The Impact of Oil Prices on Carbon Dioxide Emission Levels in Sweden

A time-series regression analysis of Sweden

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The Impact of Oil Prices on Carbon Dioxide Emission Levels in Sweden. A time-series regression analysis of Sweden

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Abstract

Globally, CO_2 emissions have increased over the last decades. This trend has been broken in Sweden, where CO_2 emissions are declining. Oil is one of Sweden's largest sources of energy, accounting for over 20 % of all energy consumption, and oil combustion is a large source of CO_2 emissions. This paper aims to answer the question, "How have oil prices impacted carbon dioxide emissions in Sweden?" which is relevant for policy-making regarding emission reduction, as it can explain how effective economic instruments are in reducing CO_2 emissions from oil. The study is conducted by setting up a Multiple Linear Regression Model where the correlational effects of oil prices on CO_2 emissions are studied, as well as the effects of control variables. Sweden is the only country studied, between 1980 and 2021, by looking at monthly data. The effects of the oil price increases were lagged to see the effects in different months after the price increase. The results were that oil price increases lead to an immediate increase in CO_2 emissions while decreasing after a more extended time. The direct effects of an oil price increase suggest that increases in oil price increase CO_2 emissions by 0.179 kg per capita and month, which according to economic theory is inaccurate. In the longer time frame, CO_2 emissions were shown to be reduced by between 0.24 to 0.42 kg per capita depending on the time after the price increase. However, because of possible biases and endogeneity occurring in this study, the results will explain the correlation between oil prices and CO_2 emissions, and not the cause-and-effect relationship. There is therefore no proof of causality in this study. Previous research has suggested that oil demand is inelastic, meaning demand does not change much due to price changes. Here, the opposite is proven since significant effects are found from price changes in oil. These results are important for how policies should be introduced in the future since it found that oil price increases are effective in the long run for reducing emissions. Future studies should include other EU countries if tariffs are to be imposed, and it could also be a good idea to look at a longer time frame and lag the oil price for all months. Instrumental variable regression could also be conducted to get more reliable and unbiased estimators.

Keywords: oil prices, CO_2 emissions, oil price elasticity, Multiple Linear Regression Model, Sweden, correlation

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Abbreviations

Here, some common abbreviations that will surface in the paper are explained, to make it easier for the reader to understand what is being discussed.

CO_2	Carbon Dioxide
CPI	Consumer Price Index
GDP	Gross Domestic Product
GHG	Green House Gas
Oil price	Brent crude oil price
OPEC	Organization of the Petroleum Exporting Countries
SEK	Swedish Crowns
USD	United States Dollars

1. Introduction

Globally, emission levels have been rising for centuries, causing global warming and extreme weather. However, some countries have been starting to decrease emissions over the last decades. One country that has reduced CO_2 emissions drastically, is Sweden. As more than one-fifth of the total energy consumption comes from oil combustion, studying the effects of oil prices on CO_2 emissions is of interest. Therefore, this study aims to see how effective economic incentives are in reducing emissions, looking specifically at oil prices.

This paper will examine the correlational relationship between oil price increases and CO_2 emission levels in Sweden between 1980 and 2021. A multiple linear regression model is set up to analyze the relationship between oil prices and CO_2 emissions. The regression includes control variables and lagged variables for the oil price, to study the effects in different periods separately.

Here, what is being studied is not the causal effects, but the correlation between the variables included in the regression. Even though this does not imply that there is a cause-and-effect relationship between oil price and CO_2 emissions, and instead only shows how the variables are related, the results from such analysis can provide valuable insights (Aldrich 1995). Understanding the relationship and correlation between variables can help us find economic patterns, which could be used as guidelines when introducing economic policies and provide insights for further research. Nevertheless, it is impossible to make strong assumptions based only on correlation between variables.

Previously, most studies regarding oil pricing have been conducted on developing countries. Here, Sweden will be studied to provide insights on how the effect differs depending on economic structures. This paper will also study the correlational effects instead of the causal effects.

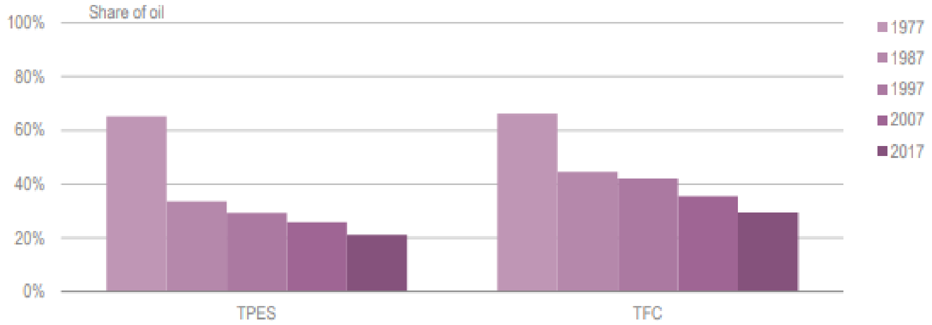
The immediate effect of oil price increases is estimated to be positive, while negative in the long run. It is shown that oil price increases have a significant effect on CO_2, while previous studies have shown that oil demand is inelastic and does not reduce when prices increase. The results have important policy implications since they suggest that economic incentives, such as price floors or tariffs on oil, could be effective in reducing emissions.

1.1 Background

The total energy supply in Sweden contains 21 % of oil, which is the largest share of all fossil fuels in the energy mix (IEA 2019). Oil consumption has decreased in the last decades, as shown in Figure 1. Most of the oil in Sweden is consumed in the transportation sector, which can be seen in Figure 2 (Swedish Energy Agency 2022).

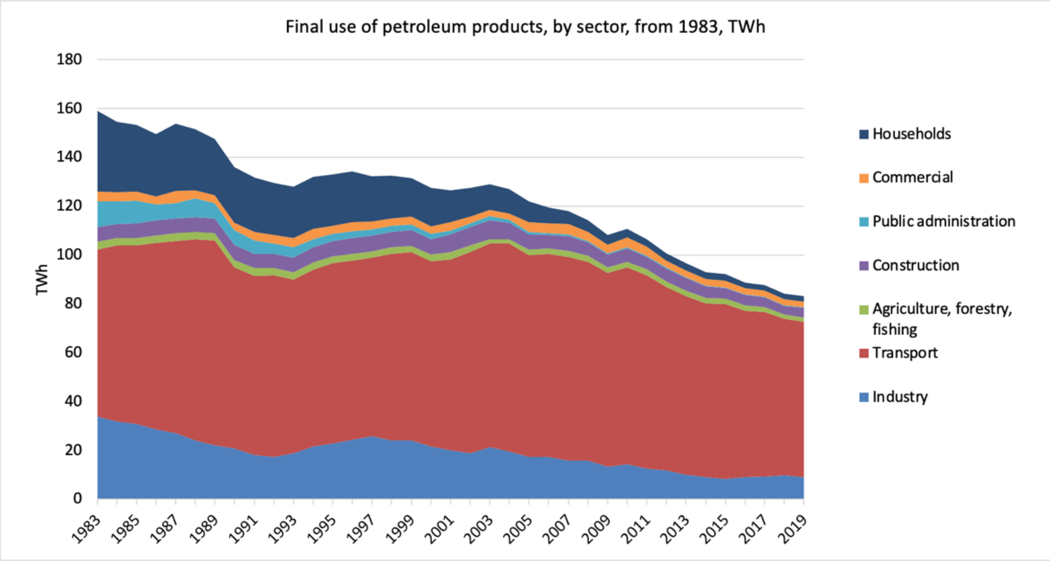
Figure 1. *The total share of oil in Sweden.*

TPES shows Total Primary Energy Supply and TFC shows Total Final Consumption.



