Carbon dioxide, renewable energy and economic growth

[A Swedish non-EKC case study]

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ABSTRACT

The purpose of this master's thesis is to investigate the relationship between renewable and non-renewable energy consumption, economic growth and carbon dioxide emissions per capita in Sweden in the period of 1970-2018. As indicators, the economic indicator will be represented by the per capita gross domestic product, GDP, as the environmental indicator this study will use carbon dioxide emissions per capita, CO2, and the energy use per capita will represent the energy consumption variable.

The research hypothesis is based on the idea of the classical EKC, the Environmental Kuznets Curve. Multivariate Vector Error Correction Model (VECM) approach which makes possible to evaluate non-stationary and cointegrating variables, while overcoming the omitted variable bias was used for the methodology part. Econometrics tests such as Augmented Dickey-Fuller Test and Johansen co-integration test are included, and the Granger causality test will provide four hypothesizes for the potential causalities between the included variable in this study.

Keywords:

Economic growth, Environmental Kuznets Curve, Granger Approach, VECM, Sweden, Renewable energy consumption

Preface

This publication is a part of our research work at the Södertörn University, funded by the Swedish Institute Scholarship. Thank you for the opportunity. We would also like to thank our supervisor Julian Eduardo for his good advising, humor and patience. You have been of great importance for our success in writing this thesis, and we will be forever happy that you came to help us out when we were lost.

Thank you.

Спасибо.

CONTENT

INTRODUCTION

One of today's biggest challenges globally is environmental pollution. To control this emerging issue, a lot of policies and agreements are set. Globally, there are agreements such as the Paris agreement, which was adopted in 2015 by 196 parties. The goal of the Paris Agreement is to limit global warming and to achieve this, the agreement encourages the countries to decrease the rise of greenhouse gas emissions as soon as possible. All countries within the agreement have set up a NDC; a nationally determined contribution, where they communicate their actions to reduce GHG:s. Further, the agreement also invites countries to develop long-term GHG strategies to show development priorities (UNCC). Sweden ratified the Paris Agreement in October 2016 and was one of the first countries to adopt a net-zero target, the long-term strategy aims for achieving net zero by 2045 and thereafter negative emissions. The Swedish government is ambitious and has set energy policy targets addressing both energy efficiency and renewable energy. The main goal of the government is to become the world's first welfare nation. The target is high, 100% renewable energy production by 2040. The government is highly determined to meet both the commitments under the Paris Agreement and the national goals, but without endangering the competitiveness. One key point in the long-term strategy is to guarantee that the objectives of climate policy and budget policy interact with each other positively. (Ministry of the Environment, 2020)

There have been many studies conducted to examine the potential relationship between economic growth and ecological degradation. The most famous hypothesis within the field is the Environmental Kuznets Curve (EKC) which was advanced in 1991 and is characterized by an inverted U-shape. Initial economic growth leads to a degradation in the environment, but when reaching a certain level the society will turn over and instead focus on improving the environmental relationship due to awareness and better technology. Hence the level of environmental degradation will start to decrease (Stern, 2018; Levinson). The EKC indeed draw attention to the importance of understanding the causality between economic growth and energy, but the hypothesis is also quite debated regarding its suitability to developed countries – that it creates an acceptance for no action, since the problem of emissions will be handled at a later stage in which the economy has reached a certain point. Instead, more recent studies choose to use models as Vector error correction model (Xu et al 2014; Zhang et al 2017) or error correction model (Pao et al. 2011). The hypothesis in many of the studies is based on the Granger Causality test, as Zhang et al 2017; Xu et al. 2014; Bercu, Paraschiv & Lupu 2019. The Granger test normally propose four different outcomes, or granger causalities, depending on the direction of the relationship between the studied variables. The causalities can help to forecast the implications of policies and therefor it is of great importance for governments and policymakers to understand these potential relationships for making proper political decisions, which otherwise risks to not reach its targets.

The purpose of this study is to analyze the relationship between economic growth measured in GDP per capita, CO_2 emissions, non-renewable and renewable energy consumption in Sweden in the years 1970-2018. To address such relationship, this study will carry out a Vector error correction model and a Granger causality test. As stated above, there are already plenty of studies exploring this area, but so far there are very few studies that separating non-renewable and renewable energy consumption into their study which will make this analyze deepen the insight even more, especially for the Swedish case. The reason for including renewable energy consumption, is due to the policies in Sweden over these years, it will be biased to not include this variable, since it is an important part of the transition towards a low-carbon economy.

RESEARCH QUESTIONS

1. Is there any short-run or long-run relationships between the non-renewable and/or renewable energy consumption, economic growth and CO2 emissions in Sweden?
2. Are there any causal relationships between the non-renewable and/or renewable energy consumption, economic growth and CO2 emissions in Sweden? If any, in what direction does the causality goes?

MAIN FINDINGS

The aim of the study was to analyze the relationship between economic growth (GDP), CO2, energy consumption (renewables/non-renewables) in Sweden for the period 1970-2018. The main econometrical tool for estimation was a Vector error correction model (VECM), and the results were analyzed through a granger causality approach. The results showed a neutrality hypothesis which means that there is no causality between energy consumption and economic growth, at least not to a high extent. Bidirectional short-run causal relationships were identified between non-renewable energy consumption and carbon emissions, and unidirectional short-run causality from CO2 emissions to renewable energy consumption. Long-run relationships were identified between all variables of interest: non-renewable and renewable energy consumption, economic growth and CO2 emissions.

STRUCTURE

The paper will be structured as followed: First, background is going to be described through two chapters which contains both the macroeconomic history to clarify the model and hypothesis within. This is followed by a short background on Swedish history to describe the individual country which is the chosen case for the study. Chapter two will evaluate previous research. The literature review will show the spread of used models for the used case, but also provide an understanding of the practical use of the EKC hypothesis.

Method chapter will outline the methods, how the data is gathered and transformed. This chapter will also describe the econometric models for interpretation. Method is followed by an Estimation chapter, which will show practically the methods used for this specific case. The transformed data from Sweden will then be applied. Estimation will analyze the results throughout and therefor contains plenty of tables, graphs etc. to visualize the result and to help compare data for the reader. The estimation chapter will also include several tests to increase the credibility of the study. The last chapter will outline the overall findings of the study and discuss the result in relation to the research question and hypothesis. The discussion is going to highlight research objectives as well as showing limitation and future research.

