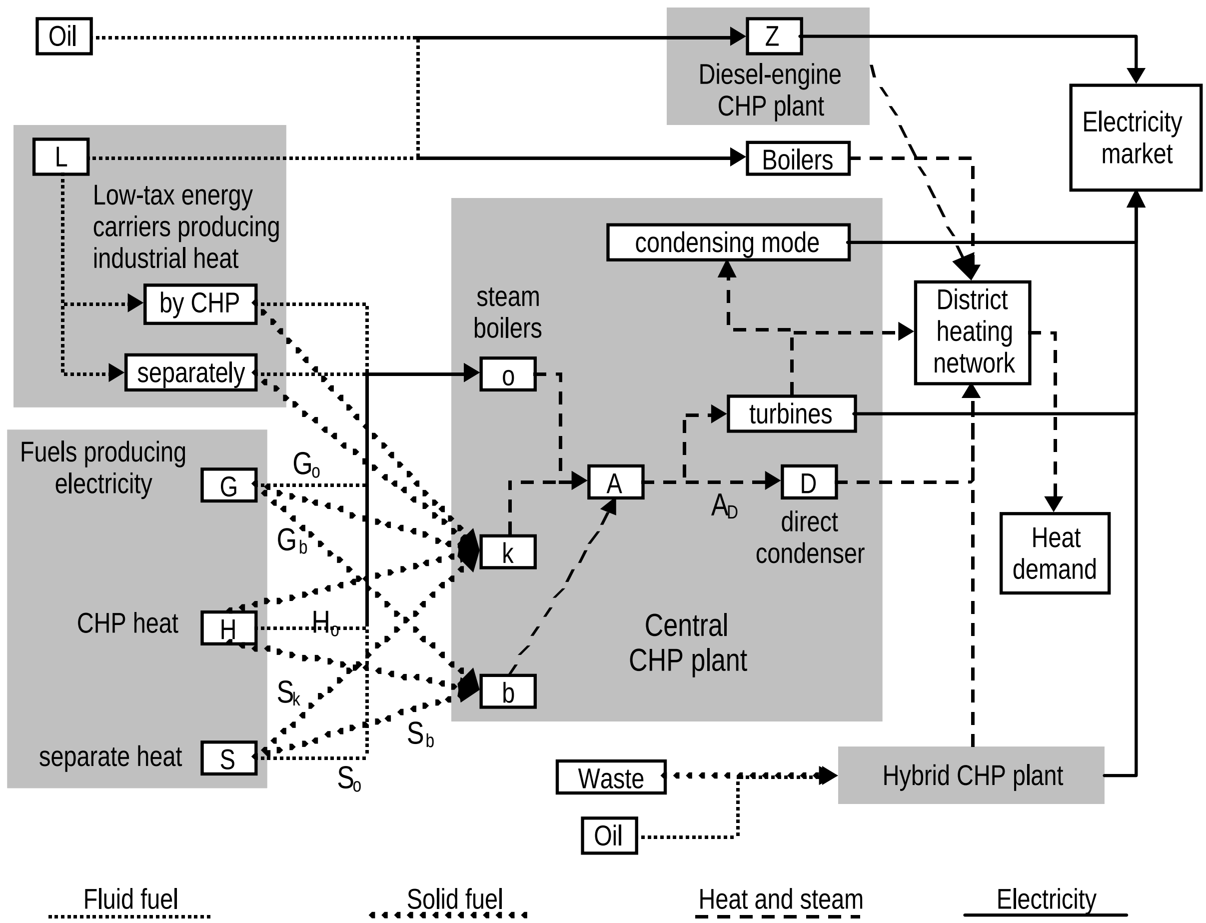

Figure 1. Simplified structure for the MODEST model of the district-heating system in Linköping (cf. Henning et al 2006)

Swedish taxation of fossil fuels that produced district heating hampered cogeneration of heat and electricity during many years. To promote CHP production, fuels that produced heat in CHP plants had half energy tax (but full CO_2 tax) during 1994-2003. However, fuels producing the wasted heat in condensing plants have none of these taxes.