IEA. (2019) – "World Energy Balances 2019 preliminary edition". Published online at www.iea.org/statistics. Retrieved from: 'https://iea.blob.core.windows.net/assets/abf9ceee-2f8f-46a0-8e3b-78fb93f602b0/Energy_Policies_of_IEA_Countries_Sweden_2019_Review.pdf [Online Resource]

Figure 2. *Final use of petroleum products, by sector.*



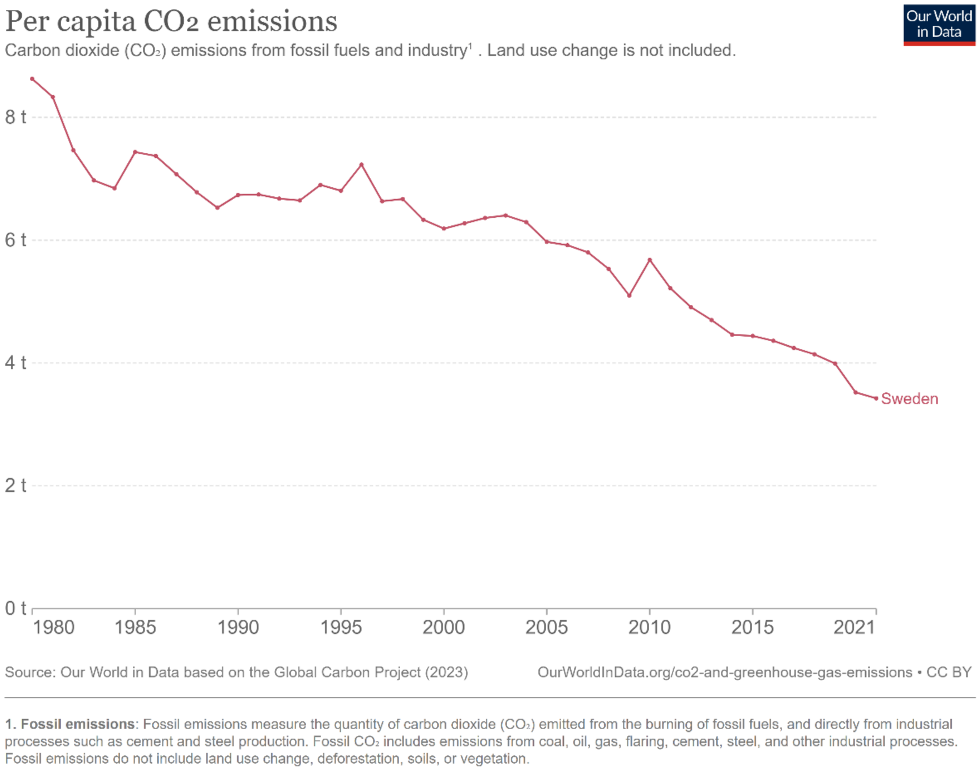
Swedish Energy Agency. (2022) – "Energy in Sweden 2021 (Excel)". Published online at https://www.energimyndigheten.se/en/. Retrieved from: https://www.energimyndigheten.se/en/facts-and-figures/statistics/ [Online Resource]

The reduced consumption in Sweden is believed to have mostly descended from a switch to electric heating occurring since the 1970s (IEA 2019). Nevertheless, when the electricity demand is peaking, oil is still used for heating and electricity. Oil consumption has also decreased as a result of more biofuels in the transportation sector. However, in 2017, 58 % of all oil was still consumed in the sector.

Burning of fossil fuels leads to waste and emissions, where CO_2 is one of them (Perman et al. 2011). Around 80 % of all CO_2 emissions come from fossil fuel combustion. It is also the GHG contributing most to climate change.

CO_2 emissions in Sweden have decreased for the last decades. As shown in Figure 3, emissions declined from about 8.5 tonnes per capita and year in 1980 to 3.5 tonnes in 2021.

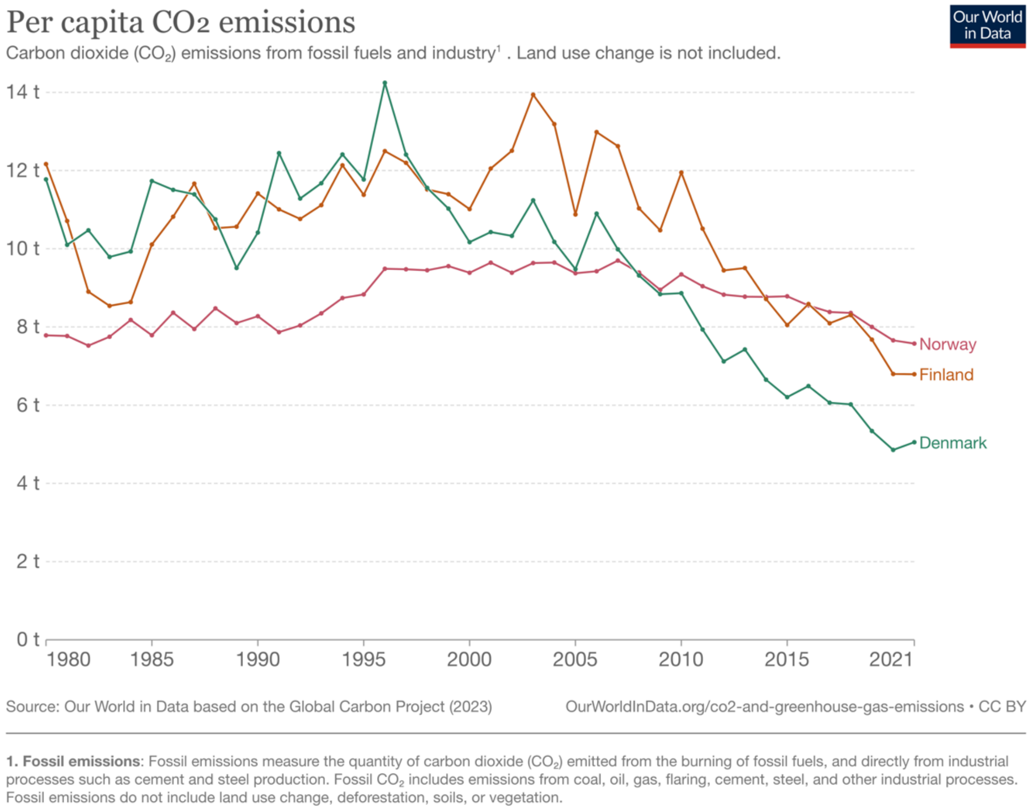
Figure 3. *CO_2 emissions per capita in Sweden from 1980 to 2021, measured in tonnes of CO_2 per year.*



Ritchie, H. & Roser, M. (2023) – "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-greenhouse-gas-emissions' [Online Resource]

Similar trends exist in other Nordic countries, where all have decreased emissions between 1980 and 2021, but the reduction differs greatly (Ritchie, Roser & Rosado 2020). Finland has decreased emissions by about six tonnes of CO_2 per capita and year, while Norway's decreased by 0.22 tonnes. This can be seen in Figure 4 Norway differs from the other Nordic countries since they produce and export oil (IEA 2022).

Figure 4. *CO_2 emissions per capita in other Nordic countries from 1980 to 2021, measured in tonnes of CO_2 per year.*



Ritchie, H. & Roser, M. (2023) – "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-greenhouse-gas-emissions' [Online Resource]

