# The Carbon Tax in Sweden

## Fact sheet

*for:*

**Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)**

On behalf of:

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European Climate Initiative EUKI

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This study is based on a policy paper with an overview of greenhouse gas emission reductions and policy instruments in non-ETS sectors across Europe (hereafter referred to as 'Policy Paper'). The Policy Paper can be downloaded from the EUKI website.

## ABBREVIATIONS

| | |
|---|---|
| EEG | Erneuerbare Energien Gesetz |
| ESD | Effort Sharing Decision |
| ESR | Effort Sharing Regulation |
| ETS | Emissions Trading System |
| EU | European Union |
| EUR | Euro |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| IEA | International Energy Agency |
| kWh | Kilowatt hour |
| MJ | Megajoule |
| $MtCO_2e$ | million tonnes carbon dioxide equivalent |
| MWh | Megawatt hour |
| OECD | Organisation for Economic Cooperation and Development |
| PJ | Petajoule |
| SEK | Swedish krona |
| TWh | Terawatt hour |
| USD | United States Dollar |
| VAT | Value added tax |

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# 1 SUMMARY


Sweden's carbon tax has been the dominant instrument of Swedish climate policy since 1991, taxing energy emissions in transport, buildings (heating), industry, and agriculture. As one of the oldest and strongest carbon price signals with the largest sector coverage in the world (currently at about EUR 120/ tonnes $CO_2$ equivalent), the tax warrants detailed examination to understand how transferring the instrument could help Germany achieve its climate targets.

To better understand the role the tax played in reducing emissions as well as the role a similar tax could play in Germany, it is vital to understand the sector contexts in which the tax operates. Thus, after a brief introduction of the national context as well as a description of its origin and functioning, we provide a detailed assessment of the tax across the sectors it operates in.

We find that the tax has had strong effects for those sectors where consumers and producers have been exposed to the full tax rate. In the residential and commercial buildings sector, where energy emissions are related primarily to heating, Sweden has undergone a fundamental transformation over the past 30 years. Apart from the rise of district heating — itself not a result of the carbon tax — fuel for district heating as well as distributed heating has been essentially decarbonised over this period, with the rise of biomass as the main contributor of this decarbonisation to no small part driven by the carbon tax.[1] We also find strong evidence that the Swedish carbon tax has reduced Swedish road transport emissions by about 10%, a significant feat given the difficulty of decarbonising transport.

As emissions-intensive industries first enjoyed significant exemptions and lowered tax rates and now are under the EU ETS and exempt from the tax, the Swedish carbon tax has never imposed very high carbon prices on emission-intensive industrial sectors[2]. Despite that, we find evidence that the carbon tax has contributed to decreasing energy emissions in industry and, in particular, has made a strong impact in reducing emission intensity.

While technology and fuel choices would likely be different in the German context, there is no fundamental reason to expect that a similarly high carbon tax would not also lead to very significant emission reductions in the German context. Indeed, the Swedish carbon tax experience reaffirms the lesson from other contexts that high carbon prices are highly effective and efficient instruments to drive emission reductions (Abrell et al. forthcoming, Barazini et al. 2017, Martin et al. 2014, Murray & Rivers 2015).

Overall, the Swedish carbon tax has been a highly effective instrument in reducing emissions. As the introduction of the carbon tax was accompanied by reductions of the energy tax, and further increases were often compensated by other tax reductions, the Swedish carbon tax remained politically feasible despite the high carbon price imposed on consumers and non-electric energy providers.


[1] For simplicity, we speak of decarbonisation in the case of biomass. Of course, biofuels do emit carbon, but — in line with Swedish, European Union and IPCC accounting — we take the lifecycle perspective as default in considering biofuels, i.e. considering them as carbon-neutral.

[2] While the reduced rates were only introduced in 1993, i.e. two years after the initial introduction of the tax, the level of the carbon tax was not high initially.

# 2 NATIONAL CONTEXT

## 2.1. National climate policy

Sweden has been a pioneer in international environmental policy and was one of the first signatories and ratifiers of the Kyoto Protocol at the turn of the millennium. The current red-green government under Prime Minister Stefan Löfven has committed Sweden to becoming greenhouse gas (GHG) neutral by 2045, five years earlier than under the previous target. Sweden already has the lowest emission intensity (emissions per unit of gross domestic product (GDP)) and the second lowest GHG emissions per capita in the European Union (EU). Sweden's 2020 target of 49% renewable energy was already exceeded in 2013 (EUR-Lex 2015). In 2016, 57% of electricity came from renewable energy sources, especially hydropower (40%), although wind power has achieved significant growth in the last ten years (SCB, 2017a). Nuclear power plants contributed another 41% to electricity generation (IEA, 2017b). Taken together, this means that electrifying energy use, e.g. with heat pumps for heating or electric cars for transport, is a highly effective strategy in the Swedish context.

For the 2018 budget, SEK 5 billion (EUR 485 million) is earmarked for environmental and climate action measures, more than twice as much as in 2014 (Government Offices of Sweden, 2017). Sweden's climate policy covers measures in all sectors. The national $CO_2$ tax was introduced as early as 1991 and is by far the strongest $CO_2$ price signal in the world (World Bank, 2017). The Swedish carbon tax currently covers all energy-related carbon emissions that are not under the EU Emissions Trading System (ETS). In addition, Sweden introduced a $CO_2$ tax on aviation on 1 April 2018, which increases ticket prices by SEK 80–430 (EUR 8–42) depending on distance and is supported by more than half of the population (The Local, 2018).

Sweden's Effort Sharing Decision (ESD) target for 2020 is to lower emission levels 17% below 2005 and is only exceeded by Denmark, Ireland and Luxembourg. This is all the more impressive given the already low emission intensity in Sweden. With the Effort Sharing Regulation (ESR), Sweden and Luxembourg have the most ambitious targets in the European Union for 2030. By then, GHG emissions in the non-ETS sectors are to be reduced by 40% compared to 2005.
According to forecasts (Swedish Environmental Protection Agency, 2017), Sweden will exceed its 2020 ESD target and achieve a decline of 30% instead of 17% between 2005 and 2015, indicating an emission reduction rate close to twice the ESD target.

In the following, we will examine the role the Swedish carbon tax has played in this impressive success.

## 2.2. Sector context

Figure 1 shows $CO_2$ emissions associated with energy use for six economic sectors: agriculture and fishing, electricity, industry, off-road transport, residential and commercial (buildings), and road transport. It is important to note that these are energy-related emissions, i.e. they do not include process emissions from industry nor most agricultural emissions from fertilisers or ruminant animals or emissions from waste. The numbers and shares are thus not equivalent to total Swedish emissions, but rather describe the situation for fuels for which the carbon tax — as a tax levied on energy — is or could be applied.

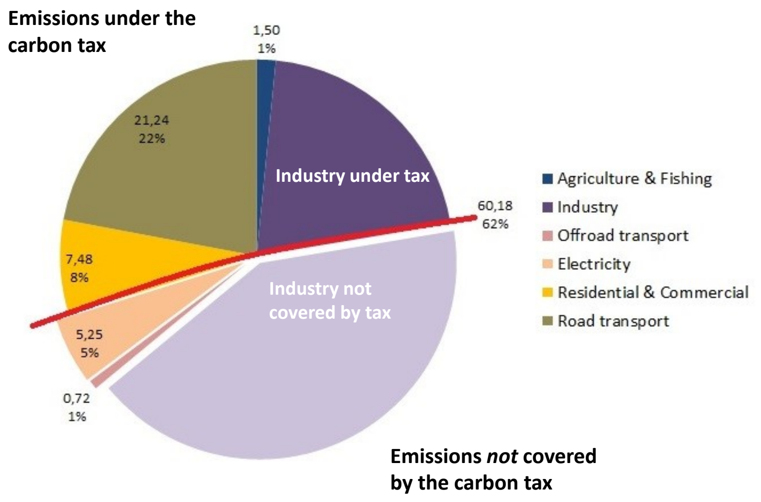


**Figure 1: $CO_2$ emissions by sector in million t and in % (2016) (based on OECD, 2016; own representation)**

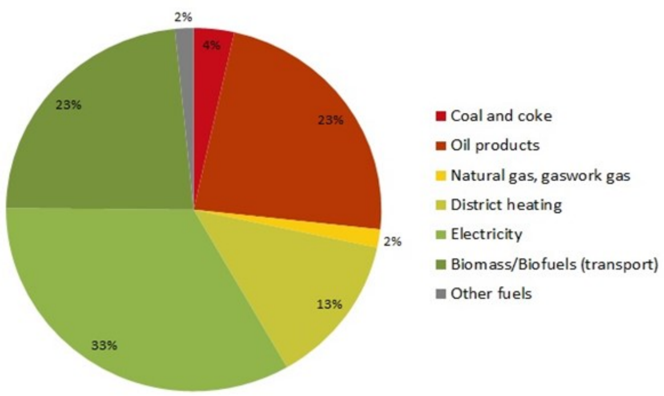


**Figure 2: Total final energy use, 2016 (Swedish Energy Agency, 2018)**

The industrial sector is the biggest contributor to Sweden's energy-related emissions (62%). Of these emissions, approximately one-third is covered by the tax, whereas two-thirds fall under the EU ETS. Besides, emissions from the electricity sector are covered exclusively by the EU ETS whereas off-road and international transport are not covered by carbon prices.