In an old study of the Linköping utility (Henning 1994), fuel that produced heat even had the same taxes for CHP plants and heat-only boilers, which was intended then. The optimisations showed that an investment in a new CHP plant would be profitable. Its fuel supply should be fossil for electricity generation and renewable for heat production to avoid all energy and CO_2 taxes. But if *all* fuel was taxed according to emissions, only wood-fuelled CHP production should expand.

The central CHP plant in Linköping has variable power-to-heat output ratio because heat and, partly, electricity can be produced separately (Fig. 1). The plant also has three boilers (o, k, b) and several fuels. Fuel that produces electricity, separate heat and CHP heat, respectively, is represented individually for each fuel in the model. The fuels that produce separate heat (S_o, S_k, S_b in Fig. 1 for oil, coal, biofuel) are related to the heat (A_D) through a user-defined equation that includes boiler efficiencies (Henning et al 2006):

$$\eta_o \bullet S_o + \eta_k \bullet S_k + \eta_b \bullet S_b - A_D = 0 \qquad \text{Eq. 1}$$

There is one such equation for every time period in the model and there are corresponding equations for CHP heat and electricity. In the latter relation, heat that is wasted by condensing-mode operation is included.

Besides waste, which yields revenues, wood is preferred for heat production, whereas coal is used in the first place for electricity generation due to taxation in 2003. Some oil and coal with low tax produce industrial heat (Henning et al 2006).

In 2004, Swedish fuel taxes were changed. Fuels that produce heat in a CHP plant now have the same taxes as fuel that produce industrial heat, that is, no energy tax and low CO_2 tax (one-fourth in 2004). In addition, each fuel in a CHP plant must be allocated to electricity and heat production, respectively, in the same proportions as the total plant output, which called for additional model constraints. For each fuel in the central CHP plant in Linköping, the relation between fuel generating CHP electricity (e.g. G_o in Fig. 1) and fuel producing CHP heat (e.g. H_o) must be equal to the power-to-heat output ratio (α) for the plant in cogeneration mode (Nilsson and Nilsson 2003). As an example, for oil (in each time period):

$$G_o - \alpha \bullet H_o = 0 \qquad \text{Eq. 2}$$

Holmgren and Henning (2004) used the new taxation scheme and proved the profitability of a new waste-fired CHP plant in Linköping. Nilsson and Nilsson (2003) found that a wood-fired CHP plant should be built in the future, unless natural gas is cheap and electricity revenues high. Higher fossil-fuel taxes make investment in a larger wood-fired plant profitable.

More than 10% of the Swedish district heating come from waste incineration. Therefore, DH systems are influenced by policy instruments concerning waste management, mainly the introduction of a landfill tax in 2000 (now 47 €/ton) and a ban on landfill of combustible waste from 2002 and from 2005 also of organic waste. This has made it more profitable to use waste as a fuel in DH systems (e.g. Holmgren and Bartlett 2004, Holmgren and Gebremedhin 2004). A tax on incinerated waste is proposed for July 1st 2006 (Ministry of Finance 2006). The fossil part of the waste will be taxed as fossil fuel according to a template. By CHP production, the tax is lower by higher electrical efficiency. This means a tax between 9-47 €/ton waste, the latter for heat-only plants.

Holmgren and Gebremedhin (2004) analysed taxes on incinerated waste of 11 and 42 €/ton, which were suggested earlier but are in the proximity of the levels now proposed for plants with CHP and heat-only production, respectively. At the tax 11 €/ton, it was found profitable for the municipal utility under study to invest in a waste incineration plant with heat only production, but not at the level 42 €/ton. A prerequisite for the result is that the utility cannot raise the gate fee for receiving waste. The results indicate, however, that at the higher tax level, other treatment options may be of interest. Figure 2 shows the fuel use in the DH system in different scenarios. The extra cost for the utility in the *waste tax 11* scenario is € 540 000 a year, compared to the reference scenario without waste incineration tax.