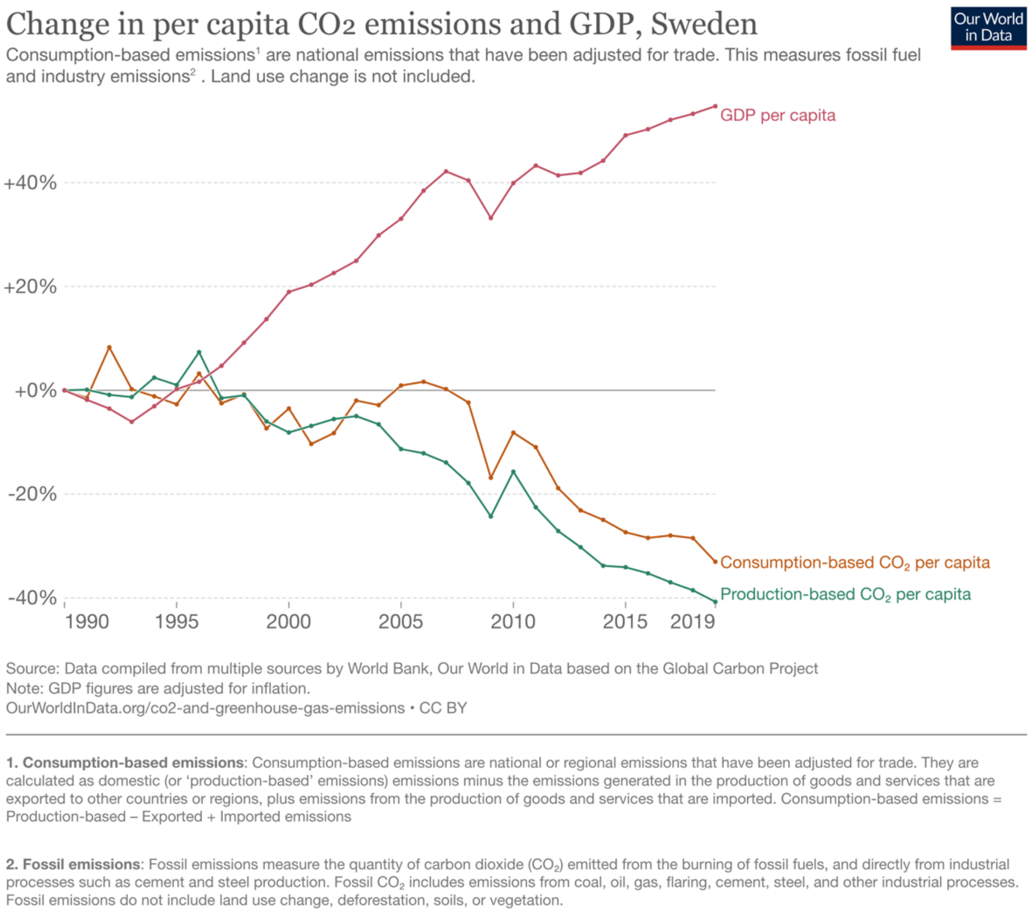
The Paris Agreement is an environmental agreement signed by many countries in December 2015. These countries are committed to keeping global warming far below 2 degrees Celsius above pre-industrial levels and aim to keep it below 1.5 degrees (UNFCCC 2015). Sweden has ratified the Paris Agreement, which went into force in November 2016 (United Nations 2015).

Climate change depends on the concentration of different GHGs in the atmosphere (Perman et al. 2011). To reduce the temperature increase and global warming, we must reduce the amount of GHGs today and in the future.

The Swedish government has imposed policies for reducing emissions, showing its commitment to international environmental agreements. In 1991, the first carbon tax in Sweden was imposed, based on the polluter pays principle, which aims to motivate consumers and producers to emit less (Government Offices of Sweden n.d.).

Traditionally, there has been a correlation between economic growth and emissions, implying that countries emit more GHGs as they get wealthier (Moldan et al. 2012). However, recently there have been indications of decoupling emissions and economic growth in high-income countries. Figure 5 shows that Sweden has decoupled CO_2 emissions and economic growth since the late 1990s. This indicates that the relationship between emissions and economic growth is not codependent, implying that economic growth is possible without increased emissions.

Figure 5. *Decoupling of emissions and economic growth in Sweden*



Ritchie, H. (2021) – "Many countries have decoupled economic growth from CO_2 emissions, even if we take offshored production into account". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-gdp-decoupling' [Online Resource]

1.2 Research Question & Hypothesis

This paper seeks to answer the research question, "How have oil prices impacted carbon dioxide emissions in Sweden?".

The hypothesis is that an oil price increase will have a negative effect on CO_2 emissions, meaning that emissions will decline as the oil price rises, which is based on the theory of supply and demand. When prices increase, the demand for normal goods decreases. When the demand for oil decreases, consumers may change to fossil-free energy sources, reducing their emissions. In the estimated regression, other variables have also been included, and their expected effect on emissions are described in Table 1. The expected results should be interpreted as how an increase in the independent variable will affect the CO_2 emissions.

Table 1. *Expected effects of the independent variables on the dependent variable.*

Variable name	**Expected effect**
Dependent variable	
CO2cap	
Independent variables	
monthlyoilprice	-
inflation	+
GDPcap	+
envtax	-
Paris	-
EUmember	+
covid	-

Inflation is believed to have a positive effect. When inflation rates increase, consumers' purchasing power decreases, meaning that they can buy less for an equivalent amount of money. Consumers therefore change consumption patterns and opt for cheaper goods, which may be produced less environmentally friendly. Higher inflation could also mean less money is invested in technology for the green transition due to economic uncertainty.

GDP per capita is believed to have a positive effect, as economic growth could lead consumers to consume more and emit more CO_2. The environmental tax variable is believed to negatively affect emissions as it increases the cost of emitting and should therefore lead to a decrease in demand for environmentally harmful goods. The Paris Agreement is believed to affect emissions negatively, as it aims to keep global warming from increasing by reducing emissions. The EU-membership is believed to positively affect CO_2 emissions since it has allowed Sweden to increase its trade, which could lead to higher emissions. When the pandemic (covid-variable) took place, global emissions decreased. The hypothesis is therefore based on the belief that the same decrease should be seen in Sweden.

Oil may not be consumed in the same time period as it is bought, since economic agents can choose to store oil instead of consuming it immediately (Downey 2009).

Oil storage can be used for different reasons, for example as a security for unforeseen changes in the market or to sell when the price is higher. When oil is being stored instead of consumed, it should also reduce CO_2 emissions from oil combustion in the same time period. Therefore, there is also a hypothesis that the oil price might not immediately affect CO_2 emissions. For this reason, the oil price variable was lagged to show the effects in the months after an oil price increase.

1.3 Scope, Novelty & Aim

The years between 1980 and 2021 are being studied, and the reasoning behind this is that, during this period, there has been a great advancement in the environmental sector and much has happened in the world economy, such as booms and recessions. We have also seen a notable enlargement of the European Union along with a global pandemic.

Sweden is the only country studied in this paper. In previous literature within this area of environmental economics and preceding studies, Sweden has yet to be thoroughly studied. Oil has historically had a substantial impact on the development of developing countries. For this reason, most previous studies have been done on developing countries. There are gaps in existing literature regarding how developed countries react to oil price changes and how these price changes affect oil-importing countries. This paper could therefore add to existing knowledge.

More than 20 % of all energy consumption in Sweden comes from oil (IEA 2019). Therefore, it is important to study the effects of price changes for this energy source, as it contributes vastly to energy consumption and emissions. Sweden is typically recognized as a role model in the green transition and sustainable energy production, thus it is also interesting to see how policies regarding the transition towards a more carbon-neutral future have affected this progression.

During oil combustion, approximately 99 percent of the carbon in fuel oil is transformed into CO_2 emissions (Environmental Protection Agency 1999). Considering this paper will be studying the relationship between oil prices and emissions, it is only relevant to study the CO_2 emissions from oil combustion, not other GHGs as well.

This research paper aims to examine how the independent variable, oil price, affects CO_2 emissions. By examining this correlational relationship, it is possible to show how effective price changes have been on CO_2 emissions, which can be used for future policymaking regarding economic instruments for emission reduction.

1.4 Structure

The structure of the paper will be as follows. First, an introduction section and a literature review, where previous studies within the same area are discussed in relation to this paper, can be found. Next comes a theory section explaining the theoretical framework behind the study. The main parts of the paper, Method, Results, and Discussion, will follow after the theory section. Lastly, the conclusion, references, and appendix will be found at the end of this paper.

2. Literature Review

Most previous research on oil prices and CO_2 emission levels has been performed on oil-exporting countries, with economies primarily depending on the oil market. This section will summarize previous literature on this subject to further increase understanding.

2.1 Oil-exporting countries

Nwani (2017) studies the relationship between oil prices, energy consumption, and CO_2 emissions in Ecuador. The researcher used the Autoregressive Distributed Lag Model and showed a significant, positive relationship between oil prices and energy consumption. Since Ecuador economically gains from higher oil prices it increases their energy consumption. Agbanike et al. (2019) conducted a similar study in Venezuela, focusing on the same variables. The results were similar to Nwani's, where they showed a positive relationship between oil prices and energy consumption. Both studies also found that the higher the oil price, the higher levels of emissions (Nwani 2017; Agbanike et al. 2019).

