UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Financial Economics

Is the EU ETS effective?

Examining the impact of the EU ETS on methane emissions

Bachelor Thesis 15hp

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Abstract

The European Union Emission Trading System (EU ETS) is the world's largest trading system for emissions. It has a crucial role to play in meeting the goals of the Paris Agreement. However, there has been debate over its effectiveness. This thesis examines how the EU ETS impacts methane emissions. The study uses Swedish emission data from 2005 to 2021 and employs a fixed effect model with two exogenous and two endogenous variables. While the test produced significant results for carbon dioxide emissions, it could not do so for methane emissions. The thesis concludes that EUA prices have a negative effect on carbon dioxide emissions, while electricity prices have a positive effect. The impact on methane emissions could not be determined. Previous research is divided, suggesting that financial solutions like a cap and trade system can have varying effects depending on the sector and perspective. A new model with interaction variables, more control variables, or a different data set could yield significant results.

Acknowledgement

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1. Introduction

It has not escaped anyone that global warming is a problem. Global warming is characterised by an increase in Earth's average surface temperature caused by human activities, such as burning fossil fuels that emit greenhouse gases into the atmosphere. Global warming poses a significant risk as temperature increases raise the risk of heatwaves, diseases and droughts. Scientists agree that global warming will continue to increase if we do not decrease the emission of greenhouse gases (NASA, 2011). Carbon dioxide is the most common greenhouse gas emitted (Worldbank, 2020a). It is emitted from a wide range of sectors, and there are systems in place to reduce its emissions, such as carbon taxes and the EU ETS. However, other gases, such as the second most emitted gas, methane (Worldbank, 2020b), contribute to global warming without such systems. When comparing the effects of these greenhouse gases, their respective greenhouse warming potential (GWP100) is used. The GWP100 is calculated as the 100-year impact on global warming, where carbon dioxide is set to 1, and one ton of methane equals 25 (Eurostat, 2017).

The Paris Agreement, adopted in 2015, provides clear guidelines based on GWP100 to limit global warming to a maximum of 2°C by 2050 (United Nations, 2023a, n.d). However, a shortcoming of the GWP100 is that it fails to account for the short-lived effects of methane. The effects of methane emissions are greater during the first 20 years, with a warming effect of up to 80 times greater than carbon dioxide (UNEP, 2022). Acknowledging the short-term effect shows that it is crucial to reduce methane emissions to meet the Paris Agreement's requirements. To reduce methane emissions, current procedures must transition into new, more sustainable operations (Formas, 2023). In order to transition into new, more sustainable operations, stakeholders need to be held accountable for their contributions to global warming. Holding stakeholders accountable is usually done through financial systems, such as taxes, or cap and trade systems, such as the EU ETS. However, few systems are put in place to reduce methane emissions. Therefore, it is essential to investigate whether new systems are needed or if carbon-based systems such as the EU ETS are sufficient.

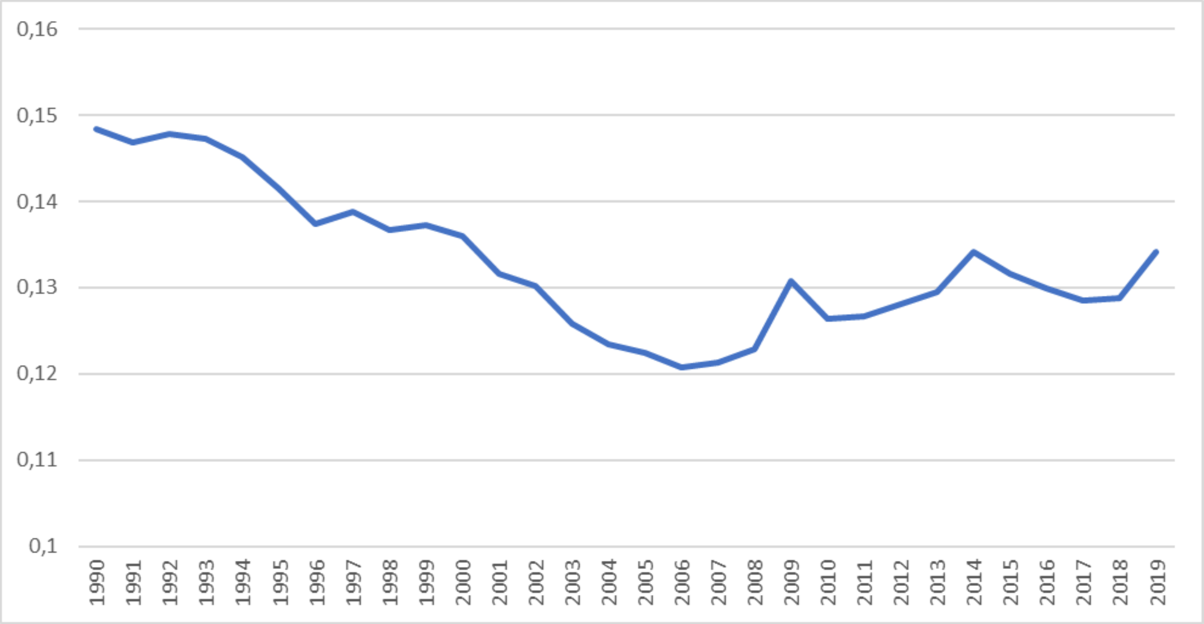
Exploring current financial solutions can help determine if new solutions are needed. A carbon tax is one of the more common financial solutions used. Carbon taxes set a price on carbon dioxide emissions that polluters must pay (World Bank, n.d.).

Another financial solution proposed to combat global warming and reduce greenhouse gas emissions is the European Union Emission Trading System (EU ETS). The EU ETS is a cap-and-trade system where greenhouse gas emissions have a cap that is reduced each year, which should reduce emissions if it has the intended effects. The EU ETS was adopted as a policy instrument to meet the targets of the Kyoto Protocol established in 1997 (European Commission, n.d.a). The idea of the EU ETS is to force reductions in emissions from the energy sector, the manufacturing industry and aircraft operations. It covers around 40% of the EU's total greenhouse gas emissions and sets a cap for mainly carbon dioxide emissions. The emission allowances used in the EU ETS are called European Union Allowances (EUA). Entities participating in the EU ETS must hold enough EUAs to cover their emissions at the end of each year; otherwise, fines are imposed. A company's excess EUAs can be sold to other companies within the EU ETS (European Commission, n.d.b), rewarding companies for reducing their emissions.