Background

First Part - Economics

The discussion of the potential relationship between economic growth and energy goes way back. Stern and Cleveland (2004) are in their paper leading the way through several growth models, debating what's missing and then ending up with the conclusion that energy and growth are closely linked. They mean that the classical economic literature plays too little attention to this linkage to economic growth and instead only base the theories on main factors as labor and capital, and by that also decline the role of energy as a driver of production and economic growth (6). The neo-ricardian models are unable to take substitution between factors of production into account when not considering the biophysical constraints of mass balance and energy conservation. In the neoclassical perhaps the Solow model (1956) is one of the more well-known theories of growth. The Solow model is assuming that countries grow faster due to small capital stock per worker but eventually will reach a stationary level where there is a zero-growth equilibrium. The only chance of continuous growth can be due to technological development, but just assume that the change can come about without specifying further (Stern & Cleveland, 2004, 7). It is worth mentioning that there is neoclassical literature which includes both growth and natural resources which are promoting growth. Sustainability is possible, determined by the institutional and technical conditions. Technical condition in this case includes resources which are both renewable and non-renewables, initial endowment of natural resources and capital and substitution among inputs (10). Solow (1974) show that it is possible to achieve sustainability, in a model where the utility was maximized over time. This model thus resulted in exhaustion of both consumption and resources, and then the welfare will decrease to zero (Stiglitz, 1974). Other neoclassical studies which have been investigating the role of both resources and technological change are not yet providing conditions for reaching sustainability, and the main criticism is that they all tend to focus on institutional limits. (Stern & Cleveland, 2004, 12).

Ecological economists, according to Stern and Cleveland (2004), has another mindset than the economists presented in previous part. Instead, they are focus on the economy's basis of material where they pay attention to the weight of limits to the substitution type, especially capital (including energy). Ecological economists also consider that neoclassical theories reject the physical interdependence, that all kind of process and maintenance of tools will constantly demand a flow of material and energy. Therefor it will not be possible to substitute produced capital, it will also demand more. While the neoclassical economists' states that the technical change will create continuous growth, the ecological argues that the changes in technology only can occur by developing new which are embodied in improved capital, skills and experiences among the labor. All these factors will demand energy and a flow of material. (Stern & Cleveland, 2004, 15-17)

Connected to the oil crises in the 1970s which created a big debate concerning the slowdown in production, the relationship between economy and energy suddenly gained attention. The 1972 UN Conference in Stockholm was called upon to shed lights on environmental problems and especially towards transboundary pollution but resulted in three major products, in which the linkages between environment and development issues gained focus. In 1971 an economist called Simon Kuznets was awarded to the Nobel Prize in Economics for his interpretation of interaction between science, innovation, and institutional skills, alongside with factors external to the economies impact on the progress of growth. (Stern & Cleveland, 2004, 2; Brisman, 2011). Among Kuznets theoretical research, the economist also presented the Kuznets curve, which was an inverted U-curve between income inequality and economic growth. The model implicated that the differences in income will increase with economic growth in a higher extent in poor countries than in rich, which was explained that to develop economic growth in poor countries they had to shift from agriculture to industrial, which would create large income disparity at first, but in time living conditions such as education rises and will create opportunities to decrease the inequalities in income. (Kuznets, 1955)

The Environmental Kuznets Curve was advanced by the economists Grossman and Kruger in 1991 to include environmental factors as well and has been the dominant approach to model emissions among economists since then. In 1992, the model was first populated in a simple empirical approach at the World Bank and the model is characterized by initial growing economic development which leads to a degradation in the environment, but when reaching a certain level, the society will instead improve the environmental relationship due to awareness and better technology, and hence the level of environmental degradation starts to reduce (Stern, 2018; Levinson). But just as the curve's shape, the interest for the model has seen its rise and fall. The model has met a lot of criticism in recent years, mainly because of the flimsy results of the EKC and that countries in 2020 generally are more technical developed than they were when the model was created. Energy sources are not producing a lot of CO_2 emissions nowadays, and many scholars find issues in EKC theory primary based upon this criticism (Stern, 2004). Stern (2004) mean that EKC equation regressors are correlated with the country effects and time effects, which indicates that the regressors are likely correlated with omitted variables. The omitted variables could be changes in economic structure or product mix, changes in technology, and changes in input mix, as well as underlying causes such as environmental regulation, awareness, and education. Instead, Stern (2004) is suggesting some modified versions of the classical EKC model, to avoid the omitted variable bias. Stern is proposing is the Vector Error Correction Model, which together with the Granger causality tests should fit better for developed countries both to show relations between variables and the causalities.

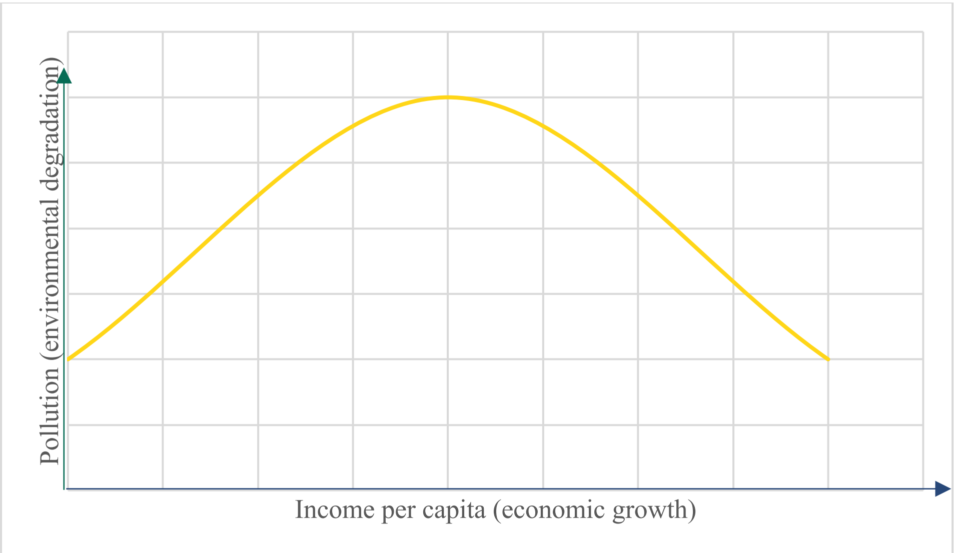

Figure 1. The EKC is showing the relationship between pollution and economic growth at different stages of economic development as an inverted U-shape

SECOND PART - SWEDEN

For the last decades, the economy in Sweden has been relatively stable and mainly been growing, at least since the 70's. But the path until today hasn't always been smooth, the Swedish economy suffered from high inflation and low growth which made the krona devaluated in late 1980's and beginning of the 90's. In the 90's there was a serious financial crisis, where the unemployment increased, the governmental spending's rose as also the national dept did, and the banks went unstable. Sweden landed on its feet's and succeeded to manage control mostly by a series of regulations and remained control during the global financial crisis in 2008. The regulations that were introduced in 1996 were both a surplus goal for the state budget and a ceiling for public spending, and ever since 1995 the national dept of GDP has fallen. In 2007, a Fiscal Policy Council was established to ensure the financial policy decisions meet the goals of employment, growth, and financial sustainability. (Riksgälden; Sweden.se).