In regard to this paper, these articles are interesting to study since the structure of the countries' economies differs remarkably from Sweden's.

2.2 EU

Rasheed et al. (2021) conducted a study on the relationship between energy sources, emissions, and oil prices in the EU. They showed that oil prices impact both energy consumption and the total share of energy from renewable sources. In the long run, they were able to demonstrate that oil price increases reduced CO_2 emissions. Despite the different approaches and the relationship between variables, this study is the closest connected paper regarding oil prices and the EU.

2.3 Sweden

Carbon taxation and emissions in Sweden have been studied widely. One study, between 1990 and 2010, found that carbon taxes are unaffected by price changes and that emission reduction from these taxes is lower in Sweden than the rest of the EU (Sterner 2020). In the paper, he explains that other incentives are likely needed to reduce emissions from the transportation sector.

Additionally, there is also a study looking at taxation on energy and carbon between the years 1961 and 2012 in Sweden. The researchers found no significant effect of such taxes on emissions in Sweden (Shmelev & Speck 2018). However, some of the other variables had significant effects. One of those was the oil price, which had a significant, negative effect on emissions with a lag of two time periods. Since they were looking at yearly data, they found a reduction in emissions two years after an oil price increase.

2.4 This study

This study differs from previous literature while examining similar relationships using comparable methods. As Sweden is an oil-importing developed country, it is interesting to see if the same effects are found there as in the mentioned South American countries, gaining from selling oil.

Comparing this paper to the study on EU countries, the method is similar, with a comparable regression model and variables. This paper will, however, span over a more extended period, look at Sweden specifically, and study the correlational relationship between oil price and CO_2 emissions. Their focus lies on energy consumption and the composition of energy sources, while this will study oil prices in general.

Looking at the studies from Sweden, this paper will be a continuation of the first paper, looking at economic incentives for emission reduction. Sterner's study is qualitative, while this paper will examine the quantitative effects of carbon taxes and oil prices separately. This paper will be similar to the second study from Sweden, using similar methods and variables, but instead studying the correlational effects with monthly data.

3. Theory

In this section, the theoretical framework of the research will be discussed.

The optimal quantity and price in an unregulated market are found where the demand and supply curves intersect (Pindyck & Rubinfeld 2018). This is also true for oil, where prices are set based on supply and demand globally (EIA 2022).

Energy demand and demand for fuels from the expansion of the transportation sector increase as countries become wealthier (EIA 2022). Petroleum products are therefore crucial for most countries today, and the energy source accounts for almost a third of the total energy consumption globally.

OPEC is an organization of countries that controls over 70 % of all oil reserves in the world (EIA 2022). Therefore, they have market power when it comes to oil pricing and set targets of how much these countries produce. By reducing production, while demand is high, they can increase the price.

One reason why oil price changes occur is how non-OPEC countries are producing and the price they set. OPEC countries, therefore, follow trends of the market while being able to save their oil resources (EIA 2022). Another factor that determines the price is political stability. Most oil-producing countries are located in a part of the world with much political instability, which often leads to uncertainty in markets as well.

According to a study, the global demand for crude oil is inelastic, both short and long term, meaning that increases in oil prices contribute little to reducing consumption (Krichene 2002).

Wang et al. (2020) showed a positive relationship between oil prices and a switch to renewable energy sources, when prices increased.

The energy sector accounts for 41 % of all CO_2 emissions globally, where oil is the second largest contributor (World Bank 2014). When the price of an energy source increases, consumers switch to cheaper sources (EIA 2022). Oil price increases could therefore lead consumers to other energy sources and thus reduce CO_2 emissions.

With reference to these theories, an oil price increase is expected to lead to decreasing emissions. The demand for oil has been increasing, and while keeping supply lower, prices have increased. There are, however, studies suggesting that oil demand is inelastic, and that price increases will have a small effect on demand. By reducing the share of energy from oil combustion, we could reduce CO_2 emissions.

4. Method

Here, the methodology and a data description will be presented, as well as the econometric model the research is based on. Graphs on the estimated relationship between some of the variables will also be presented.

4.1 Methodology

This study is based on regression analysis with monthly data between 1980 to 2021 in Sweden.

STATA was used for data management and regression analysis. Two separate regressions were conducted, one main regression and one naïve, with an extra variable but fewer observations. Both are Multiple Linear Regression models.

Some of the original data was initially quarterly or yearly data, while some were monthly. To control for time variation when expanding the data into 12 points each year, a smoothing command was used to account for irregularities.

The variable of most interest is the oil price. As stated in the hypothesis, an oil price increase might affect future emissions as well. To account for this, new oil price-variables were created to see the effect after 6, 12, 18, and 24 months.

A regression with multiple regressions is based on six assumptions (Stock & Watson 2020). These are;

1. The distribution of the error term has a mean of 0
2. The observations are independently and identically distributed
3. Large outliers are rare
4. The regressors are not perfectly multicollinear
5. The error terms are homoscedastic with no autocorrelation[1]
6. Error terms are normally distributed

[1] I will relax this assumption in my econometric model.

This method is rather simple, which leads to limitations. There is a risk of multicollinearity, where some of the independent variables may correlate with each other, making it harder to estimate the true effect of a specific. The effect of oil price changes on CO_2 emissions might be overestimated, since oil prices are correlated with, for example, inflation. There is also a risk of endogeneity, where the independent variables and the error term are correlated. This leads to wrong estimates of the regressors and reduces the model's overall fit. In this case, oil prices might be correlated to a variable in the error term, meaning that the true effect of an oil price change is lower in reality than the model shows. There could be more variables affecting emissions that are not taken into account in this study, which means that there is a large risk of omitted variable bias. There is also a risk of reverse causality between not only CO_2 and oil price but also between emissions and the other independent variables, such as GDP/cap and the Paris Agreement. Higher CO_2 emissions might in reality also cause increases in oil prices from environmental policies. This would mean that the estimated effect of oil price changes is higher than the actual effects.

These limitations, especially the risk of endogeneity, lead to the results showing only the correlation between the variables and not the causal effect. The results can still give valuable insights into the relationship between the variables, however, remember that it does not show the direct cause-and-effect relationship between changes in oil price and CO_2 emissions.

To reduce the risks of biases having a large effect on the estimated effects, IV regression would be a suitable research design. It would reduce the risks of biases by adding new variables in the regression to estimate unknown factors affecting emissions, and isolate the part of the regressor that is correlated with the error term to analyze the unbiased estimate of the coefficient on its own (Stock & Watson 2020). Vector autoregression could also be used to regress both oil prices and emissions as the dependent variable in two different regressions, to see the correlation between these variables and the rest, and also by lagging the regressors.

In this study, the relationship between CO_2 emissions and oil prices is studied. However, a problem regarding this type of research question is that changes in emissions could be caused by changes in oil demand as a result of the new price and not directly by a price increase.

4.2 Data Description

Data was collected between the years 1980-2021 in Sweden. The dependent variable is the monthly CO_2 emissions. The independent variable of greatest interest is the oil price. The data set also contains control variables to control for confounding effects on CO_2 levels, with data on environmental taxes, GDP per capita, inflation rates, and dummy variables for the COVID-19 pandemic, European Union membership, and the Paris Agreement.

Table 2. *Units for all variables except dummy variables*

Variable name	Unit
Dependent variable	
CO2cap	Tonnes per capita
Independent variables	
monthlyoilprice	USD
inflation	CPI in percent
GDPcap	Million SEK
envtax	Million SEK

As seen in Table 2, the dependent variable CO2cap is measured in tonnes of CO_2 per capita (Our World In Data 2023). CO_2 emissions are the dependent variable, as it depends on the rest of the variables included in the regression. The unit is used to give a more accurate picture when comparing countries with different population sizes.

The monthlyoilprice variable is the monthly world average price of crude oil per barrel measured in USD (World Bank 2023). I decided to keep this currency to not let other factors, such as changing exchange rates, impact the interpretation of the price changes. There was difficulty finding monthly historical data on exchange rates, so this also reduced the time spent on data collecting.