There are plans for the EU ETS to include more sectors, such as the shipping industry, by 2024, and other greenhouse gases, such as methane emissions, for the shipping sector in 2026 (European Commission, n.d.c). This will likely be the first cap and trade-based system to reduce methane. There are other types of regulatory policies that strive to reduce methane emissions, but seemingly no financial solutions yet, such as a system like the EU ETS for carbon dioxide or voluntary methane credits allowances. A part of this gap will be addressed by including methane gas in the EU ETS, but other solutions might be needed.

One can look at the quota between carbon dioxide and methane emissions to determine if new systems are needed to reduce methane emissions. The quota will provide insight into whether both gases are being reduced at the same rate, as a change in quota would mean that one of the gases reduces or increases at a different rate. If a carbon dioxide-based system reduces carbon dioxide, then ceteris paribus, the quota between methane and carbon dioxide emissions should increase. If, on the other hand, the quota holds constant, then it could indicate that the system also affects methane emissions. To illustrate this, the quota between methane and carbon dioxide emissions in the European Union (EU) is calculated from the data obtained by the World Bank (2020a, 2020b). The data is presented in CO2 equivalents calculated by the GWP100 between the years 1990 to 2019. In 2019 carbon dioxide accounted for 80.1%, and methane accounted for 10.8% of total greenhouse gas emissions in the EU. Figure 1 shows the quota for methane emissions and carbon dioxide between 1990 to 2019 within the EU.

Figure 1



Notes: The quota between the total amount of methane emissions and carbon dioxide emissions within the EU from the starting year 1990 until 2019

As shown in Figure 1, the quota between methane and carbon dioxide emissions decreased between 1990 to 2005, indicating that the emissions changed at different rates. The trend shifted in 2005, indicating that the reduction rate changed between the gases. This could be because the EU ETS was implemented in 2005, causing reductions in carbon dioxide emissions. Figure 1 indicates that the EU ETS only affects carbon dioxide, but this is a simplification as many factors can affect the emission levels. Thus no conclusion can be drawn. Isolating the effect of the EU ETS will answer if the system affects methane emissions in any way.

1.1 Problem Description and Purpose

As mentioned in the introduction, methane emissions significantly contribute to global warming. Reducing methane emissions is, therefore, crucial to achieving the goals set out in the Paris Agreement. Although there are established solutions for reducing carbon dioxide emissions, such as carbon taxes, the EU ETS and voluntary carbon credits, it is unclear if these solutions affect methane. It is also unclear if methane emissions would reduce if methane was included in the EU ETS, which is interesting to examine since it will be included in the shipping sector by 2026. Previous research has indicated varying impacts regarding how a carbon tax or a methane-based cap and trade system could affect other greenhouse gas emissions.

According to research by Key and Tallard (2011), implementing a carbon tax and a methane-based cap and trade system could reduce methane emissions. However, there exists conflicting research. The backfire effect, by Ravigné and Naudad (2023), demonstrates that natural gas emissions can increase when carbon emissions are reduced. Additionally, Goulder and Schein (2013) have highlighted that introducing another greenhouse gas into a cap and trade system may be ineffective, as pollution may shift to other areas. The ineffectiveness of introducing further regulation also holds for emission policies if a cap and trade system is already in place. Research by Key and Tallard (2011) suggests that a carbon tax and a methane-based cap and trade system could reduce methane emissions. The research by Key and Tallard (2011) contrasts the backfire effect mentioned by Ravigné and Naudad (2023). The backfire effect demonstrates that when a reduction in carbon emissions is made, there could be increases in natural gas emissions (methane). Goulder and Schein (2013) have shown that introducing another greenhouse gas in a cap and trade system may be ineffective, as pollution may increase elsewhere, and that it is also ineffective to introduce regulation when a cap and trade system is already in place. Testing if the EU ETS already affects methane emissions could help determine if there is a rebound, backfire or spillover effect and also give policymakers more information when creating new financial solutions to reduce methane emissions.

1.2 Research question

In order to fulfil the purpose of this thesis, the following research question will have to be answered.

What impact does the price of emission allowances in the EU ETS system have on methane emissions?

To answer the research question, the following hypothesis is tested.

Ho: The EUA price does not have an effect on methane emissions

Ha: The EUA price has an effect on methane emissions.

2. Foundation

2.1 Exogenous price settings

Before further examining how emissions can be reduced through financial solutions, it is essential to explore the underlying theories that these solutions are based on. One crucial concept in reducing emissions through measures like emission taxes or, to some extent, the EU ETS is the concept of exogenous price settings. Exogenous price setting refers to price floors and limits that make producers shift their production levels to a new optimum. Exogenous price settings occur when prices are determined externally to the market by factors such as regulations or policies (Perloff, 2021). Exogenous emission price settings are usually in the form of a limit, where the carbon tax is the most common. The EU ETS uses an exogenic price setting as a cap but could be considered a more nuanced approach due to the market deciding the prices.

2.2 Neoclassical theory

Neoclassical theory is another fundamental theory that financial policies rely on and sheds light on why emissions are not naturally reduced without intervention from external actors. "The Neoclassical model assumes that firms maximise their profits from producing and selling goods and services" (Goodwin et al., 2022). If any financial solution is to be effective, firms need to follow the principles of profit maximising. The assumption also means that firms are cost-effective and strive to find the most efficient way to reduce costs. Since emissions are costly, profit maximising might mean the producers ignore their emissions and let another market participant stand for that cost. For the case of evaluating the result of this thesis, one central assumption that will be utilised is that firms act rationally and are profit-maximising.

2.3 Law of demand

A second classic economic concept that may be used as support for a financial solution is the law of demand. The law of demand states that if all other things are equal, the quantity of a good or service demanded by consumers is affected by price in a linear relationship where demand increases as prices decrease (Hayes, 2022). Suppose a good or service is elastic, meaning its demand changes significantly in response to price changes. In that case, it is likely that the consumption of that good or service will decrease if emission prices increase due to regulatory policies such as carbon taxes (Hayes, 2022). This principle can be applied to any emission, including methane, as Key and Tallard (2011) described for the agriculture sector. Consumption of emission-intensive products will decrease because consumers substitute them for cheaper, less emission-intensive goods or services. Key and Tallard (2011) showed that methane emissions have a price elasticity of 0.02 at a carbon dioxide price of USD 20/tCO2-eq. The positive price elasticity means that methane emissions within the agriculture sector are shown to decrease when the price of carbon dioxide emissions increases. Therefore, the law of demand can explain how price fluctuations affect methane emissions.