Figure 2 shows the total final energy use, which comes from industry, transport, and the residential and services sector, differentiating between different energy sources. As this chart illustrates, Swedish energy supply is comparatively very low-carbon with about 75% of final energy use coming from zero- or very low-carbon sources[3]. Thus, even though few countries consume more energy per capita than Sweden, Swedish GHG emissions are lower than those of most other European countries (4.25 tonnes

[3] As Werner (2017, p. 425) documents, district heating is, by now, very low-carbon with an emission intensity below 10 $gCO_2e/MJ$ heat delivered. This is similarly true for electricity, with a lifecycle carbon intensity of 24 $gCO_2e/kWh$ in gross electricity production, the EU-28 average being 387 $gCO_2e/kWh$ (Moro and Lonza, 2017).

of $CO_2e$ ($tCO_2e$) per year per capita compared to the EU average of 6.91 $tCO_2e$). This can to a large proportion be traced back to the high share of low-carbon electricity (nuclear, hydropower, and wind; together over 90%) as well as a high share of district heating (Sweden.se, 2018) and biofuels in heating and transport.

# 3 GENERAL DESCRIPTION OF THE POLICY INSTRUMENT

## 3.1. History

Sweden has a long history of energy taxes on fuels, initially primarily for fiscal purposes. The oil crises in the 1970s and rising fear of energy shortages contributed to raising the energy tax. Amid rising environmental concerns, the central government introduced a carbon tax in 1991 (Raab, 2017, pp. 2), one of the first $CO_2$ taxes within Europe (Brännlund et al., 2014; p. 845; Bohlin, 1998; p. 285). The introduction of the carbon tax was part of a major tax reform of 1990/1991 that affected all sectors and also introduced a tax on sulphur (1991) and nitrogen oxide (1992) as well as a value added tax (VAT) on energy (Raab, 2017; p. 4; Brännlund et al., 2014; p. 845; Ekins & Speck, 1999; p. 376). Labour taxes were reduced and simplified, and the energy tax — the tax levied by energy rather than carbon content — was halved.

The tax rate for $CO_2$ was originally set at 250 SEK (EUR 27) per metric tonne and was applied equally among sectors (Sumner et al., 2009; p. 11). Until 1992, industrial companies were not exempt from taxation but were subject to the same tax rates for energy and carbon content. When in 1993 energy and $CO_2$ taxes increased, the manufacturing sector was exempted from the energy tax and was taxed at 25% of the $CO_2$ tax, which was raised to 50% of the $CO_2$ tax in 1997 (Brännlund et al., 2014; p. 845; Andersen & Ekins, 2009; p. 44). These exemptions were applied to energy-intensive industries (Lin & Li, 2011; p. 5140). Additional refunds were available for industries with high tax bills until 2007 (Brännlund et al., 2014; p. 846; Andersen & Ekins, 2009; p. 45).

A ‘Green Tax Shift’ took place between 2001 and 2006, when environmental taxes were substantially raised while cutting income taxes in order to relieve the tax burden on low-income households (Raab, 2017; p. 4). In the period following 2007, environmental taxes were again gradually increased.

Even though the general carbon tax levels (in EUR per $tCO_2$) rose from just over EUR 25 to EUR 120 between 1991 and 2017, the effective $CO_2$ tax level for industry stayed well below EUR 40 until 2014 (Raab, 2017; p. 7). A steep increase in tax levels for industry has been paving the way towards closing the gap between differing tax rates in 2018.

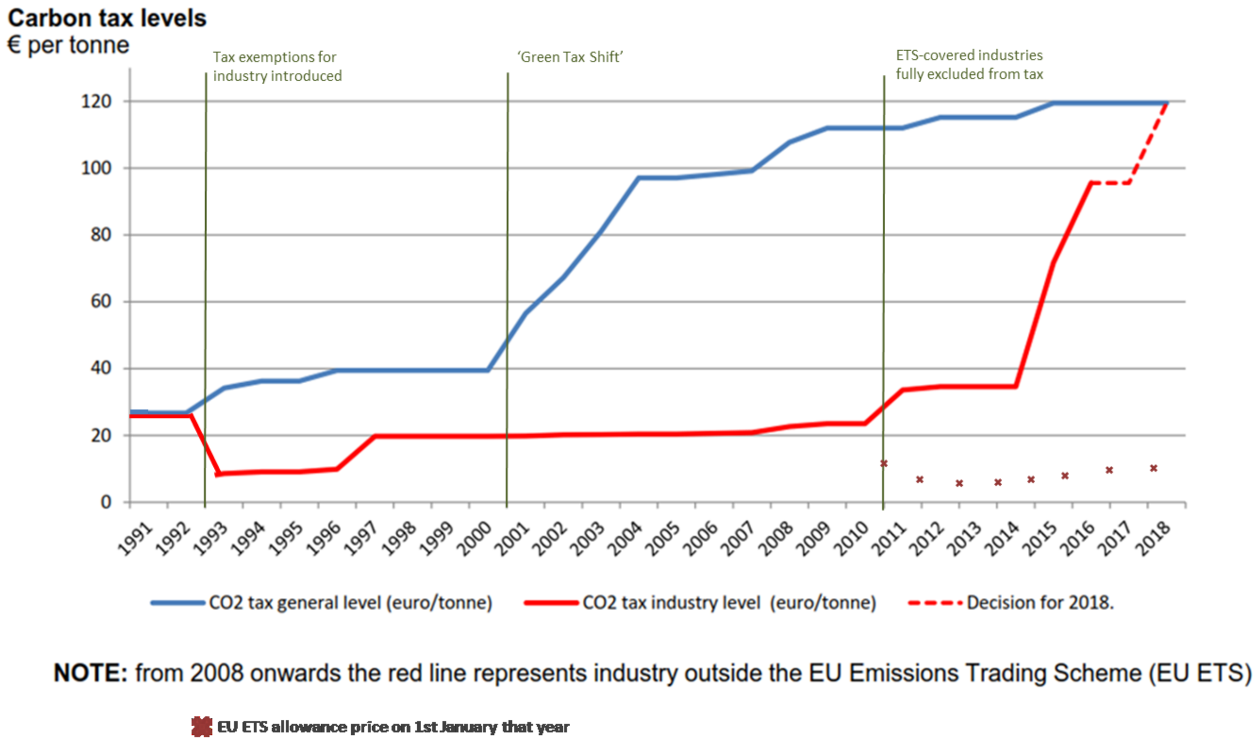


**Figure 3: Carbon tax levels in EUR/t 1991–2018 (based on Raab, 2017; p. 7); adjusted and extended with own research**

## 3.2. Legal basis

The legal basis is provided by the Energy Tax Act (SFS 1994, 1776). The $CO_2$ tax applies to the same fossil fuels taxed under the energy tax, at rates varying in proportion to the respective carbon content (OECD, 2018a; p. 6). The tax rate, the tax base and reliefs are set by the central government. It is collected by the National Tax Authority.

## 3.3. Functioning

The Swedish carbon tax is *an* energy tax, meaning it is applied to fossil fuels that are combusted to generate energy. Importantly, the Swedish carbon tax does not cover fossil fuels combusted for electricity generation; however, these are very limited in the Swedish context where most electricity generation is decarbonised. It complements and is levied with *the* energy tax that is levied based on energy rather than carbon content. Like the energy tax, the carbon tax does not tax most biofuels. It is collected in the same way as the energy tax, which, apart from the ease of upstream collection, keeps administrative costs low (0.1% of revenues generated by carbon and energy tax; Åkerfeldt, 2011; p. 12). The revenue generated through the tax goes towards the government's general budget, representing between 0.5 and 1% of the Swedish GDP between 2000 and 2015.

All sectors that produce energy-related emissions outside the electricity sector are covered by the tax. This hence includes agriculture and fishing, industry, residential and commercial, and road transport. A large share of industrial facilities has first been exempt from paying the tax or the full tax rate and was later excluded due to their participation in the EU ETS.

Since the launch of the EU ETS in 2005, the carbon tax has been gradually phased out for entities participating in the EU ETS (Brännlund et al., 2014; p. 846). Swedish ETS installations thus face a much lower carbon price (EU ETS allowances currently trade around EUR 20) than the EUR 120/t$CO_2$ tax rate otherwise applicable in Sweden.