The inflation variable was collected on a monthly basis and is measured in percent and based on the CPI for all goods and services in the economy except housing costs (Statistics Sweden 2023a). In itself, inflation might not largely impact emissions. However, it was included as it affects other variables in the regression, such as GDP and environmental tax revenues.

The GDPcap variable shows the GDP per capita, in million SEK, with the expenditure approach, considering all private and government consumption plus net investments and exports (Statistics Sweden 2023b). The data was originally on quarterly basis and was therefore transformed into monthly data. This variable is included to show the relationship between economic growth and emissions, to see the environmental impact of economic activities, as well as examine the decoupling, to differentiate the reduction of emissions caused by economic growth to find the exact effect of the oil price changes.

The Envtax-variable shows environmental tax revenues collected in Sweden, measured in million SEK, and was originally yearly data but later transformed into monthly (Statistics Sweden 2022). Environmental taxes are policies used as economic incentives for emission reduction (United Nations 2014). Introducing taxes of this type aims to reduce emissions by price increases. Therefore, it is interesting to add environmental tax revenues as a control variable to account for the effect these taxes might have on emission levels.

Dummy variables have also been added as control variables in this regression. The first is Paris, which shows the effect of the Paris Agreement ratification, enacted in November 2016 (European Council n.d.). Therefore, the variable takes the value 1 for November 2016 and every month after. For previous months, it will take the value 0. Including this in the regression allows for examining if it has significantly reduced CO_2. Additionally, it controls for the emissions that are reduced as a result, separating this effect from the changes in oil price.

EUmember is controlling for the membership of the European Union, which Sweden joined in January 1995 (European Union n.d.). Therefore, all months before this date will take the value 0, while January 1995 and all months thereafter take the value 1. The EU-membership allows for more accessible trade between member states, but can also be a way to cooperate on issues that affect more than one country, such as environmental concerns. Including it will show if the membership has mainly been positive or negative for overall CO_2 emissions, and control for the changes in emissions caused by the membership.

The last control variable, also a dummy variable, is named covid and shows what effect the COVID-19 pandemic had on CO_2 emissions. Since covid was declared a pandemic in March of 2020 (WHO 2020), March of this year and all months thereafter take the value 1, while all other months take the value 0. When the pandemic occurred, emissions were reduced (Liu et al. 2020). This variable is therefore included to control for the pandemic's effect on CO_2 emissions.

The variables for the oil price change's effect in coming months are called oilprice6months, oilprice12months, oilprice18months, and oilprice24months. They are interpreted as how changes in oil price affect CO_2 emissions 6, 12, 18, and 24 months after the price increase. These lags have been chosen randomly but with the same time span between them.

Table 3. *Descriptive statistics of variables*

Variable name	**Observations**	**Mean**	**Std. Dev.**	**Min**	**Max**
Dependent variable					
CO2cap	504	0.5034702	0.1028306	0.2854167	0.719
Independent variables					
monthlyoilprice	504	42.94933	28.82844	9.616667	132.8252
oilprice6months	498	42.61922	28.82837	9.616667	132.8252
oilprice12months	492	42.31223	28.8588	9.616667	132.8252
oilprice18months	486	42.34587	29.01105	9.616667	132.8252
oilprice24months	480	42.33859	29.17331	9.616667	132.8252
inflation	504	0.269246	0.5553881	-1.4	3.3
GDPcap	504	0.0234306	0.0108976	0.005714	0.0480127
envtax	348	1.25	0.6855241	0.0833333	2.416667
Paris	504	0.1230159	0.32878176	0	1
EUmember	504	0.6428571	0.47963349	0	1
covid	504	0.0436508	0.20451991	0	1

Table 3 shows descriptive statistics of the data used in this paper. As seen, most variables have 504 observations, which are all months for the 42 years studied. The environmental tax-variable only has data from 1993 and onwards, which explains why this variable has 348 observations. Since the variables for oil price effects in future months are lagged, the number of observations for these variables is the total observations minus the number of lagged months.

The table also shows the mean, minimum and maximum values and the standard deviation for all included variables.

4.3 Econometric Model

The econometric model is a time-series linear multiple regression model. Huber-White standard errors, called robust standard errors, are used to account for possible heteroscedasticity in the sample and provide a more accurate estimation of the standard errors, since heteroscedasticity would change the conclusion being drawn (Hayes & Cai 2007). OLS is used to estimate the error terms.

4.3.1 Main regression

The main regression is specified as:

$$y_t = \beta_0 + \beta_1 oilprice_t + \beta_2 oilprice_{t-6} + \beta_3 oilprice_{t-12} + \beta_4 oilprice_{t-18} + \beta_5 oilprice_{t-24} + \beta_6 Inflation + \beta_7 GDPcap + \beta_8 Paris + \beta_9 EUmember + \beta_{10} covid + \varepsilon$$

where y_t is the dependent variable CO_2 emissions/capita. β_0 is the constant, β_1 is the effect of an oil price change today, β_2 is the effect of an oil price change six months ago, β_3 is the effect of 12 months ago, β_4 is the effect 18 months ago, and β_5 is the effect of an oil price change 24 months ago. The β_6 shows the effect of inflation and the β_7 shows the effect of GDP per capita. The effect of the different dummy variables is shown by β_8, β_9, and β_{10}. Lastly, the ε is the error term of the regression.

4.3.2 Naïve regression

A second regression was also conducted, specified as:

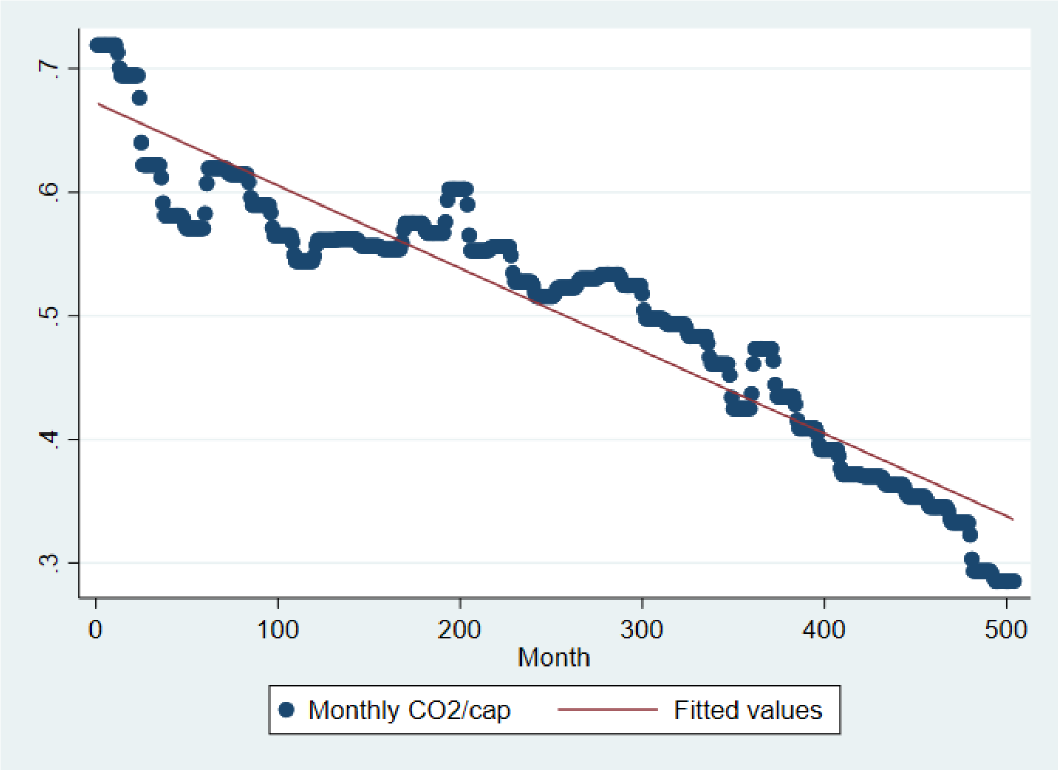
$$y_t = \beta_0 + \beta_1 oilprice_t + \beta_2 oilprice_{t-6} + \beta_3 oilprice_{t-12} + \beta_4 oilprice_{t-18} + \beta_5 oilprice_{t-24} + \beta_6 Inflation + \beta_7 GDPcap + \beta_8 envtax + \beta_9 Paris + \beta_{10} EUmember + \beta_{11} covid + \varepsilon$$

where all variables from the main regression are included, as well as a variable showing the environmental tax effect. The name of the beta-coefficients for the dummy variables differs from the main regression since the environmental tax effect is shown by β_8.