2.4 Rebound Effect

Previous research states three effects that describe how solutions affect emissions. The rebound effect is a concept where environmental improvements may increase consumption. Increased reductions within consumption areas, such as electricity consumption, lower the usage cost, leading to increased electricity consumption (Umweltbundesamt, 2019). The rebound effect is important when discussing emissions, especially concerning the EU ETS, which does not capture global emissions. If energy efficiency improvements lead to increased consumption, the emission reductions achieved may result in little or no net reduction. The rebound effect shows a limitation of the study. Even if there is an effect, it could be the case that the emissions were rebounded to another country outside of the EU.

2.5 Backfire Effect

The second effect described by previous research is the backfire effect. The backfire effect is a theory describing the phenomenon where a decrease in carbon dioxide emissions may backfire and lead to increased methane emissions (Ravigné & Nadaud, 2023). Ravigné and Nadaud give an example of a carbon tax that did reduce carbon dioxide emissions. Reducing carbon dioxide emissions may render it successful, but Ravigné and Nadaud show that natural gas consumption increased after introducing the tax. The backfire effect could be an issue for EU ETS, because the intended carbon reductions lead to increased methane emissions. Suppose that the EU ETS has a positive effect on methane emissions. Then the backfire effect could explain this positive effect.

2.6 Spillover effect

The third effect described by previous research is the spillover effect. The spillover effect is the impact that events or actions in one country or economy can have on other countries or economies. These effects can be positive or negative and are caused by many things which have become more prevalent in the more interdependent world (The United Nations' Sustainable Development Solutions Network, 2022). Siping et al. (2021) describe that carbon dioxide positively correlates with other emissions. They consider it a risk because carbon dioxide emissions are rising in China. Therefore other emissions may too because of the spillover effect. However, this effect could also explain why decreased carbon dioxide emissions reduce methane emissions. Therefore, The concept helps explain the potential effects of EU ETS on methane.

2.7 The Effect of Financial Solutions on Emissions

The three effects described previously help explain the possible effects of the EU ETS. However, further examining previous research is needed to gain a deeper understanding of the potential effects of the EU ETS. In Carbon taxes versus cap and trade: A critical review (2013), Goulder and Schein look into the performance of two financial systems, a carbon tax compared to a cap and trade system. They show that with an established emission price, in this case, carbon dioxide, both taxes and cap and trade systems incentivise firms to change their production processes to reduce emissions. These policies also affect consumers through the law of demand, encouraging changes in their consumption to less carbon-intensive emission goods. The way this change is made differs from the policy used to increase the price. With a tax, the emissions price is fixed according to the tax rate (exogenous price setting), whereas in a cap and trade, the price is more indirect and set by the market. Regardless of the policy used, the firms affected by them face the same price of emissions, which, if firms are cost-minimising according to the neoclassical theory, then emissions will be reduced to the margin where the cost of emissions is equal to the emission price.

Goulder and Schein (2013) also compare the relative advantages and disadvantages of the two financial solutions. One relative disadvantage mentioned for a cap and trade system is that the amount of allowances is inelastic, which means that price changes of emissions due to demand shifts can produce volatility (Nordhaus, 2007). The critical takeaway from price volatility is that uncertainty about emissions prices under cap and trade systems constrains the firm's ability to respond to any changes in climate policies.

Another topic discussed in their thesis is whether introducing a new limit on any greenhouse gas has an effect. For the cap and trade system, they argued that the effect of introducing a new greenhouse gas to the trading system or a limit to emissions might be ineffective (Goulder & Schein, 2013). They demonstrated the ineffectiveness of introducing another limit through an example of the United Kingdom's (UK's) electricity production after introducing a carbon tax. The UK energy producers had to pay an additional fee to the UK government, apart from the EU ETS allowance price. The amount of emissions from UK energy production was reduced. However, the overall pollution from energy production in Europe would be shown to rebound, leading to increases that would equal the diminish from the UK. The rebound effect shows that the pollution could increase if the production is in countries with more lax policies or if they are excluded from the EU ETS.

The rebound effect is important since a significant flaw with the cap and trade system is shown. The effect of introducing another emission-limiting policy will be offset by the effect of any cap and trade system such as the EU ETS. The policies merely relocate the emissions to areas outside the country rather than reduce them. The effect of the policies in a country also depends on the influence it can exert over the cap and trade system imposed on it. A sufficiently large country influences the cap and trade system, and they can therefore affect the system in their favour.

The rebound effect showed that existing policies may have unintended effects on new solutions. It is, therefore, essential to investigate the existing policies and financial solutions targeting methane emissions. This includes analysing any interactions or possible causes of the result, as highlighted by Goulder and Schein (2013). In this context, Key and Tallard (2011) examine whether a carbon tax may reduce methane emissions in the agriculture sector and if a methane-based cap and trade system reduces methane emissions.

Key and Tallard (2011) use a recursive-dynamic partial equilibrium model (this will not be explained in this thesis, but it may be interesting to know what model was used) of global agriculture to investigate whether a carbon tax and a cap and trade system similar to the EU ETS based on average national methane could be effective. They base their study on a methane-based sectoral cap and trade system, where allowances flow between countries, not companies. Therefore, the companies do not have any incentives to reduce their emissions. Key and Tallard (2011) demonstrate that if Annex 1 countries imposed a carbon tax in the agriculture sector, methane emissions would decrease by 3.9%. Therefore, a carbon tax has a negative effect on methane, which could mean that the EU ETS also has a negative effect on methane.