In Global competitiveness report 2019 Sweden was at the top ten, stating: "Sweden, Denmark and Finland have not only become among the world's most technologically advanced, innovative and dynamic economies in the world, but are also providing better living conditions and better social protection, are more cohesive, and more sustainable than their peers at a similar level of competitiveness." Sweden is export-oriented and has traditionally been maintaining a trade surplus. (World Economic Forum, Sweden.se)

After the II world war, Sweden grew rapidly into an industrial society fueled by low prices on oil and energy as well as natural resources. In the early 1970, oil was accounted for 80% of energy supply, but an early policy objective was to decrease the dependency and in the years of 1973-1985 the use of oil decreased to around one third, much due to big expansion of nuclear power and energy efficiency, and since then the use of oil has been quite stable at level. Nuclear power raised debates; thus it was a substitute to oil the discussions in the following decades and resulted in policy decisions to close reactors through the 1997 energy bill, which set the date of phasing out the nuclear power by 2010. Since the 70's use of biomass has increased, and wood fuels has been growing for district heating since the 90's. Today, almost half of the electricity production is from hydropower. Natural gas is used mainly in the south-west parts of Sweden and was introduced in 1986. Wind power has increased since the 1990s, but in 2002 it was only contributing with 0.5 % of the total energy production. There are primary three kinds of renewable energy categories that are suitable for Sweden: Hydropower, biomass and wind power. Others can be important too, but as with solar power the northern location of the country will make it less useful during winters, when the energy demand is the highest. The energy intensity (primary energy use/GDP) decreased during the period 1970-2002 by 31% (OECD, 2003; Nilsson et.al, 2004, Swedish government, 1997)

Already at the end of 1980, the issue of climate change rose to be a key question which ended the use of coal. The government adopted sustainable development as a principle in 1991, where the main policy objective on energy is to secure energy supply without endanger the international competitiveness. The sustainable energy system should develop through energy efficiency, support of renewables and cost-effective domestic sources, and the program included three categories: an energy efficiency program, investment subsidies and technology funding (RD&D). Generally, the GDP/capita on RD&D connected to renewable energy and energy efficiency has been higher than in most other IEA countries. In the 90's Sweden planned to join the European Union and therefor liberalized the energy market in 1996, which mean unbundling distribution and transmission from both production and trade. The introduction of carbon tax emerged in the 90's as well and has correspondent for about 2-3 percent of the Swedish GDP for the last 25 years. The carbon tax was one of the first globally, and still is one of the most expensive. One result of the inclusion in the European Union, is the quota-based system as Sweden introduced in 2003 where consumers were required to buy electricity produced by renewables. (Swedish government, 1991; Statistikmyndigheten, 2021; Nilsson et al. 2004; Energiforsk, 2019)

Despite the early policies, carbon dioxide stands for approximately 80% of the total emissions in 2018, and the largest source of emissions is the energy sector (including transport). Already in 2020, the renewable energy accounted for the largest proportion of energy production, where the wind power is at expansion and will play a big role in the future energy system, and Sweden is committed to fight climate change. According to the International Energy Agency (IEA, 2019), Sweden has both the second lowest emissions per capita and per GDP among the members. The energy use is considered as effective, and the country also has the lowest part of fossil fuel-based energy. Sweden was one of the countries who signed the Paris Agreement in 2015, which implies a commitment to reduce emissions from the sectors not included in EU's emissions trading system (EU ETS) with 75 % to 2040 compared to the levels in 2010. IEA points a bit of criticism about the policies, that those are not as powerful as needed and despite the ambiguous goals, it is time for Sweden to step up to next level towards transformation of the energy sector by affordable, secure, and sustainable means. (Ministry of Environment, 2020: 21-22; IEA, 2019).

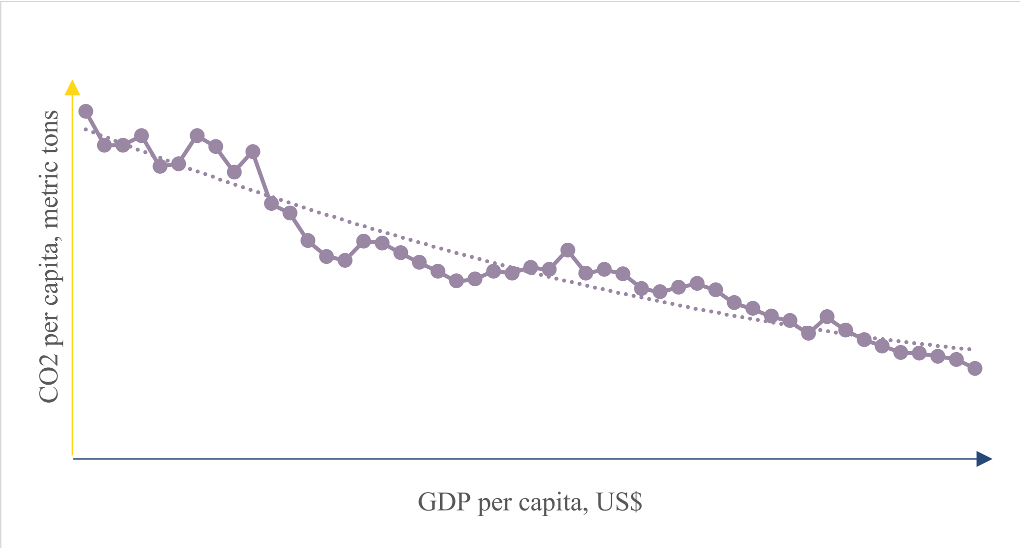

Figure 2. The relationship of CO2 per capita in Sweden, metric tons to GDP and GDP squared per capita in Sweden, constant 2015 US$ for the period 1970-2018

LITERATURE REVIEW

In the field of this thesis, there is a lot of literature and previous studies to be found, one example is Frauke and Nordensvärd (2018) who studied the Nordic countries with evidence from the EKC. Their result indicated that EKC could be observed in Denmark, Iceland and Sweden but not in Norway and Finland, in terms of the total emitted CO_2. For the other results they all indicated the same, but also that EKC could not be observed in Norway and hence the authors could recommend the Norwegians to implement more stringent policies to reduce the emissions. The rest of the Nordic countries were set as valuable lessons for low carbon energy transitions.

David Stern has been conducting several papers regarding the relationship between GDP/CO_2, often mentioning the flaws within the EKC. As example in Stern 2004 in where the author criticizes the EKC of being econometrically weak with possible omitted variable bias, and that EKC has never been shown to fit to all environmental impacts or pollutants. Stern (2004) mean that under certain assumptions, it is easy to develop models that will result in the

EKC but that the econometric part will be a failure due to the difference in panel data with fixed effects and random effects model since the random effect model cannot be consistently estimated, if estimate the model of fixed effects. The general critique regarding the EKC is falling into four categories, omitted variable bias, cointegration issues, heteroskedasticity and simultaneity.