### 3.4. Interlinkages with other policy instruments

There are several other taxes levied on fuels: the energy tax, the VAT on energy, and potentially other environmental taxes (e.g., sulphur and nitrogen oxide taxes). Thus, for many decisions related to energy use, consumers and producers are exposed to the carbon price signal as one of several price signals, a point that will become elaborated upon in the discussion of effects on road transport.

The carbon tax is particularly closely linked to the energy tax, which provides the basis for the carbon tax's collection and, consequently, also affects its scope (e.g. by excluding biofuels). Apart from this administrative interlinkage, there is an important political interlinkage: It is very likely that the coupling of reducing the energy tax with introducing the carbon and other environmental taxes made the overall package more politically palatable. Indeed, increases in the carbon tax have often been accompanied by reductions in the energy tax thereby reducing the increase in overall tax burden for energy but increasing the carbon price signal component. It is thus fair to say that the energy tax, originally levied for fiscal purposes and then to incentivise energy efficiency after the oil price shocks, has strongly facilitated the establishment of a strong carbon price signal.

# 4 IMPACTS OF THE POLICY INSTRUMENT

### 4.1. Effectiveness

Analysing the effectiveness of the Swedish carbon tax, we need to differentiate between its impact on different sectors, reflecting the fact that the effective carbon tax rates are differentiated by sector and that abatement potentials and costs vary strongly.
In principle, the carbon tax can be effective through three levers: (i) It incentivises lower production/consumption of carbon-intensive goods and services; (ii) it incentivises a reduction in energy intensity whenever energy has a carbon footprint; and (iii) it incentivises a reduction in the carbon intensity of energy. In other words, it affects all three terms that define the energy-related sectoral emissions:

**Formula 1: Decomposing emissions**

$$(a)\ \mathit{Energy\ emissions\ in\ sector}\ X = (b)\mathit{Output\ level\ in\ sector}\ X \times (c)\mathit{Energy\ intensity\ in\ sector}\ X \times (d)\mathit{Carbon\ intensity\ of\ energy\ in\ sector}\ X$$

As we have seen above, there are three sectors for which a major impact is likely to have been observed: commercial and residential buildings (heating), road transport, and those parts of industry not covered under the EU ETS[4]. We discuss these sectors in turn, focusing on whether the carbon tax

[4] There could also be effects on the energy-related emissions in agriculture. For the sake of brevity and because it is less relevant in terms of energy emissions that are covered by the tax, we do not discuss this sector here.

 

was the likely driver of observed reductions in emission levels (a), outputs/consumption (b), energy intensity (c) or carbon intensity of energy (d), see Formula 1.

### *4.1.1 Effectiveness in the building sector (heating)*

Looking at the buildings sector in Sweden, there are six observable main trends that have shaped developments since about 1990. Overall, emissions have decreased, driven by some reduction in energy use (trend 1, see Table 1) and strong reductions in energy intensity (trends 2 and 3) as well as a significant reduction in the carbon intensity of energy (trends 4, 5, 6). Importantly, while district heating has now largely transitioned under the EU ETS (Ericsson & Werner 2016), its decarbonisation had been largely achieved before.

In Table 1 below, we **bold** those trends that are plausibly affected or even primarily driven by the carbon tax. The sequencing within columns reflects an ordering by significance for emission reductions, with a more detailed discussion of attribution to the carbon tax and significance below. For those trends where we believe the carbon tax has played no role, we provide a brief discussion for our reasoning in Appendix 1.

 

**Table 1: Trends in emissions and energy/carbon intensity — buildings sector (data from: Lin & Li, 2011; Werner, 2017; extended by own research)**

| **Energy emissions in buildings** (Heat) | **Production / Consumption Level** (output) | **Emission intensity** (GHG per output) | |
|---|---|---|---|
| | | **Energy intensity** (Energy per output) | **Carbon intensity of energy** (Carbon per energy) |
| **Strong reduction** (over 80% reduction since introduction of carbon tax for residential emissions, also strong reduction in emissions in district heating) | **1. Decrease in household energy use by 2.1 %** (per capita, 1990–2008) | 2. Increase in district heating (from about 30% to over 50%).<br><br>**3. Changing composition of electricity-based heating** (from resistance heaters to heat pumps; low effect on emissions given that electrical energy efficiency is not very relevant in Sweden due to low-carbon electricity supply). | **4. Phase-out of fuel oil** (from about 25% to less than 5%)<br><br>**5. Decarbonisation of district heating through biofuels**<br><br>**6. Slight increase in electricity-based heating** (from about 30% to about 35%) |

### *Trend 1: Effects on energy use of households*

While households only reduced energy use by 2%, this was likely strongly affected by the carbon price signal especially given that other energy taxes were reduced. The fact that residential energy emissions decreased by 80% while demand only decreased by 2 percentage points to strong reductions in emission intensity through the effects on carbon intensity of energy.

### *Trend 4: Phase-out of fuel oil*

Fuel oil has been essentially phased out since the introduction of the Swedish carbon tax, replaced — in terms of net percentage shares — to about 75% by district heating and to about 25% by a rise of electric heating, in particular heat pumps. This is likely due to a combination of the increasing availability of district heating as well as, through the carbon tax's price increase for fuel oil, more favourable economics for electricity-based distributed heating.

### *Trend 5: Effect on fuel switching to biomass in district heating*

There is strong evidence that the Swedish carbon tax has driven a significant transformation of the district heating sector by increasing the share of biofuels. Between 1990 and 1995 alone, i.e. the first years of the carbon tax, the energy from biofuels for district heating doubled from 36.7 PJ to 73.  PJ (Bohlin, 1998; p. 287). Bohlin finds a resulting estimated emission reduction effect of 0.5–1.5 million t (Mt)$CO_2$/year (Bohlin, 1998; p. 288).

The carbon tax has surely not driven these changes alone, so we need to assess its contribution. Bohlin (1998; p. 290) concludes that the carbon tax made wood fuels more competitive than fossil fuels for district heating and that, directly before the introduction of the tax, the lower oil prices of the 1980s had exerted a dampening effect on the biofuel industry. However, he also argues that subsidies to reduce the fixed cost of the fuel switch, subsidising furnace switches, were equally necessary to allow for the transformation.

*Trend 6: Slight increase in the share of electricity-based heating*

Electricity-based heating has increased by one-sixth, from about 30% to about 35%, between 1991 and 2014, with much of the strong gain in heat pumps (from 0% to over 20%) 'eaten up' by a corresponding decline in conventional electric heating. Thus, while the carbon tax has likely contributed to this change — electricity as the input of these heating technologies is exempt whereas fossil carbon alternatives face the full carbon tax — the overall decarbonisation effect of this shift is thus far limited: The increase in electricity-based heating corresponds to about 25% of the decline in fuel oil as the primarily displaced carbon-intensive fuel in distributed heating.

### *4.1.2 Effectiveness in the road transport sector*

In Swedish road transport, emissions in 2005 were back to 1990 levels and have decreased since. Table 2 below summarises central trends in our framework. Both fuel intensity (energy intensity; trend 2) and carbon intensity declined, the latter through an increased use of diesel and a decline of petrol as well as biofuels and, lately, electric cars (trends 3–6). In Sweden, transport fuel is taxed by three different taxes – the energy tax levied per energy content, the carbon tax levied by carbon content and a VAT on energy introduced shortly before the carbon tax. By 2005, the carbon tax reached the same level as the VAT at about 80% of the energy tax (Andersson, 2017; p. 7)[5]. Those taxes are passed on to consumers (Andersson, 2017, pp. 8–9), thus giving strong incentives to drive less, buy more efficient cars, and switch to lower-carbon fuels. Given that these taxes are strongly correlated, it is difficult to clearly attribute observed effects to the carbon tax. For example, biofuels are exempt from the energy tax and the carbon tax.

**Table 2: Trends in emissions and energy/carbon intensity — transport sector (data from Kahn, n.d.; Myhr, 2018; Andersson, 2017)**

| **Energy-related emissions in the transport sector** | **Production / Consumption Level** (output) | **Emission intensity** (GHG per output) | |
|---|---|---|---|
| | | **Energy intensity** (Energy per output) | **Carbon intensity of energy** (Carbon per energy) |
| Increase in 2007, **decline since** | 1. Increase in road transport kilometres | **2. Increased fuel efficiency in cars** | **3. Increased demand for diesel** |
| | | | **4. Decreased demand for petrol** |
| | | | **5. Increased use of biofuels in transport** |
| | | | **6. Increased electrification of transport** |

[5] Importantly, the declining differential between the energy and the carbon tax is driven both by an increase of the carbon tax and a decline of the energy tax, increasing the carbon price signal within the overall fuel tax regime.