Their thesis is built upon a linear relationship between production (in the agriculture sector) and methane emissions. The study shows that methane emissions are reduced when a carbon tax is used. The effect depends on if the carbon tax is global or just on industrialised countries (Annex 1). When taxes are limited to Annex 1 countries, Key and Tallard's model shows that two-thirds of the reductions will rebound through increased production in other countries. In either case, introducing a carbon tax or a cap and trade system based on methane emissions for each specific country could reduce methane emissions according to their model. An important highlight of their study is that the effectiveness of the policies may vary depending on what strategy is implemented. Suppose every country uses a similar strategy, such as a tax. In that case, the effect of the cap and trade system will remain constant regardless of how high the cap is. This also means that the effectiveness of a cap and trade on methane may depend on the respective countries' methods to reach these targets. The fact that cap and trade systems are shown to have different effects in different countries makes it challenging to create a single model that can explain how the EU ETS affects emissions in all countries. However, Key and Tallard (2011) describe that Annex 1 countries are similar and seem to use the same solutions to reduce emissions. Therefore, a cap and trade system would have similar effects within Annex 1 countries.

3. Data

In order to create and test a model of the effectiveness of the EU ETS, it is essential to collect reliable data on emissions, free from significant inaccuracies. The model should also produce results that can be applied to other populations. Key and Tallard (2011) suggested that the effects of a cap and trade system should be comparable for all Annex 1 countries. As Sweden is an Annex 1 country, its data can be used to generalise the effects of the EU ETS on other Annex 1 countries. The Swedish Environmental Protection Agency (2022) has assessed Sweden's data according to Swedish and EU laws, making it more reliable.

The data used for this thesis is publicly available. Thus we deem the ethical risks of the data to be non-existent. The rest of the thesis should be in accordance with research ethics as described by 4 § Lagen om ansvar för god forskningssed och prövning av oredlighet i forskning (SFS 2019:1150).

The data used in this thesis is based on carbon dioxide and methane emissions. The data on carbon dioxide is gathered from the Swedish Environmental Protection Agency (2022) and is categorised by sector. The data covers seven sectors, collectively accounting for 94% of Sweden's total emissions. These sectors include industry (27%), domestic transport (28%), foreign transport (13%), agriculture (10%), energy (8%), machines (5%), and waste (3%). The data is given as carbon dioxide equivalents for each sector annually between 2005 and 2021.

A limitation of the data from the Swedish Environmental Protection Agency (2022) is that it only includes total carbon dioxide equivalents for different sectors and does not provide information on methane emissions. Therefore, methane levels need to be estimated for each sector. One way is to use quotas for each sector. However, it is difficult to determine accurate quotas as there is a lack of data on methane emissions for each sector. Therefore, data from the World Bank (2020b) on Sweden's methane emissions levels are used between 2005 to 2019. The national quota between methane and carbon dioxide equivalents is calculated annually between 2005 and 2019. There is no data on methane emissions after 2019. Therefore, the quota between methane and carbon dioxide equivalents is assumed to remain constant between 2019 and 2021. These quotas are then applied to all sectors in Sweden. This may affect the reliability of the model if sector-specific effects are being tested, as quotas are likely to differ between sectors.

The variable of interest in the model is the EUA price. It is obtained from the World Bank (2023). The EUA price is given as yearly averages from 2005 to 2021, presented in US dollars.

Lastly, Electricity price is used as a control variable. *Further explanation as to why it is chosen as a control variable is explained under Chapter 4, Research Design.* Data on the electricity price is gathered from Nordpool Group (2023). The data represents Sweden's yearly average household electricity prices between 2005 and 2021.

In 2011 Sweden underwent changes in the electricity market. 4 electricity regions were created, denoted as SE1, SE2, SE3, and SE4 (Energimarknadsinspektionen, n.d.). This means that the data of the prices prior to 2011 are for the whole of Sweden, whereas after 2011, it is divided. An average of the electricity prices was created for the data after 2011 in order to structure the data. For 2011 there is no data. Therefore, an average of the prices in 2010 and 2012 was calculated.

All variables used in the model are described in Table 1.

Table 1 *Variable description*

Variable	Description
CO_2	Annual Carbon dioxide emissions (Mt)
CH_4	Annual methane emissions, (Mt) carbon dioxide equivalents.
EUA_price	Average yearly price for one EU ETS allowance in US dollars.
Electricity_price	Average household electricity price in Sweden (EUR/MWh)
$\ln CO_2$	Log of CO_2
$\ln CH_4$	Log of CH_4

The described variables' average characteristics are presented in Table 2. The table displays the observations, mean, standard deviation, and minimum and maximum values. The dataset contains emission levels during 17 years divided by seven sectors, summarising 119 observations. The dataset also contains the EUA prices and electricity prices.

Table 2 *Descriptive statistics*

Variable	Obs	Mean	Std. Dev.	Min	Max
CO_2	119	10.373	7.117	.99	24.14
CH_4	119	1.393	.954	.135	3.153
EUA_price	17	17.279	12.42	1.26	49.78
Electricity_price	17	37.867	11.064	18.957	57.89