Xue et al. (2014) is analyzing the causality between CO_2 emissions, economic growth and fossil energy consumption in nine European countries for a period of 1970-2008 by a Granger Causality test which they follow up by a risk analysis of the impacts on the economic growth. In their study, the result was showing that there were causal feedback relationships both unidirectional and dual-directional granger causality, but that the impact of reducing emissions for economic growth varied between the countries. Their conclusion is that in a short term, the reducing of CO_2 can imply some problems for the economic development, but this is due to that the long-term case in where the authors see that reducing CO_2 emission could as well increase the development of several renewables. Acaravci & Ozturk (2010) is using an autoregressive distributed lag and granger causality test to investigate the relation between energy consumption, CO_2 emission and economic growth in nineteen Europe, in a study similar to Xu et al. (2014). The authors explore the causalities by the Granger causality test. They found no long-run relationship for Sweden (among more) and their result generally indicated that energy conservation policies were likely to have no effect on the economic growth, and the authors also consider that the EKC hypothesis can be rejected and are not valid for the study.

Zhang et al. (2017) is using the significance of renewable energy and non-renewable energy consumption when studying EKC in Pakistan. The study was done through autoregressive distributive lag, fully modified least square, ordinary least square and a cointegrated regression. Moreover, the VECM granger approach was used to clarify the causalities in the study. Their result indicated a strong presence of EKC, and that renewables plays an important role for decreasing the emissions of carbon dioxide. They observed a bi-directional causality between both renewable energy consumption and CO_2 emission, and hence gave a recommendation to expand the investments in renewable energy for Pakistan to contribute to mitigate climate change. Kherzi, Heshmat and Khodaei (2022) is also including renewables in their study for asian-pasific countries, and their study as well confirmed the EKC hypothesis which show that complexity in economies indicate an increase in the economic growth effects to increase CO2 emissions through higher production and energy use. The authors also state that increasing solar and wind energy has decreased the emissions in countries with lower economic complexity, but on the other hand in the more complex countries there was a scale effect associated with the increased use of renewables which resulted in higher CO_2 emissions as well.

Pao et al. (2011) models the CO_2 emissions, energy use and economic growth in Russia where the result not supported EKC but indicated that both energy conservation policies and economic growth could reduce emissions without negative impact on the economic growth. The causalities were investigated through the granger approach, and indicated a bidirectional strong causality between output, energy and emission, so in order to reduce emissions, the policy recommendation is to increase energy efficiency. Pao et al. (2011) do not use GDP squared in the model – which is notable since it has been used as a variable for the previous articles. The same occur in Perman and Stern (2003) and Shabbir, Kousar and Kousar (2020). Narayan and Narayan (2009) argue that EKC literature is econometrically weak and when model emissions as a function of income by income-squared or cubed variable will suffer from multicollinearity, which is confirmed by undertaking a test for collinearity between income squared and cube in their econometric analysis.

In Bercu, Paraschiv and Lupu (2019) the authors are investigating the energy-economic relationship from a governance perspective, by analyzing the long-term relationship between energy consumption, economic growth and good governance for 14 European countries. To examine the causalities between their included variables, the authors used a VAR model and granger causality approach. The result of the study indicates that there is a causal relationship between economic growth and electricity consumption and are highlighting the importance of good governance, for example decencies in economic energy system led to slower economic growth. The result of the study encourages investments in the energy sector, which will contribute to increased competition and decrease inefficiencies in all energy related sectors.

Conflicting results in the causality can be summarized by the fact that countries can not be generalized, due to their different characteristics, but also time periods and omission variable bias can play a role. Therefore, and due to the high CO_2 emissions in developed countries, the economic growth, and the expansion of renewable energy production this study will investigate the case of Sweden inspired by above-mentioned studies.

Table 1. Summary of literature review

Author	Period	Country	Methodology	Variables analyzed in the study	Causality directions
Xue et al. (2014)	1970-2008	9 European countries	Co-Integration Test, VECM Granger Causality	GDP, CO2, Energy Consumption Intensity (ECI)	CO2 ↔ ECI no causality between GDP and CO2
Acaravci & Ozturk (2010)	1960-2005	19 European countries	ARDL, ECM Granger Causality	GDP, GDP square, CO2, Energy use	no long-run relationship between carbon emissions per capita, energy consumption per capita, real GDP per capita and the square of pecapita real Sweden
Zhang et al (2017)	1970-2012	Pakistan	ARDL, VECM Granger Causality	GDP, GDP square, CO2, non-renewable (NRE) and renewable energy (RE) consumption	NRE ↔ CO2 RE ↔ CO2 No causality between GDP and energy consumption
Pao et al. (2011)	1990–2007	Russia	Co-integration test, ECM Granger causality test	GDP, GDP square, CO2, energy use (E)	E ↔ CO2 GDP ↔ CO2
Shabbir Kousar and Kousar (2020)	1972-2016	Pakistan	Co-integration test, VECM Granger causality test	GDP, CO2, population density (POP), water renewable resources (WR), deforestation (DF)	CO2 → GDP POP → GDP WR → GDP DF → GDP
Narayan and Narayan (2009)	1980–2004	43 developing countries	Time series and Panel cointegration techniques	GDP, CO2	GDP → CO2 only for 35% of the sample

Bercu, Paraschiv and Lupu (2019)	1995-2017	14 Central and Eastern European countries	Transversal dependency test, Granger causality	GDP, final energy consumption (ELEC), Good governance (GOV), Gross fixed capital formation (GFCF), Urban population (URB)	GDP ↔ ELEC GOV ↔ ELEC GOV ↔ GDP
Kherzi, Heshmat and Khodaei (2022)	2000-2018	29 AsiaPacific countries	PFMOLS	GDP, GDP square, CO2, renewable energy production (RENEW), urbanization (URB), trade openness (OPE), energy intensity (ENER), and the Economic Complexity Index (ECI).	N/A
Frauke and Nordensvärd (2018)	1960-2015	Denmark, Finland, Iceland, Norway, Sweden	Statistical analysis in Excel	GDP, CO2 emissions per capita, energy use, electric power consumption, energy mix data, including the share of low carbon energy sources and fossil fuels	N/A

METHODOLOGY

THEORETICAL FRAMEWORK: VECM, COINTEGRATION AND GRANGER CAUSALITY

This study will analyze the relationship between included variables by a Vector Error Correction Model (VECM) followed by a Granger causality approach. The choice of VECM can be justified that this approach makes it possible to evaluate non-stationary and cointegrating variables while overcoming the omitted variable offset and the concerns for normalization in a single multivariable setting. Moreover, the VECM approach significantly reduces multicollinearity and can be used for investigating both short and long-run relationships. (Payne, 2010; Stock & Watson, 2015; Juselius, 2006).