For the period 1990 to 2005, Andersson (2017) finds that the carbon tax reduced transport emissions by about 6.3% per year. Importantly, towards the end of this period, with the increasing carbon tax, the carbon tax is estimated to cause an almost 10% reduction in transport emissions (9.4%).

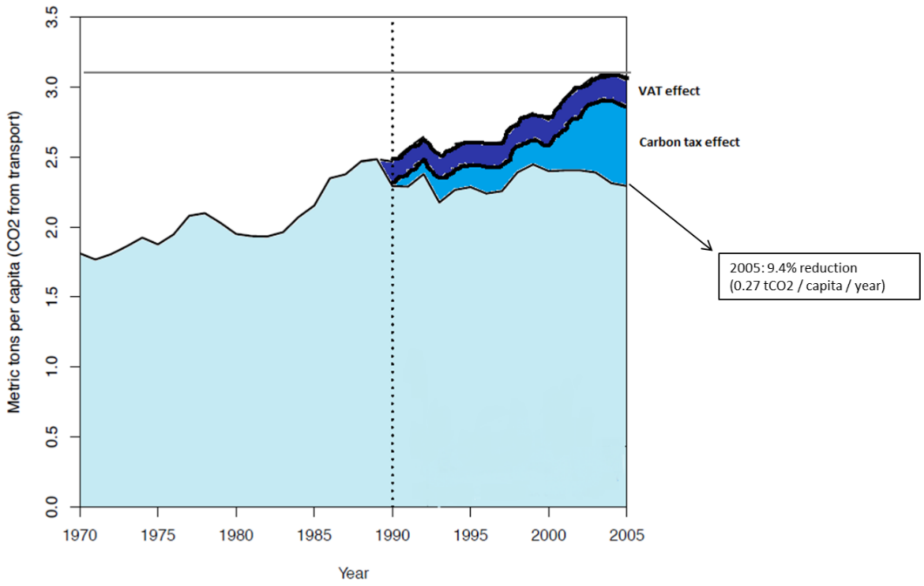


**Figure 4: Effects of VAT and carbon tax on emissions (adapted from figure 11 in Andersson, 2017; p. 29)**

While we do not have conclusive evidence on this given the studied period ends in 2005, the further increases in the carbon tax since 2005 have likely further strengthened the effect of the carbon tax on transport emissions.

Even if the effect had remained constant, an almost 10% reduction compared to a scenario without carbon tax is quite significant given the difficulty of decarbonising road transport and the increasing trend of road transport emissions in Germany (Umweltbundesamt, 2017) and many other advanced economies.

In terms of how these emission reductions were achieved, a reduced demand for gasoline and increasing demand for diesel (Andersson, 2017; p. 29), more efficient cars as well as a transition to biofuels and, lately, electric cars, have all played a role (Scharin and Wallström, 2018). Given that there are already three different taxes that interact and affect fuel prices, apart from additional policies, we are unable to clearly identify the specific effect of the carbon tax on all the different trends affecting the carbon intensity of the fuel mix (trends 3–6, see Table 2). However, it is important to stress that for moving towards greater fuel efficiency (trend 2) all three taxes — energy, carbon and VAT — act in the same way likely making the carbon tax's relative contribution lower. By the same token, the carbon tax's relative effect is likely stronger for the move towards lower-carbon fuels.

### *4.1.3 Effectiveness in the industrial sector*

Between 1990 and 2004, the most useful comparison period as the launch of the EU ETS in 2005 reduced the share of industry covered by the Swedish carbon tax, energy-related industrial emissions decreased by 10%[6] (Brännlund et al., 2014; p. 845) despite a production increase of 35% in the same period. This decoupling was driven to a small degree by a structural change towards lighter industry, but primarily by decreases in energy intensity as well as decrease in the carbon intensity of energy (Martínez & Silveira, 2013) that together led to a strong decrease in emission intensity (Brännlund et al., 2014). While attribution to policy instruments becomes more challenging with the introduction of the EU ETS and a step-wise shift of some industrial activity from the tax to the ETS, we show at the end of this section that the central trend of reducing industrial combustion emissions continues up to the present.

**Table 3: Trends in emissions and energy/carbon intensity — industrial sector (data from Martínez & Silveira, 2013; Brännlund et al., 2014)**

| **Energy-related emissions in industry** | **Production / Consumption Level** (output) | **Emission intensity** (GHG per output) | |
|---|---|---|---|
| | | **Energy intensity** (Energy per output) | **Carbon intensity of energy** (Carbon per energy) |
| **Reduction of energy-related emissions in industry** (10% between 1990 and 2004) | 1.Production increased strongly<br>**2. Shift in relative shares towards lighter industry (ancillary)** | **3. Decrease in energy intensity of industry** | **4. Decrease in carbon intensity of energy** (increased use of electricity in industry as well as cleaner fossil fuels and some biofuels) |

For most of these trends leading to lower overall emissions, the carbon tax is a likely main or ancillary driver as described in the following sub-sections.

### *Trend 2: Shift to less emission-intensive industries*

While both traditionally emission-intensive as well as lighter (less emission-intensive) industries have been growing in Sweden, lighter industry has been growing much faster. This structural change has been found to have some impact on reducing overall emission intensity of the sector (Martínez & Silveira, 2013). While the carbon tax, when covering all of industry, could have contributed to this by making investments into less emission-intensive industry relatively more attractive, we do not have conclusive evidence on this. In any case, emission-intensive industries now face a significantly lower carbon price than lighter industry due to the former being included in the EU ETS and the latter facing a carbon tax that is an order of magnitude higher. Hence, these incentives are now reversed.

### *Trend 3: Decrease in energy intensity*

For the decline in energy intensity, the Swedish carbon tax is found to have had an effect, albeit the energy tax has been relatively more important (Martínez & Silveira, 2013; p. 127). This is not surprising given that the carbon tax only incentivises a move towards lower-carbon energy, but not less energy

[6] As pointed out by Lin & Li (2011), the Swedish carbon tax did not lead to an absolute emission reduction in the Swedish industrial sector. Indeed, emissions increased by 13.3% sector-wide and by 27% for iron and steel between 1990 and 2008 (Lin & Li, 2011, p. 5143). However, these are total industrial emissions, which also reflect process emissions that are not under the carbon tax. In addition, the timeframe until 2008 is less meaningful to assess the effects of the Swedish carbon tax given that some industrial activity was already moved (or was expected to move shortly after) to the EU ETS.

 

consumption per se. With electricity rising as an input compared to fossil fuels, the relative carbon price signal per unit of energy input decreased. In other words, the carbon tax's success in reducing carbon intensity of energy (see below) also reduces its impact on reducing energy intensity.

#### *Trend 4: Decrease in carbon intensity of energy*

Primarily through a greater reliance on low-carbon electricity as well as a switch to cleaner fossil fuels[7], the carbon intensity of energy has significantly decreased since the introduction of the carbon tax (Martínez & Silveira, 2013; p. 124). While this has also been driven by changing fossil fuel prices and other non-policy influences, the carbon tax is found to be the strongest policy influence (Martínez & Silveira 2013; p. 127).

### *Trends in industrial combustion emissions since the introduction of the EU ETS*

In Figure 5 below, we have graphed the emissions trajectory of combustion emissions from all industrial subsectors between 1990 (one year before the carbon tax) and 2014 (the last year for which complete data are available). Apart from subsectors we also report the total as well as the total of all sectors except iron and steel (iron and steel is by far the dominant sector). Vertical red lines indicate various important changes — the introduction of the carbon tax (1991), the introduction of lowered rates for industry (1993), the beginning of the 'Green Tax Shift' (2001), the introduction of the EU ETS (2005) and the completion of the transition of large industrial facilities under the EU ETS (2011).

Unfortunately, given that the move into the EU ETS was step-wise and given that falling under the EU ETS rather than the tax is also dependent on size thresholds, we cannot cleanly identify the degree to which sectors are under the carbon tax or ETS, respectively. It is for this reason that our analysis of effects in industry focused primarily on the 1991/1993–2004 period for which inference is possible (this issue is also discussed in Brännlund et al., 2014).

Over the entire period (1991-2014), total industrial emissions have decreased by 13%, with a 24% reduction in industrial combustion emissions outside iron and steel, whereas emissions of iron and steel have increased by about 10%. Interestingly, there is a clear absolute emissions reduction trend starting about 2001 which is driven by the sectors outside iron and steel. In this period, total emissions dropped almost 24%, driven by a 27% reduction outside iron and steel and a reduction of about 18% in iron and steel production. While, as discussed above, it is difficult to link those trends towards specific policy instruments (given ETS and tax scope cannot be clearly identified), this pattern is consistent with stronger reductions in less emission-intensive industries exposed to higher carbon price levels. It is furthermore noticeable that a clear absolute emissions reduction trajectory has been maintained ever since total industrial combustion emissions peaked in 2001.