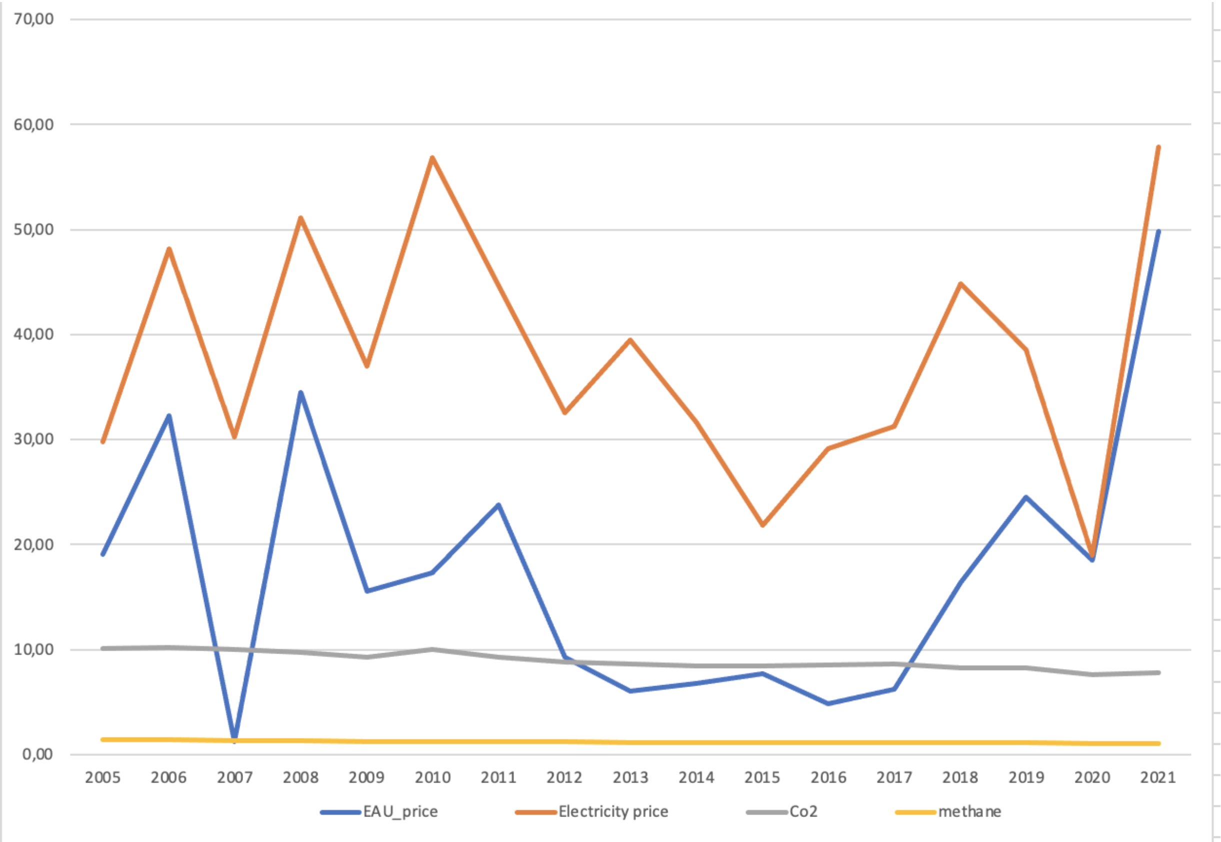
Before creating a model, it is important to investigate if the data suffer from multicollinearity. This is done by calculating the correlation between the variables. Table 3 presents the correlation between the exogenous and endogenous variables, specifically the correlation between EUA_price and Electricity_price. According to the table, the correlation coefficient is calculated as 0.684, indicating that the dataset does not exhibit perfect multicollinearity (Stock & Watson, 2020). If the correlation between EUA_prices and Electricity_price exceeds 0.8, it may pose challenges in measuring the individual effects of each variable.

Table 3 *Correlation matrix*

Variables	(1)	(2)	(3)	(4)
(1) CO_2	1.000			
(2) CH_4	0.999	1.000		
(3) EUA_price	0.001	0.001	1.000	
(4) Electricity_price	0.043	0.026	0.684	1.000

Another way to show the correlation between the variables and their underlying trends is displayed graphically in Figure 2. The electricity and EUA prices display high variance compared to the emission levels. EUA and electricity prices seem to correlate but are not perfectly collinear.

Figure 2



Notes: *Graph of EUA prices, electricity prices, carbon dioxide and methane emission. The Y axis represents the dollar price for EUA prices, SEK for electricity and million tonnes for methane and carbon dioxide.*

4. Research design

With the data specified, the research design could be conducted. This analysis aims to isolate and analyse the EUA prices' effect on methane emissions. There are many challenges, as there are a multitude of factors that can affect emissions. These factors need to be considered to isolate the effect of the EUA price (Löfgren et al., 2013).

Previous research by Löfgren et al. (2013) used a difference-in-difference OLS estimator when analysing the effect that the implementation of the EU ETS had on green research and development. Using a difference-in-difference estimator was unsuitable for this thesis because difference-in-difference estimators are used to analyse the effects of policy changes and not price fluctuations.

It can be challenging to isolate the effect of the EU ETS by controlling for other environmental policies because no data is available to match with the sector-level data (Löfgren et al., 2013). Environmental policies are assumed to be equal within sectors but differ between sectors and can therefore be controlled using a fixed effect model (Löfgren et al., 2013). Thus, the fixed effect model was used to control the sector-specific policies.

An assumption for the data was made that there is a linear relationship between the prices of carbon credits and emission levels. OLS regression is therefore preferred when analysing the effects of price changes, as the OLS estimator captures their linear relationship. OLS regression is also the preferred choice for economists and statisticians. (Stock & Watson 2020, pp. 151-152).

OLS regression is valid if the coefficients are consistent and unbiased. Sources of bias arise when the regressors are correlated with the error term. Therefore, the OLS regression model is successful if the statistical inference can be internally and externally valid (Stock & Watson, 2020, pp. 330-331). The model is externally valid if the statistical inference is valid for the population studied (Sweden), and that it can be generalised to other populations, such as Europe (Stock & Watson, 2020, p. 331).

For the model to be internally valid, the regressors need to be unbiased and consistent (Stock & Watson, 2020, p. 333). This means that EUA_price cannot correlate with the error term, which can happen if relevant variables are omitted. To avoid this, the model must include variables that can explain emission level variation and correlate with EUA_price. A tradeoff is made when including explanatory variables, as including relevant control variables does reduce the risk of OV bias, but it also increases the variance of the model. (Stock & Watson, 2020, pp. 334-335)

Löfgren et al. (2013) included fuel intensity as an instrumental variable for fuel price. They argued that the price of fuel could dictate if companies would adopt new emission-reduction technologies. Since our model does not test how the EU ETS changes investment behaviour but tests if and how the price of emission allowances affects emissions, a different control variable was needed. One variable that was more interesting than the fuel price for our model was the electricity price. As Löfgren et al. (2013) mentioned, "There is a risk that fuel prices suffer from endogeneity problems because investment in abatement technology will decrease the use of fossil fuels." Swedish electricity prices are based on European demand, not solely Swedish demand (Vattenfall, 2021). Therefore, the Swedish emissions do not explain the variation in the Swedish electricity prices. Thus, Swedish Electricity prices should not have the same endogeneity problem as fuel prices. Therefore, the electricity price is a valid control variable as it can explain emissions and correlate with the EUA price. It may, however, be problematic to assume that Swedish electricity prices are exogenous because Sweden is a part of Europe. Therefore the Swedish emissions do, in fact, affect Swedish electricity prices to some degree, albeit the effect is small compared to the effect of all of Europe's emissions.