This study work with time series which have unique properties such as stochastic trends existence, volatility, seasonality, etc. (Stock &Watson, 2015, 623, 684). Researchers use a range of models to work with time-series data, which include a vector autoregressive model (VAR), error correction model (ECM), vector error correction model (VECM), distributed delay autoregressive model (ARDL), and Granger causality test (Shrestha & Bhatta, 2018; Al-Mulali et al., 2015; Zhang et al 2017). To specify the model, it is important to first and foremost understand which kind of data going to be interpreted. Economic variables are generally non-stationary (Johansen and Juselius, 1990) which means that these time series variables' mean, variance, and autocorrelation structure are constant over time (The National Institute of Standards and Technology, 2014), and if these variables share the common stochastic trend, it means that they are co-integrated. For this type of time series data, both non-stationary and cointegrated, the vector error correction model (VECM) could be applied. Since the Vector Error Correction model considers existing co-integrating relationships in the model, it restricts the long-run influence of these relationships between endogenous variables and simultaneously permits short-run adjustment changes. Each of the cointegrating vectors from which the error correction term arise contains information about the specific independent direction of where the long-run equilibrium state exists. The negative and statistically significant ECT coefficient expresses the existence of long-run relationships (Mishra, 2011, 61)). VECM eliminates the first differences of the variables by augmenting the VAR model by including it as an additional regressor. Since this study is including co-integrating variables the VECM is applied to investigate the correlation between the studied variables, it accepts all-time series variables as endogenous and is very useful for investigating both short and long-run relationships. If the variables weren't co-integrated, a Vector Autoregressive Model, VAR, could have been used to identify the short-term and long-term relationships (Stock & Watson 2015, 588, 703; Davidson et al. 2010; Dalina & Liviu 2015). Following Johansen and Juselius (1990), a Vector Autoregressive Model (VAR) could be expressed by:

$$Y_t = \Pi_1 Y_{t-1} + \Pi_2 Y_{t-2} + \ldots + \Pi_k Y_{t-k} + Zd_t + \varepsilon_t, \qquad (1),$$

where Π represents coefficient matrices (n× n), Z is a coefficient matrix of a vector of deterministic terms dt (n × 1), and ε_t is an error term with unobservable zero mean.

According to Johansen and Juselius (1990), considering that majority of macroeconomic variables are non-stationary, VAR models should be expressed in their first difference form, i.e. I(1). The above-mentioned VAR model can be expressed in following way:

$$\Delta Y_t = \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + ... + \varphi_{k-1} Y_{t-k+1} + \Pi Y_{t-k} + Zd_t + \varepsilon_t \quad (2),$$

Where $\varphi_i = -(1-\Pi_1-...-\Pi_{t-1})$, and $\Pi = -(I-\Pi_1-...-\Pi_{t-1})$.

The equation (2) differs from the VAR expression only by the Error Correction Term ΠY_{t-k}, which captures the effect of long-run relationships between the variables in the Y vector. Π with reduced rank can be interpreted as the matrix $\Pi = \alpha\beta'$, where β is, in turn, Kc × r matrix, where Kc – is a number of cointegrating relationships, and α is a K × r matrix, where K – is a number of endogenous variables (Johansen and Juselius, 1990; R-econometrics, 2019). For instance, the vector error correction model with 5 variables and 4 cointegrating relationships between them can be expressed as:

$$\Delta X_t = \alpha_{11}(\beta_{11}X_{t-1} + \beta_{12}X_{t-1} + \beta_{13}X_{t-1} + \beta_{14}X_{t-1} + \beta_{15}X_{t-1}) + \alpha_{12}(\beta_{21}X_{t-1} + \beta_{22}X_{t-1} + \beta_{23}X_{t-1} + \beta_{24}X_{t-1} + \beta_{25}X_{t-1}) + \alpha_{13}(\beta_{31}X_{t-1} + \beta_{32}X_{t-1} + \beta_{33}X_{t-1} + \beta_{34}X_{t-1} + \beta_{35}X_{t-1}) + \alpha_{41}(\beta_{41}X_{t-1} + \beta_{42}X_{t-1} + \beta_{43}X_{t-1} + \beta_{44}X_{t-1} + \beta_{45}X_{t-1}) + {}_{Xt} + \varepsilon_t$$

$$\Delta Y_t = \alpha_{11}(\beta_{11}Y_{t-1} + \beta_{12}Y_{t-1} + \beta_{13}Y_{t-1} + \beta_{14}Y_{t-1} + \beta_{15}Y_{t-1}) + \alpha_{12}(\beta_{21}Y_{t-1} + \beta_{22}Y_{t-1} + \beta_{23}Y_{t-1} + \beta_{24}Y_{t-1} + \beta_{25}Y_{t-1}) + \alpha_{13}(\beta_{31}Y_{t-1} + \beta_{32}Y_{t-1} + \beta_{33}Y_{t-1} + \beta_{34}Y_{t-1} + \beta_{35}Y_{t-1}) + \alpha_{41}(\beta_{41}Y_{t-1} + \beta_{42}Y_{t-1} + \beta_{43}Y_{t-1} + \beta_{44}Y_{t-1} + \beta_{45}Y_{t-1}) + {}_{Yt} + \varepsilon_t$$

$$\Delta Z_t = \alpha_{11}(\beta_{11}Z_{t-1} + \beta_{12}Z_{t-1} + \beta_{13}Z_{t-1} + \beta_{14}Z_{t-1} + \beta_{15}Z_{t-1}) + \alpha_{12}(\beta_{21}Z_{t-1} + \beta_{22}Z_{t-1} + \beta_{23}Z_{t-1} + \beta_{24}Z_{t-1} + \beta_{25}Z_{t-1}) + \alpha_{13}(\beta_{31}Z_{t-1} + \beta_{32}Z_{t-1} + \beta_{33}Z_{t-1} + \beta_{34}Z_{t-1} + \beta_{35}Z_{t-1}) + \alpha_{41}(\beta_{41}Z_{t-1} + \beta_{42}Z_{t-1} + \beta_{43}Z_{t-1} + \beta_{44}Z_{t-1} + \beta_{45}Z_{t-1}) + {}_{Zt} + \varepsilon_t$$

$$\Delta L_t = \alpha_{11}(\beta_{11}L_{t-1} + \beta_{12}L_{t-1} + \beta_{13}L_{t-1} + \beta_{14}L_{t-1} + \beta_{15}L_{t-1}) + \alpha_{12}(\beta_{21}L_{t-1} + \beta_{22}L_{t-1} + \beta_{23}L_{t-1} + \beta_{24}L_{t-1} + \beta_{25}L_{t-1}) + \alpha_{13}(\beta_{31}L_{t-1} + \beta_{32}L_{t-1} + \beta_{33}L_{t-1} + \beta_{34}L_{t-1} + \beta_{35}L_{t-1}) + \alpha_{41}(\beta_{41}L_{t-1} + \beta_{42}L_{t-1} + \beta_{43}L_{t-1} + \beta_{44}L_{t-1} + \beta_{45}L_{t-1}) + {}_{Lt} + \varepsilon_t$$