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[7] Importantly, at least for the period from 1993 (the start of the lowered industry rates) to 2005 (the start of the EU ETS), the share of biofuels even decreased (Martínez & Silveira, 2013, p. 124). In other words, unlike for the case of buildings, the switch to biofuels is not the main story of energy decarbonisation in industrial processes.

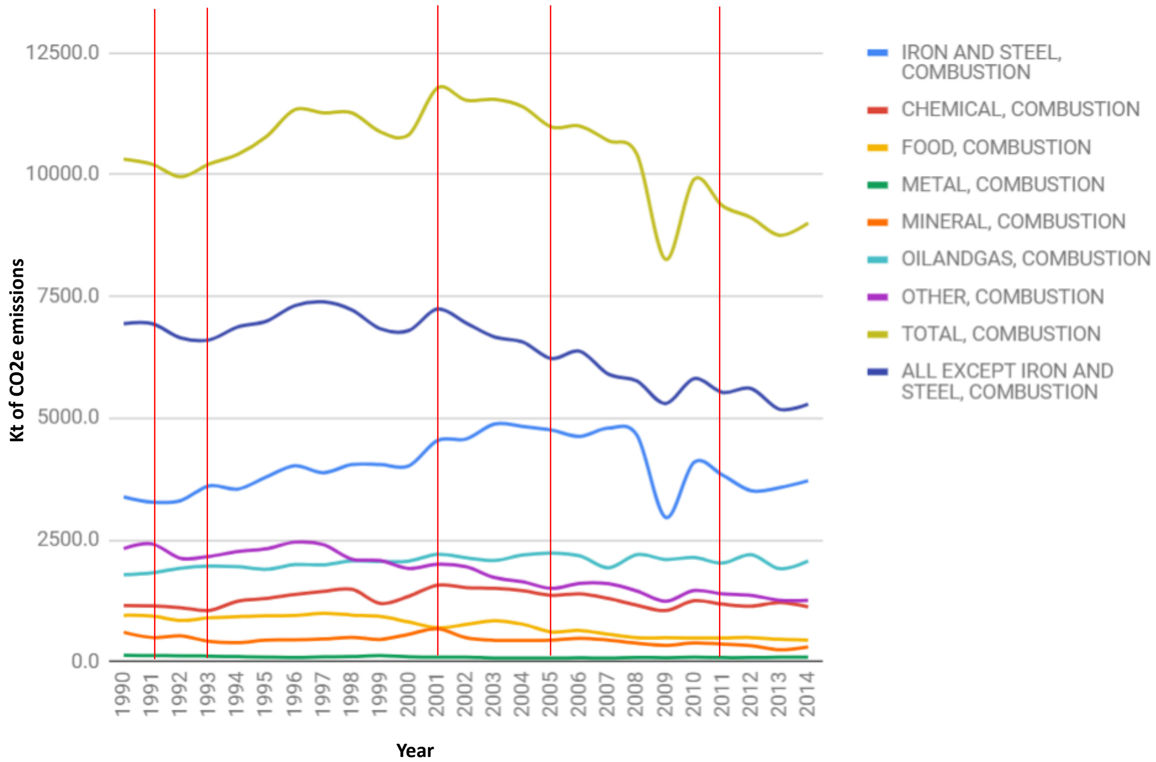


**Figure 5: Combustion emissions in industrial subsectors (own presentation, with data from Swedish Environmental Protection Agency, 2018)**

## 4.2. Cost efficiency

In principle, wide-ranging uniform carbon taxes are thought to be among the most cost-efficient tools for domestic mitigation: driving abatement up to the carbon tax level wherever possible[8]. In this section we start from this assertion of cost efficiency and discuss whether and how particularities of the instrument are likely to affect the cost efficiency.

As all carbon pricing instruments to date, the Swedish carbon tax does not fulfil this ideal case, but (a) covers a limited set of sectors and (b) has, historically, imposed heterogeneous price signals. More recently, (c) the full separation between EU ETS and Swedish carbon tax[9] and the subsequent increase of the carbon tax level has led to a strong discontinuity in carbon prices for the industrial sector based on emission levels[10]. This will be elaborated in the following.

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[8] The underlying reasoning is that when all economic activity is exposed to the same carbon price signal then all abatement options that are cost effective at the carbon price level will be implemented (and no less and no more) achieving the maximum mitigation possible under that price level. It gets more complicated when considering the long run where investments and technological innovation respond to carbon prices in which case the optimal cost efficiency of a uniform economy-wide carbon price is less likely to be the case (see e.g. Vogt-Schilb & Hallegate, 2014).

[9] Firms are only covered under one of the two instruments, also see the above section on functioning.

[10] This can lead to ‘perverse incentives’: for installations that are close to the emission level to be included in the EU ETS inclusion, increasing emissions can be highly attractive.

(a) The tax is limited in its coverage in several ways: (i) it only covers combustion emissions (excluding process, agricultural, waste, and fugitive emissions) and excludes off-road transport; (ii) it excludes the electricity sector; and (iii) it excludes facilities under the EU ETS.

Emissions under (i) are mostly for activities that are found particularly difficult to decarbonise[11], making it likely that their exclusion does not forego significant abatement opportunities in the near term but rather that it primarily causes foregone revenue[12]. In the early stages of developing decarbonisation technologies for these sectors, innovation support is likely more important than carbon pricing (Acemoglu et al., 2016), although their inclusion under carbon pricing would likely enhance cost efficiency over time (dynamic cost efficiency). (ii) The exclusion of the electricity sector is likely fairly inconsequential given that Swedish electricity is essentially decarbonised.

If those assertions are correct, then — from a pure Swedish ESD sector perspective — the Swedish carbon tax is likely fairly close to being fully cost-efficient in the short term. Cost efficiency is significantly harder to assess for the long term where differential carbon prices can be optimal given that abatement potential is limited across sectors and that some sectors have much longer investment horizons than others (Vogt-Schilb & Hallegate, 2014)[13]. However, given that the carbon tax is not the only climate policy instrument and that other instruments — such as investment subsidies — also impose implicit carbon prices for specific sectors, a uniform carbon tax rate could still be optimal for dynamic cost efficiency if factors such as differential abatement potentials and turnover rates are accounted for by other policies[14].

Whether the historically present differential tax rates across sectors led to inefficiency depends on assumptions about carbon leakage; the displacement of production to a less stringent locale; combined with increased imports that could neutralise emission reductions in Sweden or even increase global emissions[15]. The carbon tax for the manufacturing sector was lowered due to such carbon leakage and competitiveness concerns, and the carbon price faced was still higher than in almost all other jurisdictions. Thus, it could be the case that the Swedish carbon tax was still very cost-efficient since the lowered rates were indeed necessary to avoid carbon leakage. The assessment of these different rates for cost efficiency hence depends on the (1) degree to which those exemptions were indeed necessary to avoid carbon leakage, and (2) whether one ultimately cares about global emissions or the achievement of Swedish or EU targets.

With emission-intensive industry now under the EU ETS rather than exposed to lower carbon tax rates, this issue does not affect the ESD sector anymore. It is rather the delineation between ESD and ETS sectors affecting national or European cost efficiency, but this is beyond the scope of this study.

[11] The exemption here being waste, however when used energetically it also falls under the tax or the EU ETS; it is only not covered when waste is landfilled.

[12] In other words, if the carbon tax was levied on those sectors, the assumption would be that paying the carbon tax would usually be cheaper than abatement.

[13] For example, it could be dynamically cost-efficient to have higher carbon prices for industrial facilities that are built in 60-year cycles than for road transport where turnover rates are significantly shorter and, hence, decarbonisation without massive premature retirements of capital stock can happen faster.

[14] One could also argue that it makes little sense to evaluate the carbon tax's cost efficiency in the dynamic case as long as other policies exist. In this case there is no need for the carbon tax to consider effects that go beyond short-term incentive structures.

[15] Even if there was only a partial replacement of Swedish production by imports, this could still plausibly lead to a global emission increase given the low emission intensity of Swedish industry. For a jurisdiction with a similar energy profile, Québec, we are aware of unpublished studies suggesting that for commodities such as aluminium the carbon intensity varies by a factor of eight between Québec and China. The effects can thus be quite significant.