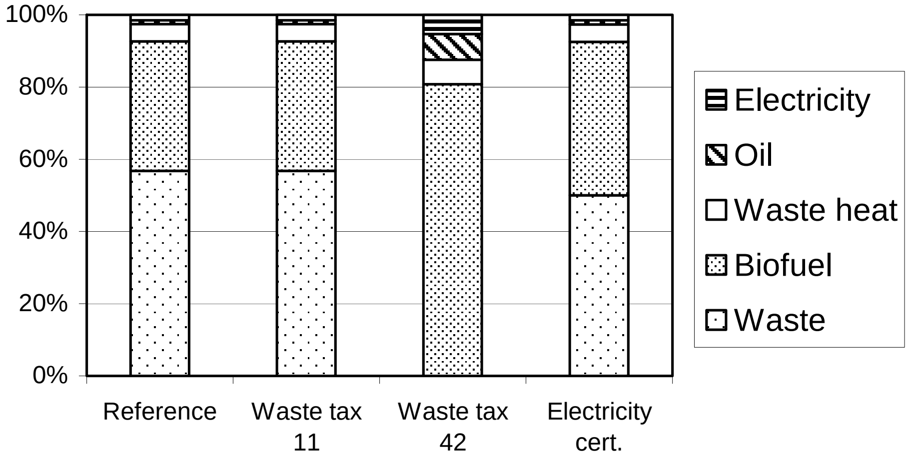

Figure 2. Energy carriers used for heat production in the DH system of Skövde in four scenarios, total demand 280 GWh/year (Holmgren and Gebremedhin 2004).

3 Electricity certificates

In several countries, there are guaranteed feed-in tariffs (e.g. in Germany) or tradable green certificates for electricity from renewable sources to increase their share of power generation. With feed-in tariffs, power producers obtain a fixed price or a fixed bonus for all renewable electricity (Ringel 2006). In Sweden, green electricity certificates were introduced in 2003 (Holmgren and Gebremedhin 2004). Plant owners receive certificates when producing electricity in approved conversion units, primarily plants fuelled with biomass, peat, biogas or sorted demolition wood waste, as well as solar cells, wind power and new or small hydropower plants. Consumers need a quota of certificates in relation to their electricity consumption, creating a demand for certificates and, thus, giving them an economic value. The aim is to increase annual renewable electricity production by 10 TWh from 2003 to 2010, when the system ends. It is now proposed to extend it to 2030.

Henning and Sjödin (2002) represented the revenue from certificates sales through a lowering of the cost for wood that produced electricity (G_b in Fig. 1). They found that the certificates, primarily, would change fuel accounting for the central CHP plant in Linköping but not real fuel use. However, they did not foresee the *proportioning* of fuels introduced in 2004 (Sect. 2). Henning et al (2006) also considered certificates in their Linköping study.

If all sold electricity becomes certificates, the estimated revenue can be added to the expected market price for electricity sales in a MODEST model. This was assumed for one scenario in the Skövde study on a new waste-fired plant (Holmgren and Gebremedhin 2004). It was found profitable to invest in electricity production in the waste incineration plant only if it would receive certificates. In the scenario with electricity certificates in Figure 2, less waste is used for heat production because some waste is used for electricity generation. The utility's earnings from electricity certificates would be 230 000 €/year, assuming a revenue from certificate sales of € 10 per MWh of electricity produced from municipal waste. However, municipal waste is not included in the certificate system, but it has been discussed to include it. Swedish electricity prices have increased since the study was made. Now, it may be profitable to invest in electricity generation even without the certificates.

4 Emission allowances

Emission allowance trading of carbon dioxide was introduced in the European Union in 2005 as a means to reduce greenhouse gas (GHG) emissions because, in connection with the Kyoto protocol, EU is committed to decrease GHG emissions by 8% from 1990 to 2008-2012. Allowances are allocated to energy, mineral, metal, pulp and paper companies in proportion to historical emissions but differently in various countries (in Sweden 1998-2001 average). This *grandfathering* may give old plants with high emissions an advantage over newer, more efficient plants. New Swedish plants are allocated allowances according to the average emissions from existing plants. Energy utilities are granted allowances corresponding to 80% of their needs (Holmgren 2006).

Costs for emission allowances were included in fuel prices in a study of the DH system of Göteborg (Holmgren 2006). Future electricity prices influenced by emission allowances were calculated. The investment opportunity for a natural-gas-fired CHP plant was calculated to € 150 million during a ten-year period. The investment seems beneficial with the assumed electricity prices though fuel costs are increased by emission allowances. For the utility's decision to invest in the CHP plant, the lower taxes on fossil CHP production since 2004 (Sect. 2) were essential.