$$\Delta M_t = \alpha_{11}(\beta_{11}M_{t-1} + \beta_{12}M_{t-1} + \beta_{13}M_{t-1} + \beta_{14}M_{t-1} + \beta_{15}M_{t-1}) + \alpha_{12}(\beta_{21}M_{t-1} + \beta_{22}M_{t-1} + \beta_{23}M_{t-1} + \beta_{24}M_{t-1} + \beta_{25}M_{t-1}) + \alpha_{13}(\beta_{31}M_{t-1} + \beta_{32}M_{t-1} + \beta_{33}M_{t-1} + \beta_{34}M_{t-1} + \beta_{35}M_{t-1}) + \alpha_{41}(\beta_{41}M_{t-1} + \beta_{42}M_{t-1} + \beta_{43}M_{t-1} + \beta_{44}M_{t-1} + \beta_{45}M_{t-1}) + {}_{Mt} + \varepsilon_t \quad (3),$$

To specify the model with 5 variables (carbon emissions, economic growth, non-renewable and renewable energy consumption, and dummy variable), the matrix specification can be expressed as:

$$\begin{bmatrix} \Delta \mathrm{Ln(CO2)}_t \\ \Delta \mathrm{Ln(GDP)}_t \\ \Delta \mathrm{Ln(NRE)}_t \\ \Delta \mathrm{Ln(RE)}_t \\ \Delta \mathrm{Ln(dum)}_t \end{bmatrix} = \varphi_1 \begin{bmatrix} \Delta \mathrm{Ln(CO2)}_t \\ \Delta \mathrm{Ln(GDP)}_t \\ \Delta \mathrm{Ln(NRE)}_t \\ \Delta \mathrm{Ln(RE)}_t \\ \Delta \mathrm{Ln(dum)}_t \end{bmatrix} + \ldots + \varphi_i \begin{bmatrix} \Delta \mathrm{Ln(CO2)}_{t-i} \\ \Delta \mathrm{Ln(GDP)}_{t-i} \\ \Delta \mathrm{Ln(NRE)}_{t-i} \\ \Delta \mathrm{Ln(RE)}_{t-i} \\ \Delta \mathrm{Ln(dum)}_{t-i} \end{bmatrix} + \Pi \begin{bmatrix} \Delta \mathrm{Ln(CO2)}_{t-i} \\ \Delta \mathrm{Ln(GDP)}_{t-i} \\ \Delta \mathrm{Ln(NRE)}_{t-i} \\ \Delta \mathrm{Ln(RE)}_{t-i} \\ \Delta \mathrm{Ln(dum)}_{t-i} \end{bmatrix} + \varepsilon_t \quad (4),$$

Since correlation and regression analysis do not show causality between variables, most studies use Granger causality and cointegration techniques to identify causative relationships and directions of these relationships between the variables (Stern & Cleveland, 2004, 3). The Granger causality test is a hypothesis test that is useful for forecasting time series and determining if one other time series is a factor. According to the Granger (1969) approach, the past values of a variable can contain information that helps to predict another variable and applying the rationale to test if there are any causalities also involves implementing F-tests and analyzing the lagged values. If the values of Y do not provide statistically significant information in the lagged values, then the test can't predict any granger causality on X, but if the lagged values are statistically significant, then it is possible to state granger causality between Y and X. The granger approach makes it possible to investigate the causalities and their direction among variables (Stock &Watson, 2015, 589-590).

CAUSALITY DIRECTIONS

By analyzing the granger causality between economic growth (GDP), CO_2 emissions, non-renewable and renewable energy consumption, this study aims to elicit the relations between the included variables. In general, there are four different causalities that have the possibility for occurring in this case study, which is commonly used for evaluating the relationship between economic growth and/or ecological indicators and energy consumption, where data on primary energy consumption, CO_2 and GDP are the indicators. Those are presented in Bercy, Paraschiv and Lupu (2019), Zhang et al (2017) and Pao et al. (2011) among others.

Neutrality hypothesis states that both energy consumption and economic growth are independent and hence there is no causality between those. Therefore, it would be possible to conclude that policies aiming at reducing CO_2 and increase share of renewables, does not have any effect on the economic growth measured in GDP. As the name indicates, there is no direction of the causality between the variables. If the result show no causality between the variables the neutrality hypothesis is true and will then make it possible to draw a conclusion that policies aiming at reducing carbon dioxide does not affect the economic growth (measured in GDP) in society, or the other way around that economic growth does not affect the consumption of energy. The same is true for the same result between CO_2 and energy consumption. (Bercy, Paraschiv & Lupu, 2019, 5; Zhang et al, 2017, 862)

Feedback hypothesis is the outcome if two or more of the variable's energy consumption (renewables and non-renewables), CO2 and economic development stimulate each other and hence are interdependent. A change in one variable will also lead to a change in the other, X affects Y, and Y affects X. This will imply that increased economic growth measured also will increase the energy consumption, and that energy conservation policies (such as reducing CO_2 emissions) will decrease the economic growth. If the causality runs between CO_2 and any of the energy consumption, it will mean that the government's investments for reaching a carbon-neutral society is crucial since the emissions and energy consumption are dependent on each other. Causation between non-renewable energy consumption and economic growth, mean that a change in the use of economic growth will affect the consumption of non-renewable energy use. If this occurs, policies aiming at increasing the economic growth will get the reversed effect on energy conservation policies. It will also mean that if reducing the level of non-renewables for energy conservation policies, will also create a decrease in the economic growth. Causation between renewable energy consumption and economic growth will be the reversed case to previous explained, policies aiming at increasing economic growth will also increase the use of renewable energy. On the other hand, policies to reduce economic growth will also reduce the consumption of renewable energy. The causality for the feedback hypothesis is bidirectional, so that it will run between both variables two ways around. (Bercy, Paraschiv and Lupu 2019; Zhang et al, 2017, 862)

If unidirectional causality occurs, it will show what variable that is affecting the other, hence it will be possible to analyze the effect of either energy conservation policies, change in the economic growth or change in emissions emitted, then two last hypotheses are:

Growth hypothesis will imply that that energy consumption plays a significant role in the economic development within the production process as an input in the studied country and therefor has the possibility to influence the economic development. In this case, use of energy conservation policies can or will have impact on the economic development. This hypothesis is a unidirectional relationship running from energy consumption to economic growth, and running from non-renewable energy consumption to economic growth, this mean that the Swedish government need to give more supplies to renewables if an energy transition is the desired way of reaching a net-zero society. On the other hand, if running from renewables to economic growth, still mean that Sweden is energy dependent but, in this case, it will mean that the renewable energy consumption plays a bigger part in the economic development than non-renewables. The same is true if relationship is running from energy consumption (either renewables or non-renewables) to CO2, hence it will mean that the energy consumption potentially play a major role for the change in emission level. (Bercy, Paraschiv and Lupu 2019; Zhang et al, 2017, 862)