### 4.3. Co-benefits and side effects

To assess the main co-benefits and side effects, it is important to recall the most significant effects of the carbon tax. We do this below and identify major co-benefits (+) as well as negative side effects (-):

- **Reduction in carbon intensity of energy in buildings and transport through biomass/biofuels** (see 4.1.1 and 4.1.2 above): Unfortunately, this decarbonisation strategy does not carry the positive co-benefits that other transitions to low-carbon energy bring. In particular, health impacts from air pollution are comparable to fossil fuels (-) and a high carbon price can even incentivise transitions that are negative for public health, e.g. from natural gas to solid biomass (-). Apart from that, there are significant sustainability and climate concerns with regard to biomass (-). On the positive side, given abundant forest and a lack of fossil resources, a greater reliance on biomass does increase Swedish energy independence (+).
- **Reduction in carbon intensity of energy in industry, transport and heating through electrification** (see 4.1.1 to 4.1.3 above): While there are concerns with hydroelectricity and nuclear power as well (-), relying on a greater role for electricity in the energy mix not only decarbonises the affected sectors, but also leads to very significant health benefits through avoided air pollution (+). In addition, wind turbines have made primarily caused capacity additions in Sweden over the last couple of years, suggesting that additional electricity demand does not necessarily lead to more hydroelectricity or nuclear power (IVA, 2016). Apart from these health benefits, increased reliance on electricity increases energy independence (+).
- **Reduction in energy intensity in transport and industry** (see 4.1.2 and 4.1.3 above): Reductions in energy intensity through greater energy efficiency share the benefits of carbon intensity reduction strategies (+)[16]. In addition, they present additional benefits in the form of long-term cost savings through reduced energy costs (+). Even in the case of electricity, which is extremely low-carbon, greater electrical energy efficiency can support decarbonisation by increasing electricity available for further electrification.
- **Increased costs for non-electric energy:** In those cases where the carbon tax makes a cheap form of fossil energy uncompetitive, energy costs increase, at least in the short term (-). For example, Andersen (2010; pp. 6–7) estimated the overall effect of the carbon and energy tax reform to be positive for GDP (+). The only negative effect in the long term, according to Andersen (2010; p. 8), lies in the cost increase for energy-intensive industries (-), estimated at the time to reach up to 4% of gross operating surplus.
- **Revenue generation and the 'double dividend' of reducing distortionary taxes:** Apart from the general revenue generating potential that lowered the burden on the government's budget (+), the revenues from $CO_2$ taxes can be used to reduce distortionary taxes (+). Since its implementation, the generated revenue has been put towards reducing income or labour taxes. There is even the possibility that the carbon tax creates net economic benefit by allowing the reduction of taxes that create distortions, such as labour taxes that disincentivise work. This effect is known as the strong form of the 'double dividend hypothesis' (Goulder, 1995). While it is unclear whether this holds in the Swedish case, it appears that the carbon tax has not imposed net negative impacts on the Swedish economy (Andersen, 2010; p. 7).

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[16] This holds as long as the marginal energy saved is high in carbon intensity. This is plausible in the Swedish context where the amount of low-carbon energy is more 'naturally' constrained than high-carbon energy. For example, an extraordinarily cold winter will lead to additional imported fossil fuels being burned rather than creating an increase in available sustainable biomass. Likewise, a peak in electricity demand will be satisfied with imported electricity that is higher carbon than Swedish electricity generation.

 

In summary, it is fair to say that the Swedish carbon tax's positive environmental and public health impacts are dampened by its effect on increasing bioenergy (negative from a public health and possibly broader environmental perspective), with greater use of electricity and — even more so — reduced energy intensity preferable in terms of co-benefits. Given the Swedish import dependence for fossil fuels, the carbon tax strongly increases energy independence.
It is important to point out that most of the co-benefits and side effects depend on the Swedish context and are not necessarily transferable to Germany, but depend on technological, economic and legal conditions[17]. For example, an expansion of bioenergy to the degree in Sweden would likely be unfeasible in Germany, limiting the negative impacts. Conversely, a stronger reliance on electricity would not convey the same co-benefits as in Sweden given the large share of coal generation with significant negative health consequences. We return to this issue in section 0.

## 4.4. Success factors and challenges

In terms of success factors and challenges, it makes sense to differentiate between factors and challenges that have affected the implementation and persistence of the tax (political feasibility) as well as the tax's ability to reduce emissions (effectiveness).

### 4.4.1. Political feasibility

Several factors are frequently cited explaining the political success of the Swedish carbon tax. Its introduction as part of a larger tax reform and in conjunction with reductions of the related energy tax reduced its political salience. As Scharin and Wallström (2018; p. 8) argue, many people are likely not aware of the significance of the carbon tax in the overall tax burden on fuels. In addition, political support for climate and other environmental policy is very high (Raab, 2017; p. 8).

While, as to be expected, there was some resistance from emission-intensive industries, the reduction of the energy tax burden as well as exemptions and lowered rates and, later, the movement of emission-intensive industry under the EU ETS, limited the effective carbon price for these emitters.

Another facilitating factor likely consisted in the ready availability of abatement opportunities. Andersen (2010; p. 7) makes this argument for emission-intensive industry: The early availability of large amounts of low-carbon electricity made energy-intensive industries comparatively less exposed to high carbon prices. As we discussed in 4.1.3, increasing the share of electricity in the energy mix was the major driver of decreasing carbon intensity of energy in industry. Likewise, a similar argument could be made for the transition towards district heating as well as the availability of bioenergy resources in heating and transport.

### *4.4.2. Effectiveness in reducing emissions*

Even a high carbon tax can be ineffective at reducing emissions when abatement opportunities are very expensive. The success in reducing emissions was greatly facilitated by abundant and affordable low-carbon electricity (Anderson, 2010; p. 7; Martínez & Silveira, 2013; p. 117), biomass, as well as the move towards district heating (Bohlin, 1998) presenting a variety of pathways to reduce emissions cost-

[17] Because the carbon tax is a technology-neutral instrument, its effects are fundamentally more contextual than that of an instrument which incentivises, deploys, or mandates a specific technology.

effectively and without the need of major systemic transformation. For heating, this was possible through fuel switching (district) and electrification (distributed), while in road transport blending with biofuels allowed emission reductions largely without new infrastructure. With significant and inelastic demand for heating[18] and transport[19] as well as an export-oriented manufacturing sector, emission reductions through reduced consumption/output have proved challenging.

# 5 TRANSFERABILITY

## 5.1. General comparability of the context

Both Sweden and Germany are highly-developed industrialised economies, with similarly ambitious emission reduction objectives. Importantly, they are also similar in their economic structure and both feature export-oriented industrial sectors. There are, however, significant differences in the energy sector to which the carbon tax applies. They are **bolded** in the comparability column in Table 4. Differences (a)-(c) are those in context that would affect the carbon tax's operation and effectiveness in Germany, an issue we examine in more detail in section 5.3. Differences summarised under (d) are likely at least partially caused by the carbon tax, they can thus be understood as context factors but also as results of the tax. We examine the implications of these differences below.

**Table 4: Key climate policy and energy indicators to assess comparability of the Swedish and German context (sources in footnotes)**

| | Germany | Sweden | Comparability |
|---|---|---|---|
| **General information** | | | |
| GDP per capita (in USD, 2017)[20] | 44,549.69 | 53,248.14 | Comparable |
| Exports (in billion USD, 2016)[21] | 1,322 (32.5% of GDP) | 151.4 (33.9% of GDP) | Comparable |
| **Climate policy ambition** | | | |
| 2020 GHG emission reduction goal (compared to1990 in %) | As close as possible to -40 | -40 | Comparable |
| 2050 GHG emissions reduction goal (compared to 1990) | GHG neutrality (80-95% reduction) | GHG neutrality by 2045 | Comparable |

[18] Even in the face of a very high carbon price, residential energy use only decreased by 2.1% between 1990 and 2014, see section 4.1.1.

[19] Even in the face of a very high carbon price, road transport kilometres increased, see section 4.1.2.

[20] Statista, 2018a and 2018b

[21] Central Intelligence Agency, 2018a and 2018b

| | Germany | Sweden | Comparability |
|---|---|---|---|
| **Relevant features of the energy system** | | | |
| Population density (per sq. Km, 2016)[22]; proxy for biomass potential per capita. | 236 | 24.36 | **(a) Not comparable**, biomass expansion infeasible in Germany |
| Carbon intensity of electricity supply ($gCO_2e/kWh$), 2013[23] | 485 | 16 | **(b) Not comparable**, electrification is less decarbonising in Germany. |
| Share of district heating (in %)[24] | 13.8 | 51 | **(c) Not comparable**, decarbonising heating in Germany involves a higher share of distributed heating. |
| Share of biofuels in road transport (in %)[25] | 4.8 | 20.8 | **(d) Not comparable**, but can also be result of the carbon tax (endogeneity) |
| Share of electric vehicles in road transport (in %, 2017)[26] | 1.56 | 5.28 | |
| Primary fuel in district heating | Coal, natural gas | Biomass | |
| Primary fuels in distributed heating | Natural gas | Electric, biomass | |

## 5.2. Properties of the instrument

An energy tax reform towards a carbon tax would in principle be possible in Germany. Germany's current energy taxes are levied within the framework of the 2003 EU Energy Tax Directive, which is also serving as a legal basis for Sweden's $CO_2$ tax.