This is a second regression because the number of observations for the envtax-variable was considerably less than the other observations which reduce the preciseness, and a higher uncertainty should be avoided if possible.

4.4 Estimated trends

Figure 6. *Estimated trend line based on the observations, showing the development of CO_2 emissions over time.*



By plotting a graph with CO_2 emissions per capita on the y-axis and time on the x-axis, we see the changes in emissions over time. This is shown in Figure 6.

Month 1 is January 1980, and the last month, 504, is December 2021. The blue dots are the observations from the data set.

In STATA, it is possible to add a fitted line in these graphs, which has been done to show the trend line for the observations in the data set. During the studied months, emission levels show a trend of reducing over time. However, this graph does not take the significance levels into account.

Figure 7. *Estimated trend line based on the observations, showing the relationship between CO_2 emissions and the world average oil price.*

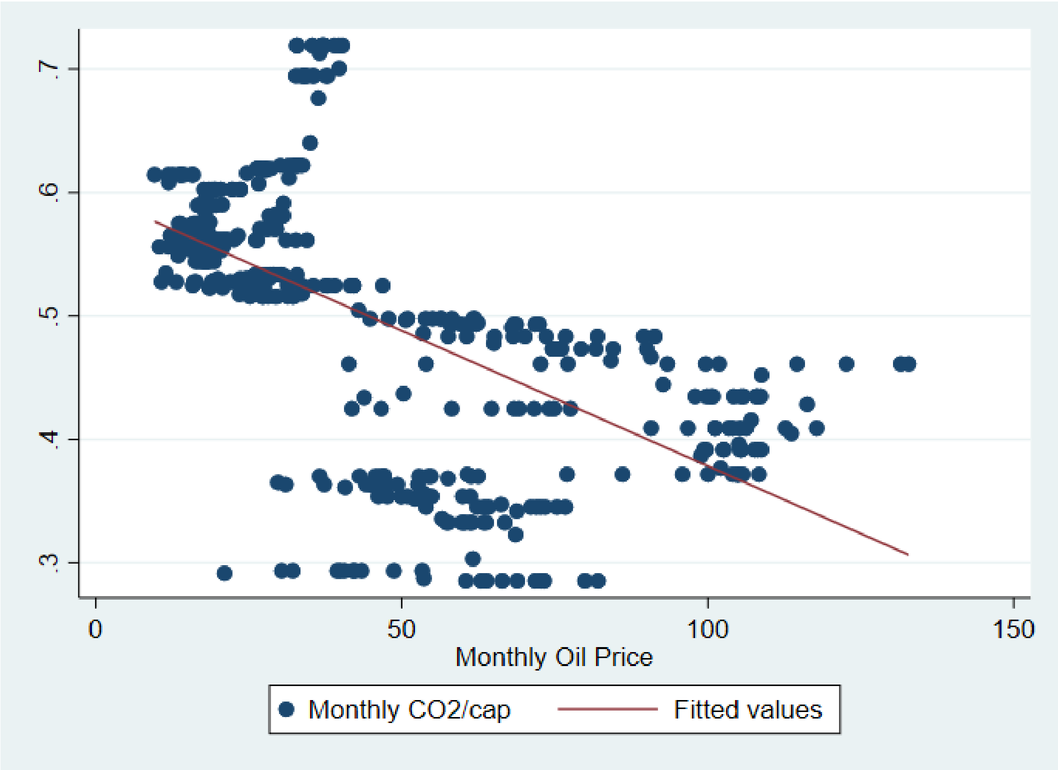


Figure 7 shows the estimation of the relationship between the monthly CO_2 emissions and the monthly oil price based on the observations in the data set. Here, the fitted line shows a trend of lower emissions when the oil price increases.

5. Results

This section will present the results of the regressions explained in the Method.

5.1 Main Regression

Table 4. *The estimated effects of each regressor on the dependent variable in the main regression.*

Variable name	**Coefficient**	**Robust standard errors**	**P > |t|**
monthlyoilprice	0.000179***	0.0000587	0.002
oilprice6months	6.17e-06	0.0000862	0.943
oilprice12months	-0.000289***	0.0000768	0.000
oilprice18months	-0.000419***	0.000088	0.000
oilprice24months	-0.000238**	0.00012026	0.021
inflation	0.00157	0.00168	0.350
GDPcap	-6.781***	0.314	0.000
Paris	-0.0556***	0.00460	0.000
EUmember	0.0272***	0.00366	0.000
covid	-0.0327***	0.00402	0.000
constant	0.741***	0.00607	0.000

***** indicates a significance level of 99 %, ** a significance level of 95 % and * a significance level of 90 %.*

The R^2 for the main regression is 0.9621. There are a total of 480 observations in this sample.

Table 4 shows the results of the main regression. It presents the effect of each regressor on the dependent variable, the robust standard errors, and the estimated p-value. The p-value and the stars seen beside the estimated coefficients explain the significance level of the results, interpreted as the likelihood that the actual value of the coefficient falls within one standard error from the estimated value (Stock & Watson 2020). A higher significance level indicates that the estimation is close to the true value with higher certainty.

All coefficients except the oil price after six months and the inflation are significant. Of the significant coefficients, all variables are significant at the 99 % level except the oil price after 24 months, which is significant at 95 %.

There is a significant positive effect of immediate oil price changes and emissions. This is interpreted as when oil prices increase today, CO_2 emissions will also increase. In the short run, a six-month interval, there is no significant effect of oil price changes on emission levels. It is therefore impossible to draw conclusions about the effect that an oil price increase will have on CO_2 emission levels six months afterward. The variables for the oil price increase on CO_2 emissions 12, 18, and 24 months later, are all negative and significant. This indicates that, in the long run, oil price increases lead to decreasing emissions.

The inflation variable is insignificant, and it is impossible to say that inflation affects CO_2 emissions.

GDP per capita has a significant, negative effect on CO_2 emissions, according to Table 4. The interpretation of this coefficient is that with an increase in GDP per capita by one million SEK, emissions will decrease directly.

The estimated coefficients of the dummy variables differ. They are all significant at the 99 % level. However, both the Paris Agreement and the pandemic show effects of reducing emissions, while the EU membership has increased CO_2 emissions in Sweden. As they are dummy variables, the effect is interpreted as how emissions change when going from 0 to 1, that is when Sweden joined the EU, when the Paris Agreement was enacted, and when the COVID-19 pandemic started.

5.2 Naïve Regression

Table 5. *The estimated effects of each regressor on the dependent variable in the naïve regression.*

Variable name	**Coefficient**	**Robust standard errors**	**P > |t|**
monthlyoilprice	0.0002016***	0.0000652	0.002
oilprice6months	2.22e-06	0.0000917	0.981
oilprice12months	-0.0003097***	0.0000782	0.000
oilprice18months	-0.0004452***	0.0000949	0.000
oilprice24months	-0.000256**	0.0001137	0.025
inflation	0.0049926**	0.0024181	0.040
GDPcap	-6.521581***	0.55947	0.000
envtax	-0.0003948	0.001483	0.790
Paris	-0.0587***	0.00726	0.000
EUmember	0.0173***	0.00450	0.000
covid	-0.0336***	0.00377	0.000
constant	0.760***	0.00715	0.000

*** indicates a significance level of 99 %, ** a significance level of 95 % and * a significance level of 90 %.*

The R^2 for the naïve regression is 0.961 with a total of 348 observations.

The results of the naïve regression are found in Table 5. Most coefficients show a similar effect, as in Table 4. However, a significant, positive relationship between the inflation rate and CO_2 emissions was found. This implies that when the CPI increases, emission levels also rise.

In this regression, a variable for environmental taxes was added, which is negative. Yet, this coefficient is insignificant and does not explain the true relationship between the dependent variable and emissions.

This regression shows that environmental taxes are less important than other factors contributing to the CO_2 emissions in Sweden, such as GDP and the Paris Agreement.