In a study commissioned by *The Office of Regional Planning and Urban Transportation* and the district-heating company *Fortum Värme*, a model that describes the DH systems of Stockholm based on 2004 figures was built by using MODEST (Levinson and Freiman 2005). The purpose of the modelling was twofold: a) to increase the knowledge about the market conditions for DH in the region, b) to analyse the impact of interconnecting DH grids (or enhancing capacity of existing connections) together with optional new CHP production. Many scenarios were developed to assess the influence of variations for some key parameters on the choice of new plants. One of these parameters was the price for emission allowances.

The annual local CO_2 emissions due to district-heating and electricity production in Stockholm would be 50 % higher if the allowance price was only 30% of the current level. This implies that the impact of CO_2 emission allowances, as a means to reduce GHG emissions, is highly dependent on allowance price. New and enhanced connections between DH grids would lower local CO_2 emissions. Another aspect of low-price emission allowances is that the investment potential for a new biofuel-fired CHP plant will be lower compared to the case with high-price allowances.

5 District heating demand as heat-sink resource

District-heating systems enable utilisation of heat resources that otherwise would be of limited use, such as industrial surplus heat and heat from waste incineration and CHP plants. The value of the DH system depends on, for example, when and where heat demand appears. Most DH systems are situated in cold climate and have outdoor-temperature dependent heat demand. This results in uneven heat production and, possibly, electricity generation in CHP plants. To increase the value of the heat sink resource, heat demand that is independent of climate variations or has a profile with inverted climate dependence (e.g. absorption cooling) can be beneficial.

In Örnsköldsvik, industrial steam demand can be supplied by the district heating utility, which is reflected in a MODEST model (Danestig and Henning 2004). The steam demand fluctuates less than the DH demand. The calculations showed that if the steam can be supplied by a new CHP-plant, the plant can also produce 90% of the district heating. Without steam supply, the corresponding figure is 70% and electricity generation is reduced to one-third of the first case.

Several heat resources in the same district heating system may cause *competition* about the heat-sink resource. The ban on waste landfill increases Swedish waste incineration, which may reduce industrial waste heat utilisation and CHP plant profitability but waste can be a beneficial complement in some systems. If waste incineration was introduced in Örnsköldsvik, model results show that electricity production would be reduced due to competition about the DH supply. Figure 3 shows how district heating can be produced with a waste-fired boiler and a CHP plant, which also supplies industrial stem. The *staircase* curve is the DH demand duration curve and step width represents time period length. Because waste fuel has a negative cost, it produces the cheapest heat and is used during the whole year. The biofuel and wood-powder boilers are used throughout the winter but electric and oil-fired boilers only during some cold days. Without waste incineration, the CHP plant would also cover the demand that the waste covers in Figure 3.