The German energy tax is applied to oil, natural gas, coal and coke products at varying rates depending on the sector (transport, heating, or process purpose). Electricity output is taxed at EUR 20.5 per MWh; reduced rates apply in rail transport. Fuels are untaxed when they generate electricity installations larger than 2 MW. Industrial installations generally receive a 25% tax refund of their total tax liability on diesel, fuel oil, liquefied petroleum and natural gas (OECD, 2018b), and can further claim a refund depending on the amount paid under the electricity tax scheme.

Reforming this according to the Swedish model would consist in reducing the general energy tax on fuels to levy a new tax on fuels based on carbon rather than energy content.

[22] Tradingeconomics, 2018a and 2018b

[23] Moro & Lonza, 2017

[24] Euroheat, 2017

[25] European Biofuels Technology Platform, 2015; Svebio.de, 2018

[26] European Alternative Fuels Observatory, n.d. a and n.d. b

An important consideration that needs to be taken into account when transferring the instrument with an identical design to Germany would be the currently high carbon intensity of German electricity supply. Because fuels for electricity are exempted from the tax, the carbon tax treats electricity as a zero-carbon alternative. When carbon tax levels are significantly higher than EU ETS prices that affect the level of fossil fuels combusted for electricity generation, this would create a strongly misaligned price signal.

Increasing carbon prices in the power sector can correct this misalignment. This could, for example, be achieved by reducing the general electricity output tax and replacing it with a carbon tax on electricity or a price floor for ETS allowances surrendered for power sector emissions as currently advanced by the French government and other EU Member States[27]. Other instruments, such as mandates for renewable electricity, could also achieve the goal of reducing the misalignment by accelerating power sector decarbonisation[28].

In Germany the discussion of carbon tax proposals takes place within the context of the renewable energy surcharge (‘EEG-Umlage’), other energy levies and taxes, as well as the EU ETS. Thus, apart from proposals focused on returning revenues equally to all citizens (‘Bürgerlobby Klimaschutz’) or through income tax reform (Mercator Research Institute on Global Commons and Climate Change), many proposals focus on using a carbon tax as part of a broader energy tax reform to shift the financing of the ‘Energiewende’ (proposals sourced from the overview provided by $CO_2$ Abgabe e.V. (2017, 20-21))[29]. For example, the expert commission for the monitoring process on ‘Energie der Zukunft’ as well as Agora Energiewende both propose using the carbon tax to (partially) replace the renewable energy surcharge, the combined heat and power surcharge (‘KWK Umlage’) as well as other energy taxes.

By aligning levies on energy with their carbon content, it would be possible to have a significantly stronger carbon price signal without increasing overall energy prices for consumers. For example, rather than making electricity more expensive irrespective of its carbon content — as happens with the EEG surcharge levied on electricity consumption — a carbon tax could be designed to make electricity cheaper in *absolute* terms by shifting revenue collection to fossil fuels in ESD sectors. Irrespectively of revenue use, a Swedish-style carbon tax would make electricity *relatively* cheaper through its non-inclusion. This would create a situation where electrification would become more attractive, a useful co-benefit in a situation where electricity decarbonisation is expected to be easier than decarbonising other forms of energy.

## 5.3. Potential impacts

The emission-reducing effect of a carbon tax depends on the availability of abatement opportunities at or below the carbon price level. To get a sense of the potential impact of a similar tax in Germany it is thus important to understand similarities and differences between abatement options across sectors.

A carbon tax in Germany could trigger solutions that have not been of primary importance in Sweden. Indeed, rather than stipulating specific solutions ex ante, discovering new mitigation potentials is one

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[27] A more detailed instrument discussion on this is beyond the scope of this study.

[28] The current target of 65% renewable electricity by 2030 would decrease the share of fossil-fuel based electricity from about 51 % today to 35% in 2030. This would decrease emissions intensity by roughly 30% and, by itself, would not change the picture that Germany’s power mix is comparatively fairly high-carbon. A shift within the fossil share towards cleaner fossil fuels – primarily, natural gas – could lead to additional reductions in emissions intensity.

[29] A third set of proposals is narrowly focused on the power sector or all EU ETS sectors, advocating for a price floor. These proposals are less relevant in the context of this study focused on emission reduction strategies in ESD sectors.

 

of the fundamental strengths of carbon pricing. With that caveat in mind, we discuss the major mitigation pathways in the Swedish context and their applicability to Germany.

- **Decrease in energy intensity:** Higher mitigation effects than in Sweden could be expected as available technologies to increase energy efficiency are comparable but the carbon intensity is much higher in Germany (reduced energy demand leads to more emissions reduction). Thus, at least in the beginning, most non-electric energy provided in Germany would carry a significant carbon price component and incentivise demand reduction and energy efficiency.
- **Reducing carbon intensity of energy through greater use of electricity:** Increase of electricity as input would be equally incentivised but significantly less effective in reducing German emissions given that the carbon intensity of electricity is about thirty times higher than in Sweden. Depending on assumptions about the EU ETS, the effect could nonetheless be as beneficial for European emissions as in Sweden. Thus, the impacts depend on what one considers the relevant reference frame (German ESD sector emissions, German emissions, EU ETS sector emissions) as well as assumptions about the EU ETS (also see the discussion in 0)[30].
- **Reducing carbon intensity of energy through greater use of bioenergy:** Increased use of bioenergy would be equally incentivised in Germany and likely similarly effective in road transport. In buildings, the lower share of district heating could reduce the mitigating impact as fuel switching for distributed heating is costlier and, in addition, requires cost sensitivity of consumers[31]. Of course, with a population density ten times that of Sweden, domestic bioenergy resources are considerably more constrained in Germany than in Sweden. On the demand side, biomass presents an attractive option to provide dispatchable low-carbon electricity, which can be used to balance intermittent renewables – it thus makes use in the power sector rather than in ESD sectors comparatively more attractive. For these two reasons, the degree to which bioenergy resources are available to decarbonise energy in ESD sectors is comparatively more limited than in Sweden.

In summary, starting about 30 years later and with a significantly different energy mix and energy policy priorities, the exact impacts of a Sweden-style carbon tax would likely manifest through different channels in the German context.

Decreases in energy intensity in transport, heating, and industry would be incentivised more than in Sweden given higher carbon intensity, whereas electrification would be equally incentivised but have lesser effects. Technologies that serve important functions for the Energiewende — for example, power-to-gas, heat pumps or other technologies enabling seasonal energy storage and sector coupling — could be larger profiteers from a carbon tax than in Sweden given that their energy system value will push them towards deployment with the carbon pricing strengthening them vis-à-vis fossil alternatives[32].

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[30] When the EU ETS cap is seen as fully fixed in both directions, then the higher carbon intensity of the German electricity supply does not matter because those emissions are under the EU ETS. Our default assumption is that, through the Market Stability Reserve as well political appetite for additional stringency contingent on surplus and price levels of allowances, the EU ETS cap is not fully fixed and reducing emissions under the cap can actually reduce emissions.

[31] The party exposed to the carbon price signal of the heating fuel is not necessarily the party that can decide on the technology used.

[32] The argument here is that the carbon tax does not stand in isolation, but in the wider climate and energy policy context. In Germany, where nuclear power is not desired as part of climate policy, and biomass and hydro potentials are relatively more limited than in Sweden, other technologies and sectors would likely profit from a carbon tax.

### 5.4. Experiences from other European carbon taxes

Lessons on transferability can also be learned from the implementation of carbon taxes in other European countries. After the introduction of the Nordic carbon taxes in the early 1990s, several smaller European countries introduced carbon taxes as well. Several larger European economies followed suit, with the Climate Change Levy (CCL) in the UK in the early 2000s — a combined carbon and energy tax — and, more recently, the French carbon tax[33] introduced in 2014.
We focus here on the French experience with a short paragraph on the UK at the end. The French carbon tax has a comparable sectoral coverage as the Swedish one, covering non-ETS industry, buildings (heating), non-commercial road transport[34] and excluding electricity, aviation and agriculture alongside some smaller exceptions (Deutsch-Französisches Büro für die Energiewende, 2018; p. 6; for smaller exceptions see footnote 22). It covers about 40% of emissions (Deutsch-Französisches Büro für die Energiewende, 2018; p. 4) — slightly less than in Sweden — which makes it the widest-reaching carbon pricing instrument in France (the EU ETS covers only about 20% of French emissions given France's decarbonised electricity sector). As in the Swedish case, the carbon tax is levied on fossil fuels outside the scope of the EU ETS.