Suppose we assume that the energy sector aims to maximise its profit as neoclassical theory describes. In that case, the energy sector will increase its output when facing high household electricity prices as this would increase its profits. Increased output increases emissions, meaning that electricity prices affect emissions. Therefore we argued that the Swedish household electricity price is a relevant control variable.

Löfgren et al. (2013) used fuel intensity as an instrument for fuel price to limit multicollinearity. As shown in Table 3 and Figure 4, electricity price correlates with EUA price. However, it is not perfectly collinear, meaning the variables do not suffer from perfect multicollinearity but rather an imperfect multicollinearity (Stock & Watson, 2020, pp. 230–231). Imperfect multicollinearity does not threaten the OLS estimator because it does not bias the coefficient estimates. However, the Standard error of the coefficient of EUA price may increase (Stock & Watson, 2020, pp. 230–231).

The OLS estimator can fail to estimate the true effect of the independent variable if the exogeneity assumption fails. The exogeneity assumption can fail if the variation of the independent variable (EUA_price) can be explained by the dependent variable (emissions) (Stock & Watson, 2020, pp. 427-429). The model would break the exogeneity assumption if it were based on the entire EU because the level of emissions decides the demand for carbon credits, which in turn explains the price of the credits, thereby violating the exogeneity assumption (Stock & Watson, 2020, p. 427). To limit this endogeneity risk, we limited the study to Sweden because the Swedish demand for carbon credits is small compared to the demand of the whole European region. Therefore, we assumed that the independent variable EUA_price is exogenous because emission levels in Sweden do not explain the demand for carbon credits. An issue with this reasoning is that the underlying macro shocks determining demand in the EU and Sweden may be correlated. Swedish demand predicts the Swedish macro shocks, which could predict the EU macro shocks. The EU shocks can predict the emissions within the EU, which is one factor that decides the EUA price. Thus, the Swedish demand could predict the EUA price.

4.1 Model specification

Given the arguments mentioned, we specified the models as follows:

$$emissions_{i,t} = \beta_1 EAU\_price_t + \beta_2 electricity\,price_t + \alpha_i + V_{i,t} \quad (1)$$

Where t is the time in years, i is the sector, V is the Error term and α is the fixed effect for each sector.

The sectors have different fixed effects denoted A, which we assumed do not change over time. We, therefore, wrote $A_t = A$. We assumed that A is a parameter and not a random variable. We, therefore, replaced A with α_i.

We defined a dummy variable $D^{(i)}_{j,t}$ for each sector which takes the value 1 if $j=i$ or 0 if $j \neq i$

The model could therefore be written as follows:

$$emissions_{i,t} = \beta_1 EAU\_price_t + \beta_2 electricity\,price_t + \sum_{j=1}^{n} \alpha_j D^{(i)}_{j,t} + V_{i,t} \quad (2)$$

We write:

$$\alpha_i = \sum_{j=1}^{n} \alpha_j D_{j,t}^{(i)} \qquad (3)$$

Plucking equation (3) in equation (2) gives our model (1)

$$emissions_{i,t} = \beta_1 EAU\_price_t + \beta_2 electricity\, price_t + \alpha_i + V_{i,t} \qquad (1)$$

Where t is the time in years, i is the sector, V is the Error term and α is the fixed effect for each sector.

A possible drawback of the fixed effect model is that we do not know the differences between the different sectors. These differences affect emissions, but as we do not know what they are, we will likely underestimate or falsely estimate the effect that EUA_price has on emissions (Stock & Watson, 2020). The case of an underestimating or falsely estimating model will be discussed further under the discussion section.

4.2 Standard errors

Another thing to keep in mind with the model is that when conducting this model in Stata, Stata will assume that all data points are independent of one another. This would rule out that a decrease in emissions today would affect emissions tomorrow (positive auto-correlation). Which likely is not true. The data table is indexed by a sector identifier (i) and a time period identifier (t).

Assuming that all data points are independent of one another rules out that a decrease in emissions today would affect emissions tomorrow (positive auto-correlation), this is not very plausible. It is more plausible that data points within sectors are dependent on one another but independent between sectors. Therefore we assumed *cross sectional independence*, i.e that $V_{i,t}$ and $V_{i',t}$ are statistically independent for $i \neq i'_t$, and not restrict the temporal dependence within a sector, thereby leaving cov($V_{i,t}$, $V_{i,t'}$) unrestricted. Therefore, we clustered the standard errors on a sector level which will increase the standard errors and p-values of the model as the model now allows for heteroskedasticity and autocorrelation within a sector. (Stock and Watson 2020, 375-376).

5. Result

Two models were created to examine the EUA price's effect on methane emissions and carbon dioxide. Model 1 examines the effect of the EUA price on methane emissions, and Model 2 examines the effect of the EUA price on carbon dioxide. An overview of the results is shown in Table 4.

Table 4 *Fixed effect regressions on the log of methane emissions (1) and log of carbon dioxide emissions (2), with clustered standard errors.*

Model	(1)	(2)
Variable	Ln_$CH_{4,}$	Ln_CO_2
EUA_price	-0.003	-0.004*
	(0.211)	(0.093)
Electricity_price	0.004	0.006**
	(0.147)	(0.048)
Cons	-0.067	1.890***
	(0.266)	(0.000)
Observations	136	136
R-squared (within sectors)	0.037	0.078

*Notes: P-values in parentheses, the significance levels of the tests are indicated by: * 10%, ** 5%, and *** 1%.*

Model 1 is shown on the left side in Table 4. The p-values associated with EUA_price and Electricity_price are 0.211 and 0.147, respectively, indicating that we cannot reject the null hypothesis based on these results. This means that the coefficients of the EUA_price and electricity_price are not significant. Therefore no further conclusion can be drawn based on these results.

Model 2 is shown on the right side of Table 4. It displays significant coefficients for EUA_price and Electricity_price at a critical alpha level of 0.1 and 0.05, respectively, as evidenced by their p-values of 0.093 and 0.048. The coefficient of EUA_price demonstrates a negative relationship, while the coefficient of electricity prices shows a positive relationship. These results suggest that increasing ETS allowance prices decrease carbon dioxide emissions. Furthermore, the result indicates that electricity prices have a greater positive effect on carbon dioxide emissions compared to allowance prices, as evidenced by the larger coefficient of electricity prices.