Conservation hypothesis is the other way around, here the economic development can be considered as the cause of increased energy consumption. According to this theory, since economic growth does not rely on energy consumption, then energy conservation policies such as improving energy efficiency or reducing CO_2 emissions will not have a negative impact on the economic growth. The unidirectional relationship for this case will be running from economic growth to energy consumption. (Bercy, Paraschiv and Lupu 2019)

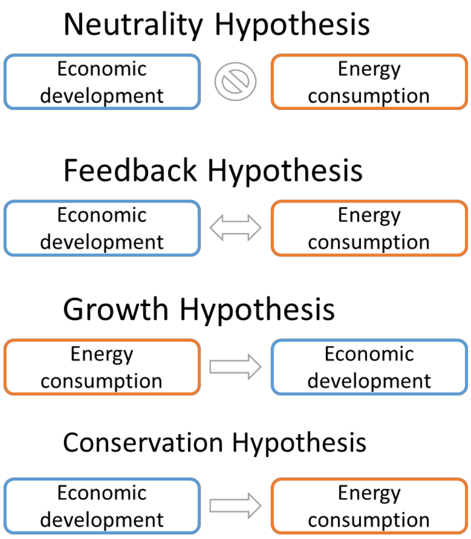

Figure 3. Causality directions

ECONOMETRIC APPROACH

For the econometric research, this paper will apply five variables: CO_2 emissions of Sweden measured in metric tons per capita, GDP per capita in Sweden, measured in US $, non-renewable and renewable energy consumption in Sweden, measured tons per capita, and dummy variable to control extremely cold and dry weather in Sweden. The variables were chosen based on the theory discussed in previous chapters and on data availability for the period 1970 to 2018. The Vector Error Correction Model and Granger Causality test has been chosen for conducting this study based on applicability for non-stationary cointegrating variables. The technical tool where the study has been conducted is R studio, the basic version.

MODEL SPECIFICATION

A significant part of previously written papers in the Environmental Kuznets Curve literature is based on standard panel regression. Standard panel regression studies usually employ model specifications, which graphically could be represented as a U-shape relation between environmental degradation and income (Chan & Wong, 2020). The standard equation in these models could be expressed as follows:

$$CO_{2t} = \beta_0 + \beta_1 GRP_{it} + \beta_2 GRP^2_{it} + \varepsilon_t \qquad (5),$$

where CO_2 is carbon emissions level in province i in year t, GRP – is Gross Regional Product in year t.

But as shown in Figure 2, the relationship between CO_2 per capita and GDP per capita in Sweden for the period 1970-2018 was represented by a downward sloping curve – not the assumed inverted U-shaped Environmental Kuznets Curve. Moreover, using income and income squared variables in one equation could lead to a problem of multicollinearity.

Considering current study's research questions, the main purpose is to investigate potential causal relationships between the non-renewable and/or renewable energy consumption, economic growth, and CO_2 emissions in Sweden. To avoid multicollinearity and consider finding causal relationships between not only economic growth but different types of energy consumption as well, this paper will drop off the variable GDP square and will specify the equation by new variables: non-renewable and renewable energy consumption, as well as dummy variable (following Al-Mulali et al., 2015; Narayan and Narayan, 2009).

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 NRE_t + \beta_3 RE_t + \beta_4 dummy_t + \varepsilon_t \ (6),$$

Where NRE is a proxy of non-renewable (the total oil, coal, nuclear and gas) energy consumption per capita (tons), RE is a proxy of renewable (total biofuels, hydroelectricity, solar, and wind) energy consumption per capita (tons), a dummy variable controls extremely cold and dry weather in Sweden.

DEFINITION OF VARIABLES

- *CO_2 emissions of Sweden, metric tons per capita*

Carbon emissions have been chosen as a dependent variable given that it accounts for 76% of total greenhouse gas emissions (Environmental Protection Agency, 2020; Stern & Cleveland, 2004, 29). Moreover, most of scientific papers related to Environmental Kuznets Curve and previously reviewed in the literature research, use carbon emissions as a proxy for environmental degradation, see Chan & Wong, 2020; Zhang et al., 2017; Xue et al., 2014; Acaravci & Ozturk 2010.

- *Gross domestic product, constant 2015 US $ per capita*

Gross domestic product per capita reflects the country's economic output per person and had been chosen as an income independent variable.

- *Non-renewable energy consumption, tons per capita*

The total oil, coal, nuclear and gas consumption per capita had been chosen as an indicator of non-renewable energy consumption.

- *Renewable energy consumption, tons per capita*

The total biofuels, hydroelectricity, solar, and wind consumption per capita had been chosen as an indicator of renewable energy consumption.

- *Dummy variable*

To control unexpected variation of non-renewable and renewable energy consumption variables which was caused by climate conditions, dummy variable "control" was added that takes value "1" for extremely cold weather in 1978 and 1979, which was the reason of abnormally high energy consumption (International Nuclear Information System, 1980, 8), and for extremely dry weather in 1996 and 2003, which was the reason of low runoff and less hydropower generation (Persson, 2015, 41), and 0 for otherwise.

As have been discussed earlier, the use of renewable energy decreases the level of carbon emissions (Zhang et al. 2017). In this study, including the variables of non-renewable and renewable energy consumption will provide an insight into the role of renewable energy when investigating the relationship between energy consumption and economic growth in Sweden. Following Al-Mulali et al. (2015) and Zhang et al. (2017) we can express an extended Environmental Kuznets curve including non-renewable and renewable energy consumption independent variables and empirical specification as follows:

$$LN\ (CO_{2)} = \beta_0 + \alpha_1 \ln(GDP)_t + \alpha_2 \ln(NRE)_t + \alpha_3 \ln(RE)_t + \alpha_4(dummy) + \varepsilon_t \quad (7),$$

where CO_2 represents CO_2 emissions (metric tons per capita), GDP reflects GDP per capita (constant 2015 US $), NRE is a proxy of non-renewable (the total oil, coal, nuclear and gas) energy consumption per capita (tons), RE is a proxy of renewable (total biofuels, hydroelectricity, solar, and wind) energy consumption per capita (tons), α1, α2 and α3 are the coefficients of the model, ε_t is an error term.