5.3 Robustness Check

Two regressions were conducted in this study. One where all variables were included, called the naïve regression, and the main regression where environmental tax revenues were excluded. These are two different models because we want as many observations as possible to estimate the true effects of each variable for more precise results. It also reduces the risks of outliers having a large impact on the estimations. Also, the naïve regression shows that the environmental tax revenue variable is insignificant even when added, making it possible to run the regression without it. The main regression is, therefore, a better fit since it explains the real-world effects more precisely due to more observations in the sample.

Both regressions have an R^2-value of about 0.96, indicating that the estimated model explains about 96 % of the changes in CO_2 emissions in Sweden over this period. Most of the coefficients also show a high significance level, meaning that the estimated effect is close to the real-world effect. However, there is always a risk of omitted variable bias. Because of the large R^2, this should not be a great issue in this paper, but more variables could have been included to reduce this risk.

6. Discussion

In this section there will be an empirical analysis, discussing the results and a shorter section on the policy implications these results could have. Lastly, there will be a part discussing areas of improvement that can be useful for future studies.

6.1 Empirical Analysis

A positive relationship between oil price increases and CO_2 emissions was found immediately. When the oil price increases by 1 dollar per barrel, CO_2 emissions in Sweden increase by 0.000179 tonnes per capita, or 0.179 kg. This could be explained by how the energy supply in Sweden is structured. As was mentioned in the study of Wang et al. (2020), oil price increases are effective for increasing the amount of renewable energy in the energy mix. There could, however, be costs associated with switching energy sources, which here might be higher than the price increase. If companies act to minimize costs today, oil consumption will not be reduced.

However, this result is unexpected and abnormal based on economic theory. When prices increase, the basic theory of supply and demand says that the demanded supply would decrease. Applying this theory here, when the oil price increases, the oil demand should decrease and the CO_2 emissions from the oil combustion should decrease too, which is the opposite of these results.

One explanation is that there is omitted variable bias in the estimated model, meaning that a factor affecting CO_2 emissions has been omitted from the model, making the estimations of the other coefficients wrong. Some variables that could be included to reduce these risks are the energy consumption from fossil fuels, prices of renewable sources and number of patents (to quantify the technological progress in the economy). The direction of the bias could be either positive or negative, depending on which variables have been omitted. Omitted variable bias leads to overestimations of the effect oil price changes have on emissions.

The study could suffer from reverse causality, meaning that the direction of the relationship between CO_2 emissions and oil prices is incorrectly estimated. In reality, changes in CO_2 emissions might also affect oil prices if governments impose tariffs, or similar economic policies, due to the increased emissions and the damages it is causing. The reverse causality could also arise if the trend of fossil-free energy sources is starting to dominate the energy market. Emissions would reduce and the oil demand would start to fall, as well as the oil price. This appears accurate according to economic theory, as increasing CO_2 means that new policy instruments for reducing emissions are imposed, and some of these target the price of oil or CO_2. This can have immense effects on the estimations of the coefficients. It could explain why a positive relationship is shown in the immediate time period instead of a negative which should be expected. The direction of this possible bias is likely negative since an increase in oil prices should lead to a decrease in CO_2 emissions, according to economic theory, while an increase in emissions should lead to economic policy changes that increase the price of oil.

There is a risk of simultaneous causality bias, which means that multiple variables influence each other simultaneously, making it difficult to estimate the true causal effect between oil prices and CO_2.

To reduce the risks of these biases, instrumental variable regression could be used, which would make the estimation of the coefficient effects more reliable. This is done by adding new variables in the regression that estimate the factors affecting CO_2 emissions, but are unknown (Stock & Watson 2020). IV regression isolates the part of the regressor that is correlated with the error term, and allows us to analyze the unbiased estimate of the coefficient on its own, for more reliable estimations.

The model is unable to explain the real-world effect in six months as no significant effect was found. If the same reasoning as for the immediate effect is applied here, it might be profitable for some economic actors to switch energy sources after a six-month period, while the costs might be too high for others. This depends on the marginal costs of production for each company. The large variation between economic agents may lead to insignificant coefficient estimates.

After more than six months, a negative effect of oil price increases on CO_2 emissions has been identified at the 99 or 95 % significance level. When the oil price increases by 1 USD, emissions reduce by about 0.289 kg per capita after 12 months, 0.419 kg after 18, and 0.238 kg after 24 months. This shows that the impacts of oil price increases can be seen long after. The largest effect is seen after 18 months.

This paper is based on the multiple linear regression model, which could be too simple for explaining the relationship between CO_2 emissions and oil price changes. The risk of using a model like this is that it may not capture all factors contributing to the change in emissions, making the results less reliable. One large issue with this model is that there may be confounding factors contributing to both changes in emissions and the price of oil. This could for example be unexpected economic growth, which can cause both a price increase and a quantity increase at the same time. Energy policies or technological advancement could be other factors that can affect both oil prices and CO_2 emissions simultaneously.

The effect of the price increases may also depend on the own price elasticity of oil. A study by Krichene (2002) found that short-run demand elasticity for oil was -0.02. This implies a minimal decrease in demand from a price increase of 1 % and that oil is inelastic, unlike what is found in this study. The differences in elasticities could be due to this study expanding 20 years after the previous and that the economic structures and oil dependence may have changed. It could also be that the demand is elastic in Sweden but not globally.

Looking at these results compared to the cross-price elasticities of demand for other energy sources would be interesting, as increases in oil prices may greatly affect the demand for electricity from renewable sources.

GDP shows a significant negative effect on CO_2 emissions, which means that economic growth in Sweden results in reduced emissions. When GDP per capita increases by 1 million SEK, emissions decrease by around 6.78 tonnes of CO_2. This shows an apparent decoupling effect. In Figure 4, the decoupling effect of CO_2 emissions and the GDP in Sweden was presented, corresponding to the conclusions drawn from these estimations. Despite this clear negative relationship, it is important to remember that a monthly increase of 1 million SEK per capita is incredibly much and unlikely in real life. However, since the relationship is so clear, it shows that emissions will be reduced no matter the increase in GDP. The trend of decoupling in Sweden during these years has been plotted in a graph in Appendix 1.

The inflation-variable shows that with increasing inflation by 1 %, CO_2 emissions increase by about 1.57 kg per capita and month. However, this result gives us little information about the real-world effects since the coefficient is insignificant. The explanation for this could be similar to the oil price after six months, namely that the variation is so big that we cannot draw a clear conclusion from the impact of inflation. Also, in itself, inflation might not have an impact but affect other variables that later affect CO_2 emissions, such as GDP.

The Paris Agreement-variable shows a significant, negative relationship to CO_2 emissions. This is interpreted as, since the Paris Agreement ratification, Swedish CO_2 emissions have reduced as a result. Here, it is shown that Sweden has managed to reduce its emissions, by almost 56 kg CO_2 per capita and month. However, no conclusions on how the agreement has reduced global warming can be drawn from this.

The EU-membership has enabled cooperation and trade between European countries to a great extent. The relationship between the membership and CO_2 emissions is significant and positive, implying that emissions have increased from the Swedish EU-membership by ca 27 kg of CO_2 per month and person. This can be a reasonable effect but may also be surprising. The cooperation on environmental issues in the EU is well-developed with policies regarding mitigation and adaptation to climate change and how to transition to a circular economy (European Parliament & Council of the European Union 2020/852). These types of intergovernmental agreements should lead to reduced emissions. However, here the opposite is shown. One reason could be that with EU-membership comes increasing opportunities for the population to increase consumption, or that Sweden could expand its export in some areas after joining the EU, and therefore more CO_2 was emitted.

As mentioned, Liu et al. found that CO_2 emissions decreased during the COVID19-pandemic. Here, the same effect is seen in Sweden. The estimated coefficient is negative and significant, showing that emissions decreased by 32.7 kg per capita in months when covid was declared a pandemic.