The foundation chapter showed that a carbon-based cap and trade system has a negative effect on carbon emissions, i.e., increased prices on allowances reduce emissions. The effect on methane emissions from carbon-based solutions is ambiguous among researchers. Ravigné and Nadaud (2023) showed that when carbon emissions were reduced, methane emissions increased from the extra usage of methane gas, just as described by the rebound effect (increased consumption overall) and the backfire effect (increased emission in another area). Key and Tallard (2011) showed with their research and recursive-dynamic partial equilibrium model that methane emissions are reduced, irrespective of whether there is an exogenous price setting for carbon dioxide, such as through the use of carbon taxes, or if a cap and trade system determine a market price. Key and Tallard (2011) proved that a cap and trade system based on methane would reductively affect methane emissions. Whether a carbon dioxide-based cap and trade system also affects methane emissions remains unclear. It is plausible that implementing policies targeting carbon dioxide reductions may result in profit increases through methane emission reductions. However, this can not be proven from the results, which raises the question of why the model does not show an effect.

6. Discussion

From the foundation, it was shown that there could be some effect from the EU ETS on methane emissions. However, model 1 fails to produce a significant result when testing methane emissions, evident by a p-value of the coefficient EUA_price higher than any reasonable alpha. This higher p-value could be attributed to various factors, including limited data points, a small effect from the EU ETS, or a wide data spread (Stock & Watson, 2020, p. 154). These factors can influence the statistical significance of the coefficient estimate and may explain the higher observed p-value. A small effect size combined with a low sample size produces insignificant results, as small samples cannot detect minor effects. Lastly, the data could be widespread because only yearly data is used, leading to higher variance. This means that the result from any model using yearly data might be less reliable. Thus, it might be better to use monthly data or wait for more data points until reconducting the model.

Even minor effects would be shown with a good model, meaning our model likely needs improvement. The model could suffer from endogeneity which would affect the p-values. Finding additional relevant control variables could fix this potential problem.

Another thing that could affect the result is the selection of a country. Different countries may receive different effects from the EU ETS. A sufficiently large country could influence the EU ETS by lobbying for their policies, thereby changing the effect, as Ravigné and Nadaud (2023) explained. It is also essential to pick a sufficiently small country so that its emissions do not predict the EUA prices. It is reasonable to expect similar results if another Annex 1 country, similar in size to Sweden, was picked. As its solutions to mitigate emissions are similar, according to Key and Tallard (2011), and a small country is not able to lobby for its own policies.

Sweden has no specific regulations or policies that should be more effective on the overall reduction compared to another Annex 1 (industrialised) country. Any policy regulating sector emissions using exogenous price settings would only change where the emissions will occur instead of reducing them, as explained by previous research from Goulder and Schein (2013). The only case where the model would fail to generalise its result to other populations would be if the country chosen in the model, in this case, Sweden, would have different exogenous prices on emissions than other Annex 1 countries. This is likely not the case, as argued by Key and Tallard (2011).

Another possible explanation for why the model cannot produce significant results might be that the model does not include all relevant control variables. It could be the case that other variables also impact methane emissions.

If relevant control variables are omitted, the EUA price will be biassed, leading to insignificant results. Since the model creates a significant result when testing for carbon dioxide, it could be the case that the models need different control variables. Thus there might be a need for other control variables to successfully capture the effect of the EU ETS on methane emissions.

Neither Key and Tallard (2011) nor Ravigné and Naudad (2023) have strong enough arguments, or enough discussion regarding a cap and trade for carbon dioxide, to state that there is an effect from the EU ETS on methane. The previous research highlights that it is theoretically possible for the EU ETS to have an effect in any direction. The discussion of whether the EU ETS affects methane emissions needs further arguments.

Previous research by Key and Tallard (2011) indicates that carbon taxes effectively reduced methane emissions in the agriculture sector and that it likely is true for other sectors as well. They, however, also show that a cap and trade system could have different effects within different sectors. For future research, it might be better to look at the effect on each sector.

One thing to remember when replicating the method is that the result (the respective p-value and the strength of effect) could change depending on the definition of sectors. The sectors capture any eventual policy, or unknown differences between the sectors regarding emissions, as long as they are constant over time. Controlling for sectors with the fixed effect model makes the model more accurate by isolating the effect of the EUA price. When replicating the model, the result could change depending on the definitions of sectors for the country used in the model. The Swedish Environmental Protection Agency (2022) had separate classes for national and international transport, for example, and differences in which industry belongs to what sector may be of discussion. The fixed effect model assumes that the differences are constant over time. However, policies may change during the time period tested, which means the result is less reliable. This is a limitation of the model since including all relevant control variables is impossible (Löfgren et al., 2013).

Due to no inclusion, some of the sectors in the model should not be affected by the EU ETS. However, an idea of why they could be affected by the EU ETS is that non-included sectors may still trade voluntary carbon credits. The price of voluntary carbon credits likely correlates with the EUA price, although this needs to be tested. Since methane is price elastic to the CO2-eq price (Key & Tallard, 2011), the carbon credits may affect methane emissions even if the sector is not included in the EU ETS. The idea is exciting, but the data for prices on voluntary carbon credits is difficult to gather.

The electricity price is statistically significant, as shown in Model 2. It can therefore be deemed a relevant control variable as it can explain the variation in carbon dioxide. The question then arises about why it is not significant when testing for methane emissions. Perhaps electricity is not a good choice in predicting methane emissions. The model also shows that electricity prices have a greater effect on carbon dioxide emissions than the EUA price. This is interesting to remember since this could mean that the EU ETS is relatively ineffective at reducing carbon dioxide emissions. The results suggest that electricity prices are essential to keep low as an increase in electricity prices increases carbon dioxide emissions. For the thesis, the magnitude of the effect of the electricity price in comparison with the EUA price might not be exciting. However, in a discussion regarding global warming, it is. Since higher electricity prices increase emissions, the discussion of electricity prices may be more important to discuss than the effect of the EU ETS.

40% of the EU electricity production is from fossil fuels, and 20% is from natural gas (European Council, 2023). Methane is a type of natural gas, which means that a key to reducing methane emissions may be keeping energy prices low so that companies do not profit from selling emission-intensive electricity.