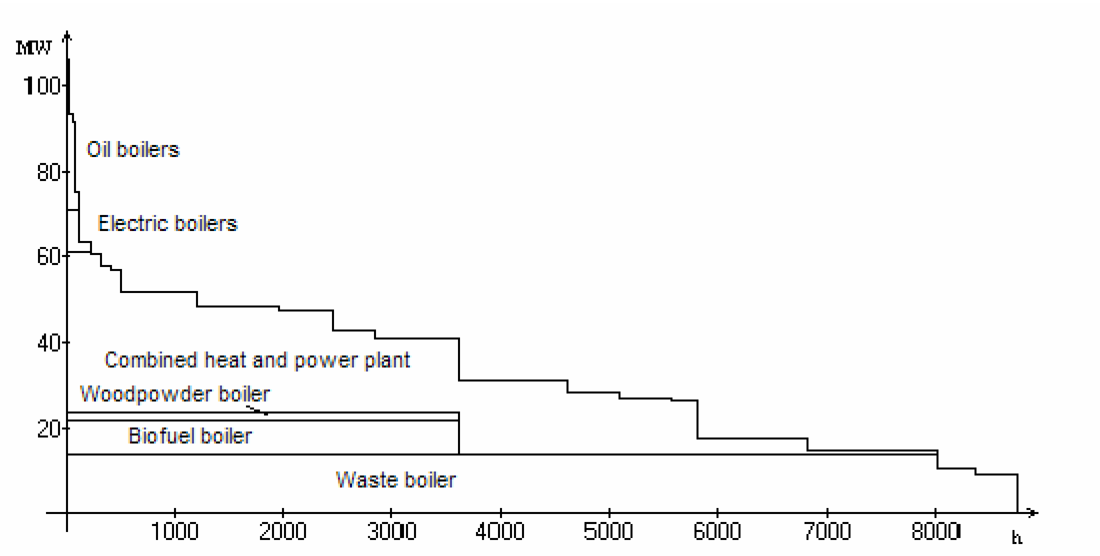

Figure 3. Possible DH supply in Örnsköldsvik during a year (Henning et al 2004)

A study of Linköping also showed that increased waste incineration decreases electricity production because it reduces the heat sink for CHP plants (Holmgren and Bartlett 2004). An overall study of waste fuel in the Swedish DH systems concluded that a decrease in electricity production would occur due to greater waste incineration capacity (Sahlin et al 2004). But conditions vary among district-heating systems. The DH system in Göteborg uses various kinds of waste heat: from industries, waste incineration and CHP plants (Holmgren 2006). The study showed that this large system can serve as heat sink for all these waste heat sources. The new natural-gas-fired CHP plant (Sect. 4) reduces heat production mainly in hot-water boilers and heat pumps but less for industrial waste heat and an existing natural-gas-fired CHP plant.

But a small district-heating system may become larger to host more available heat resources. Sahlin et al (2004) showed that increased waste incineration facilitates expansion of DH networks due to the low heat cost. A district heating system can expand through connections to new customers and other DH networks. Increased electricity and oil prices, due to e.g. emission allowances, make switching to district heating more attractive. Connection of detached houses may be beneficial despite low heat demand density. In Örnsköldsvik, the main DH system is planned to expand from 206 to 285 GWh/year through new customers and interconnection of a small local heating network, which is included in the calculations (Fig. 3, Henning et al 2004).

6 Concluding discussion

Ideally, policy instruments should reflect the external environmental costs that are caused by the combustion of a fuel. External costs have been added to fuel prices in the MODEST model of the Linköping utility (Fig. 1). Henning and Carlson (2002) omitted the NO_x fee and CO_2 and sulphur taxes, but included the energy tax because it was considered to primarily have a fiscal purpose, whereas the other aim at environmental control. External costs may also increase the cost of supplied electricity and the revenue from sold electricity in a model to reflect interaction with coal-fired condensing plants. From a local viewpoint, fossil fuel use should be reduced but with a wider perspective, CHP electricity should displace foreign coal (cf. Henning et al 2006).

Policy instruments should make individuals and companies chose solutions that are most favourable for the whole society. The interplay among instruments is important. Previous Swedish CHP taxation favoured fossil fuels for electricity generation but biofuels for heat production. Now, fossil fuel taxes for cogeneration are lower, but biofuel-fired CHP plants are promoted by green certificates. However, Swedish CO_2 taxes may be reduced for emitters who are included in the emission trading system.

CO_2 emission allowances can play a vital role to reduce GHG emissions. Current allowance-price level can accomplish a significant reduction of local CO_2 emissions due to district-heating and electricity production but the impact may be highly dependent on allowance price. A previous study showed that a natural-gas-fired CHP plant seems like a beneficial investment in one DH system when considering emission trading because electricity-market integration and emission allowances increase electricity prices. Other studies showed that a waste incineration tax may make it less profitable to invest in waste incineration, which, like industrial waste heat, can be beneficial in some DH systems but can obstruct electricity production in other.

District-heating expansion is likely to be favoured by taxes and emission allowances that make individual heating with fossil fuel and electricity, respectively, more expensive. Adding heat demand that does not have the common outdoor-temperature dependence may be promoted by green certificates because it can enhance electricity production in biofuel-fired CHP plants. Policy instruments may have a decisive influence on energy use but fluctuations of energy-carrier prices, such as the recent oil price increase, can have an even larger impact.

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