The environmental tax variable, found in Table 5, shows a negative effect of these tax revenues on CO_2 emissions. An increase in the environmental tax revenues by 1 million SEK would decrease emissions by 0.395 kg per capita. However, this effect is insignificant, and it is impossible to say that this is the real effect of the Swedish environmental taxes. One reason could be that they are calculated in million SEK, which in the whole economy is not much, as the Swedish GDP is a few billion SEK. Studying the effect of the total tax revenues compared to the environmental tax revenues would be interesting, as they usually depend on each other and the political rule in Sweden.

The effect of the environmental taxes found in this regression is the same as what can be found in previous literature. Taxing CO_2 alone does not seem to affect CO_2 emissions significantly.

6.2 Policy Implications

These results can have important policy implications. I have shown that when oil prices increase, a reduction in CO_2 emissions is seen in the long run. This is needed to stop global warming and other environmentally destructive phenomena caused by increased temperatures.

Economic incentives seem to affect emission reduction regarding oil in Sweden. This can be used to decide on new policies regarding oil combustion, for example price floors for oil. However, this can be difficult to implement as Sweden is an oil importer, and the market is based on a few sellers.

Another policy that could be implemented that might be more effective is tariffs on oil imports, to increase prices for both sellers in Sweden and the final consumers. It could, however, be difficult to impose this in Sweden alone because of the close ties with the rest of Europe. A possibility would be that these tariffs are imposed when the oil enters the EU.

It is important to have some policies regarding pricing of oil since it is environmentally destructive and leads to higher CO_2 emissions. Sweden aims to follow the polluter pays principle and if this is applied here, Sweden would have to ensure that the oil price is as high as, or higher than the costs of the CO_2 emissions it is causing.

A significant effect of environmental taxes in Sweden was not found in this study. For this reason, these taxes could be reduced as they do not have an effect or be increased further to increase the price until it is no longer worth the emissions it is causing, to nudge the consumers to switch energy sources.

6.3 Areas of Improvement

This paper could be improved in many areas. More variables could have been added to control for other factors that may impact the CO_2 levels in Sweden. Some examples of such variables are the energy consumption from fossil fuels and number of patents.

As has been mentioned, what is being studied here is the correlation between oil prices and CO_2 emissions. This means that the results do not capture the cause-and-effect relationship as when studying the causal effects. To improve this study, and get results that are more useful in policy-making, a Granger-causality test could be conducted to determine how well the regressor can predict and forecast future values of the dependent variable (Rossi 2013). In this case, it would be possible to see how well oil prices predict changes in CO_2 emissions, which shows that there is a causal effect and not just a correlation between the variables.

The study seems to suffer from bias, probably occurring from variables that have been omitted or that there is simultaneous causality bias between the independent variable and the dependent. To make sure this does not happen in future studies, one could continue this study by doing an instrumental variable regression to separate the correlation between oil prices and CO_2 emissions from the error term, which gives more reliable and unbiased estimators.

Some changes could be made to improve this paper further and simplify interpretation of the results. First, the measurements should be in lower units, for example, one hundred thousand SEK, since it is unlikely that GDP increase by one million SEK over a month. Secondly, all financial data should have been measured in the same currency for an easier interpretation. In this case, the monthly oil price was impossible to find in SEK. The exchange rate between the currencies could be added to adjust for this.

It could also be good to look at more years to increase observations in the data set, which improves the estimations' accuracy. Studies on other countries could also be conducted for more observations. In that way, it would be possible to see if the effects are similar for all countries or if they are country-specific for Sweden.

Since the original downloaded data was on different time basis, the variables were smoothed. Therefore, the monthly variables created are not completely accurate to reality since the yearly or quarterly changes were distributed to show monthly differences. For this reason, some trends between months or seasons may have been overlooked.

The oil price increases were lagged to show the effect in future months. Here, the 6,12, 18, and 24 months were chosen randomly but with the same interval. It would have been better to conduct this study by lagging on all months to see in which months the effect is the largest and when the price increases do not have an effect anymore.

7. Conclusions

In this paper, the correlational relationship between oil price increases and CO_2 emissions has been studied by setting up a multiple linear regression model with robust standard errors and control variables.

The direct effects of oil price increases were positive, suggesting that oil price increases immediately lead to increased CO_2 emissions by 0.179 kg per capita and month, which according to economic theory is inaccurate. There are probably other factors contributing to this, such as a too-simple method or omitted variable bias. In the longer time frame, CO_2 emissions were shown to be reduced by between 0.24 to 0.42 kg per capita depending on the time after the price increase.

The relationship between oil prices and CO_2 emissions does not show the causal effect of an oil price change, but instead the correlation between the two variables. Because of the simple method used when conducting this study, there is a great risk of endogeneity and simultaneous causality, that have not been taken into account which makes the estimations less reliable. There is also a risk of omitted variable bias, where a variable that is not in the data set may be affecting both CO_2 emissions and oil prices. This leads to incorrect estimates of the independent variables and affects the conclusions that can be drawn.

Previous studies suggest that oil is inelastic, meaning that price increases do not have a large effect on oil demand. Here, I instead show that oil price has an elastic demand over time in Sweden.

No significant effect was found for the inflation and environmental tax variables. There is also no shown effect on emissions six months after an oil price increase.

Oil price increases are an effective instrument to reduce CO_2 emissions in the long run. This can be important for formulating governmental policies regarding the reduction of emissions. Two examples of economic policy instruments that can be imposed to increase the price of oil and reduce emissions are tariffs or price floors.

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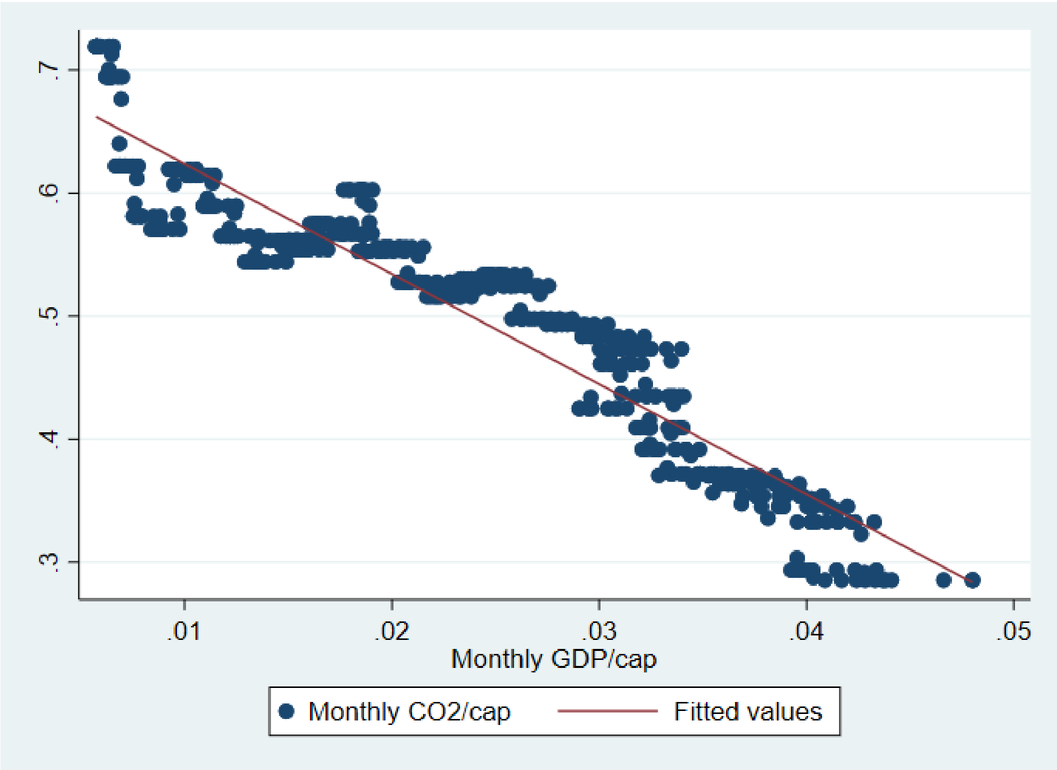
Appendix 1



This graph shows the relationship between GDP per capita on the x-axis and CO_2 per capita on the y-axis. The line is fitted to show the best-fit trend line for the observations in the data set. It is clear to see that CO_2 emissions in Sweden have a trend of reducing when GDP per capita increases.

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