As explained previously by Key and Tallard (2011), the effect of the EU ETS could differ between sectors. This could explain why the model yields an insignificant result. Our model only examines whether there is an effect from the EU ETS on methane emissions in Sweden overall and not if there are any sector-specific effects. This means that the possible sectoral differences are not shown in the model. Adding interaction variables for the sectors could capture these sector-specific effects and thereby yield a more accurate result.

Another thing to consider when discussing the sectors is the law of demand concept. There may be situations where the goods cannot be substituted (due to inherent need, such as within pharmaceuticals). The inability to substitute goods means that the effect of the EU ETS could be limited for some sectors. This further explains why the EU ETS would affect different sectors differently.

Agriculture, as an example, is a sector in which there are plenty of substitutes, whereas medicine or transport has fewer options than agriculture. It could also be argued that the effect of EUA price does not differ between sectors, as long as the emissions mitigation in the sectors is done by the same method (Key & Tallard, 2011). Key and Tallard highlight how the effect of a policy depends on what solution is used to decrease the emission. It is plausible that the sectors have different solutions to decrease their emissions. Therefore, the effect of the EUA price is likely different between sectors. This gives further basis for using interaction variables in the model.

The method section mentioned a risk of underestimating or falsely estimating the effect of EUA price on emissions due to different effects between sectors. This could be why the result is insignificant and might be mitigated using interaction variables which should improve the model's accuracy.

The model's accuracy should be sufficient because it produces a significant result when testing for carbon dioxide, making it challenging to explain why it does not yield a significant result for methane emissions. Some explanations could be derived from the variables, the underlying data or the method. Three effects describing effects from one area to another were mentioned in the foundation chapter. The previously mentioned research papers validated the effects of these three theories, either in the way that there is a clear negative impact or a positive. The result in this thesis is insignificant, i.e., we can not determine if there is an effect. This could be due to the three effects impacting at the same time. There could be a positive spillover effect, which means that the EU ETS impacts and reduces methane emissions as carbon dioxide emissions are reduced. At the same time, the carbon dioxide reduction may backfire and lead to increases in both carbon dioxide emissions and methane emissions in another area (distinctively different from the first one by locality or sector). There could also be a rebound effect, that the reduced carbon dioxide or methane emissions from the EU ETS are rebound and found in other countries. The situation is likely complex, capturing the effects of the EU ETS is therefore challenging. This gives arguments to further limit the model to specific sectors, as this would make the situation of different effects less complex.

Besides the complex situation, the next thing to examine further would be the overall model and possible limitations. The model is built upon OLS regression, which is also the case for previous research, such as the research by Löfgren et al. (2013). A better method could exist to model the problem, but to our knowledge, we have yet to find one. Further work could show this concept using another more complex model, which perhaps could model complex systems better.

A limitation of the thesis is that the discussion of whether the EU ETS impacts carbon dioxide is not highlighted. Previous research has discussed whether the EU ETS affects carbon dioxide, and our model produces significant results, but they are not discussed thoroughly. Further research on what effects the EU ETS has on carbon dioxide would contribute to the knowledge on the subject.

Lastly, it is essential to carefully review and be critical when reading research papers. Basing a model on previous assumptions may be a risk leading to poor or incorrect conclusions. One of the key things we are critical of with Key and Tallard's (2011) findings is that they assume that all Annex 1 countries would use the same mitigating solutions (a carbon tax). If this is false, they would likely receive different effects from the cap and trade system. Therefore, generalising the model's result to other populations would be difficult. Determining the effect of carbon-based financial solutions on methane emissions is complicated. The previous research has presented clear but divided information. Key and Tallard (2011) state that methane emissions will be reduced in agriculture when the price of carbon dioxide emission increases. Goulder and Schein (2013) show that increasing carbon dioxide prices are ineffective at reducing methane emissions in the energy sector. Lastly, Ravigné and Nadaud (2023) state that reducing carbon dioxide emissions will backfire, leading to increased methane emissions. This further incentivises testing sector-specific effects, as the previous research shows that different sectors would receive different effects from a cap and trade system.

Fewer sectors could be tested with interaction variables to ensure that any sector-specific effects are noticed. However, the lack of data on methane emissions on a sectoral level makes future research harder. Regardless, there is a need for more research within the area to determine the possible effects of the EU ETS.

7. Conclusion

The purpose of this thesis was to determine if the price of allowances within the EU ETS has an impact on methane emissions. The model cannot show that the EU ETS impacts methane emissions as the model produces an insignificant result. Therefore, the research question remains unanswered. However, the model produces significant results when testing for carbon dioxide emissions. The model shows that EUA prices have a negative effect on carbon dioxide emissions and that electricity prices have a larger positive effect. Conducting a new model, using interaction variables, more control variables, or a different data set might be the solution to get a significant answer. Previous research has shown that there likely is an effect on methane emissions when introducing other financial methods, such as a carbon tax. However, the direction and magnitude of the effect have been up for discussion.

Some of the research discussed in this thesis indicates a negative effect, such as reductions in carbon dioxide leading to increased methane emissions. Other research points in the opposite direction and indicates a positive effect, i.e., that reductions in carbon dioxide emissions also lead to reductions in methane emissions. Therefore, It is impossible to answer the research question solely based on previous research. It would be important to test sector-specific effects because previous research states that financial solutions may have different effects depending on the sector.

The lack of data on methane emissions is a serious issue that makes researching the area challenging. Policymakers must acknowledge this lack of information in order to enable future research.

Policymakers should also be careful when considering the effect of carbon policies. There could be spillover, backfire and rebound effects, which are challenging to model. Considering the three effects is essential since adding exogenous prices does not ensure emission reductions. The best way to reduce one type of emission is to tie the financial solution specific to that specific emission and that the solution is global. If the EU ETS does not reduce methane emissions, there could be a need to introduce a new financial solution specifically targeting methane.

The Paris Agreement states that global warming needs to be limited to a maximum of 2°C by 2050 (United Nations, 2023a). The GWP100 bases the warming effect of gases on a 100-year timeframe. In this timescale, methane is calculated to have a warming effect that is 25 times greater than carbon dioxide (Eurostat, 2017). However, methane emissions have a global warming effect of 80 times greater than carbon dioxide during the first 20 years (UNEP, 2022). Therefore it is essential to reduce methane emissions to reach the goals set out by the Paris Agreement.

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