At an initial rate of EUR 7 and a current rate of EUR 44.6/t$CO_2$e the tax rate is at about a third of the current Swedish carbon tax but comparable to the Swedish tax in its early years (see Figure 3). With a 2030 target of EUR 100/t$CO_2$e and a current policy momentum towards more ambition than the set-out plan, there is a strong investment signal sent. This is important given that many abatement options involve long-lived investments such as new heating systems or home insulation. Similar to Sweden, electrification in France is a strongly decarbonising option while, comparable to Germany, bioenergy per capita is more limited than in Sweden.

The tax is estimated to have reduced emissions by about 1 Mt$CO_2$e in road transport and 2 Mt$CO_2$e in buildings in 2017, which corresponds to about 0.78% and 1.75% of emissions of annual sector emissions, respectively (abatement data as cited in Deutsch-Französisches Büro für die Energiewende 2018; p. 8; sectoral emissions data from OECD, 2016). As in Sweden, then, emission reductions are estimated to be strongest in the buildings sector (heating). Demand for mobility and heating is fairly inelastic (also see discussions in sections 4.1.1 and 4.1.2). Therefore, it can be expected that most emission reductions are likely to come from changed investment decisions, e.g. buying an electric car or installing heat pumps rather than fossil fuel alternatives. The effect of the policy is thus likely to increase with the duration as more consumers face investment decisions under a carbon tax. For the Swedish case, Andersson (2017; also see Figure 4 of this paper) estimates the mitigation impact of the carbon tax in road transport to have tripled between 2000 and 2005. In this timeframe the carbon tax increased from about EUR 40/t$CO_2$e to about EUR 100/t$CO_2$e, suggesting that significant additional mitigation potential could be unlocked with increasing tax rates[35].

While it is still very early in the policy's development and we could not identify ex-post analyses of the French case, we expect significant mitigation effects. With lower tax rates than in Sweden and lower potentials for bioenergy substituting fossil fuels, the effect could be somewhat smaller. However, quantifying this intuition would require analysis beyond the scope of this paper. Ultimately, apart from

[33] Officially, the Contribution for Climate and Energy (contribution climat-énergie); for simplicity we will refer to it as French carbon tax in the remainder.

[34] Heavy-duty vehicles and taxis can receive reimbursements while agricultural and construction vehicles profit from reduced rates. The carbon tax thus mostly targets private road transport.

[35] Of course, the abatement options in France in 2018 are likely different than in Sweden in the early 2000s, this should be more seen as a stylised argument for an increasing tax rate rather than a precise estimate/prediction on additional effects.

the abatement cost structure, the effect also depends on the policy mix as additional policies, such as the bonus malus system for car purchases, can lead to positive synergies leading to additional abatement[36].

The UK's Climate Change Levy (CCL) has been the subject of rigorous econometric analyses and has been found to have strong *causal* effects. Martin et al. (2014) demonstrate strong emission reduction effects for energy-intensive industrial firms, while Abrell et al. (forthcoming) show that the Carbon Price Support (CPS), the implementation of the CCL in the electricity sector, has been highly effective at contributing to the rapid decarbonisation of the UK power sector.

## 5.5. Conclusion

There is a strong agreement that a broadly applied, robust carbon price signal is one of the most efficient tools to achieve emission reductions in the short term (Abrell et al., forthcoming; Barazini et al., 2017; Martin et al., 2014; Murray & Rivers, 2015) and, crucially, also to facilitate — alongside other policy instruments —deep decarbonisation in the long term (Tvinnereim & Mehling, 2018). While in Germany such a carbon price signal is provided by the EU ETS for the electricity sector and large industrial facilities, about 60% of German emissions are not under a carbon price. Not surprisingly, then, introducing a carbon tax in Germany has gained some attention in the policy debate, often in the context of a broader reform of energy taxes and levies and the Energiewende as well as in the context of the expected gap to the German ESD target for 2020.

It is against this backdrop that examining the carbon tax of Sweden, one of the most successful climate policy pioneers, is of the utmost relevance to discern which role the tax has played in achieving Swedish emission reductions and whether and how this success might be transferred to the German context.

To assess this question, we traced the impact of the Swedish carbon tax across the three main levers in which a carbon price levied on energy can incentivise mitigation, namely (1) output/consumption, (2) energy intensity, and (3) carbon intensity of energy. We examined this across the three ESD sectors with the most significant energy-related emissions, namely buildings (heating), road transport, and small industry[37]. Apart from the detailed points discussed in the preceding sections, there are four broad conclusions that can be drawn from this for a carbon tax proposal in Germany:

First, in all three sectors the main levers in which emissions are reduced are through reductions in energy intensity and carbon intensity of energy ((2) and (3) above). This is good news because policies that can succeed by incentivising cleaner, more efficient, technologies and fuels appear more politically palatable than policies requiring demand/output reductions[38].

Second, while the technological and economic decisions incentivised in Germany would doubtlessly be different than in Sweden, there is no fundamental reason that a similar carbon tax could not also be highly effective in Germany. Even when the energy sources profiting most from the Swedish carbon

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[36] For example, it could be the case that the combination of bonus malus and carbon tax leads to many consumers switching to lower-emission vehicles, while neither of those policies would have much effect on its own.

[37] Of course, the more emission-intensive facilities in industry are now under the EU ETS. However, the evidence for Sweden that we review in the industrial sector also provided evidence for the time in which Swedish industry was completely under the tax.

[38] This is not to say that demand reductions are not an effective and desirable path towards emission reductions but rather that it is a strength, in terms of political robustness and effectiveness, that it is not necessary for the policy to succeed. In other words, a carbon tax in Germany could be successful even if industry covered by it decides (as in Sweden) to increase production levels and, as in Sweden, demand for heating and mobility does not significantly decrease or even increase.

tax, i.e. biomass, hydroelectricity, and nuclear power, are unfeasible or undesirable in the German context, there are multiple pathways towards emission reductions, and a carbon tax would facilitate all of them. Indeed, because the carbon tax does not exist in a vacuum but, inter alia, alongside technology-specific deployment policies and legal requirements, it would enable desired technologies in the context of the Energiewende while, at the same time, strengthening cost efficiency.

Third, and related, not taxing fossil fuels combusted for electricity as is the case under the Swedish tax, could be problematic in the German context when the carbon tax is high compared to other instruments affecting choices between electric and non-electric energy as it would mask the carbon intensity of electricity. However, there is also an argument for that exclusion with the electricity sector being under the EU ETS. Thus, coverage of the electricity sector and the resulting interactions with the EU ETS would need to be carefully considered.

Fourth, with regard to political feasibility and implementation, it is important to note that the favourable option of introducing a carbon tax as part of a (energy) tax reform is also available in Germany. Indeed, discussions around restructuring Energiewende financing through a carbon tax open a window for this debate. As in Sweden, a carbon tax could first be introduced at a moderate level, with increases becoming politically easier as decarbonisation progresses.

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# 7 APPENDIX

## Appendix 1: Trends in buildings not likely driven by the carbon tax

### *Transitioning to district heating*

Bohlin (1998, p. 289) also hypothesises that the carbon tax might have contributed towards amplifying a move towards district heating by affecting investment decisions. This argument stems from the fact that it is more efficient and easier to save emissions when moving to district heating (i.e. the average carbon cost should become lower). However, the evidence for this claim is weak at best. The move towards district heating started well before the carbon tax and the carbon tax has not altered the trajectory of district heating expansion.

While it is possible that expansion would have levelled off in the carbon tax's absence, we find it more plausible to assume that district heating, through its advantage in higher energy efficiency, would have continued to spread also in the absence of the carbon tax. Importantly, the carbon tax has, through the tax swap with reduction of the general energy tax, even reduced incentives for energy efficiency whenever the reduced energy tax is not outweighed by the carbon tax signal (i.e. when the carbon intensity of energy is low, the overall signal to consume less energy, e.g. go to higher efficiency through district heating, is weakened). We thus believe that the carbon tax has not been the primary driver of district heating expansion, even though it has played an important role in the decarbonisation of the district heating supply (see above).

### *Changes in the composition of electricity-based heating technology*

Since electricity is not under the carbon tax, the carbon tax cannot explain the shift from electric heating (resistance heaters) to heat pumps (using electricity to pump the heat). The latter use less electricity per heat output, i.e. are more efficient, but the carbon tax does not reward consuming less electricity. In other words, to the carbon tax there is no difference between resistance heaters that declined in share and heat pumps that increased in share.

The relative shift from resistance heaters to heat pumps is thus likely driven by a combination of increasing electricity prices, the energy tax levied on electricity output (distinct from the carbon tax and not in proportion to carbon content), investment subsidies for heat pumps, and changes in relative technology cost.

In terms of emissions consequences, the shift from resistance heaters to heat pumps can nonetheless be significant by reducing electricity demand in heating (higher efficiency) which allows an easier expansion of electrification through lower cost and less pressure on electricity demand. Nonetheless, this effect is not plausibly driven by the carbon tax.