The existing relationships between energy consumption, carbon emissions, and economic growth had been widely investigated by previous scholars (Xue et al., 2014; Acaravci & Ozturk, 2010; Zhang et al., 2017; Pao et al., 2011). The well-established existing relationships between the chosen variables assume multicollinearity between independent variables for the current study. However, the multicollinearity effect is ordinarily subsisting in time-series data. Using the Vector Error Correction model significantly reduces multicollinearity, since "differences are much more 'orthogonal' than the levels of variables" (Juselius, 2006, 60). Equation (6) is presented in the linear form. Later different econometric methods for testing short-run, long-run, and causal relationships between the variables under study will be applied.

DATA

In this study, 4 variables of interest will be used based on the theoretical background discussed in the previous chapters and the availability of the data. The data employed is annual data for Sweden for the 1970 to 2018 period collected from the World Bank and BP database. The variables include CO_2 emissions per capita (metric tons), GDP per capita (constant 2015 US$), non-renewable and renewable energy consumption per capita (tonnes of oil equivalent).

DATA TRANSFORMATION

With the aim to reduce dispersion all the time series variables were transformed into natural logarithms for the econometric modeling purposes. Moreover, the majority of the observed literature uses data that was transformed into natural logarithm (Acaravci & Ozturk, 2010; Pao et al., 2011; Narayan and Narayan, 2009; Shabbir Kousar and Kousar, 2020; Al-Mulali et al., 2015)

DESCRIPTIVE STATISTICS

Table 2 presents the descriptive statistics of the data. According to the results of descriptive statistics, the mean of the Gross Domestic Product in Sweden for the period is 37 389 US$. In 2018 GDP per capita in Sweden is higher than the world's average GDP per capita by the factor of 5.02. The highest GDP per capita was recorded in 2018, reaching 52 983 US$. The mean of CO_2 per capita in the 1970-2018 period is 6.869 metric tons. The highest CO_2 emissions per capita were recorded in 1970, reaching 11.486 metric tons. The minimum value of CO_2 emissions was 3.538 metric tons in 2018. According to European Environment Agency (2017), developed countries reduce CO2 emissions due to their technological progress. Non-renewable energy had been decreasing for the analyzed period and reached the minimal value of 1.611 toe per capita in 2018. With regards to renewable energy consumption, minimal and maximum values were recorded in 1970 and in 2015 with 1.234 and 2.386 values respectively.

Table 2. Descriptive statistics of the variables of interest for the period 1970-2018

	CO_2 per capita, metric tons	GDP per capita, US$	NRE per capita, toe	RE per capita, toe
Mean	6.869	37389	2.779	1.896
Min	3.538	24388	1.673	1.234
Max	11.486	52983	4.580	2.386
Standard deviation	2.14	9130.49	0.73	0.24

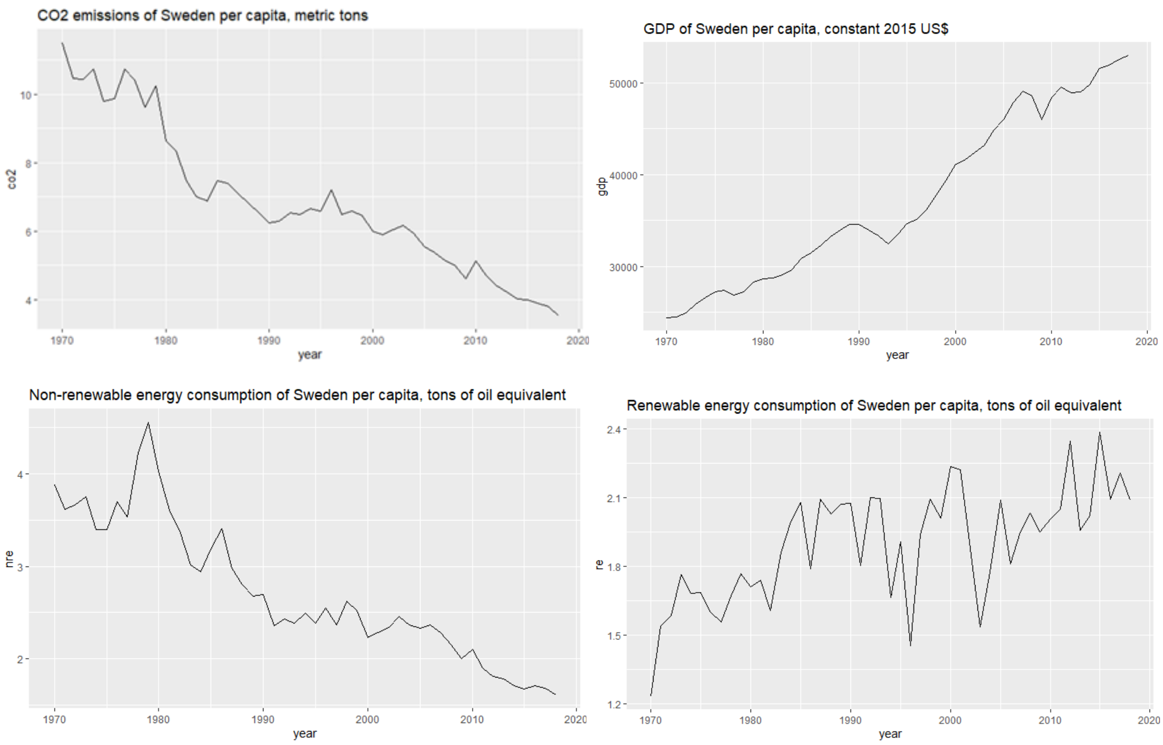

Figure 4. Variables of interest's trends

ESTIMATION AND ANALYSIS

The Estimation procedure involves several stages. First, chosen data should be tested for a unit root existence in the error correction term, followed by testing for a unit root in the residuals from the regression. Engle-Granger Augmented Dickey-Fuller test can be used for testing unit root existence (Engle ang Granger, 1987 cited in Stock & Watson, 2020, 226). When the unit root test is done, data should be checked for co-integration. For this purpose, the Johansen co-integration test based on Trace and Maximal Eigenvalue Statistic will be applied. Then Vector Error Correction Model on the Maximal Likelihood (ML) estimation will be applied which will show short-run and long-run relationships between dependent and independent variables. Granger causality test will be applied to identify the type of causality (bidirectional, unidirectional, or neutral) between variables. In the end, the model post-estimation tests will be applied to check on serial correlation, for heteroscedasticity, and test for normality of residuals.

AUGMENTED DICKEY-FULLER TEST

For the checking of the non-stationarity of variables Augmented Dickey-Fuller Test Results will be applied. The latter estimation is most frequently used in practice for the testing of the variable's stationarity (Acaravci & Ozturk, 2010; Zhang et al, 2017). The ADF regression is augmented by lags of the dependent variable and is expressed as follows (Stock & Watson, 2015,605):

$$\Delta Yt = \beta 0 + at + \delta Y_{t-1} + \gamma_1 \Delta Y_{t-1} + \gamma_2 \Delta Y_{t-2} + \cdots \gamma_p \Delta Y_{t-p} + u_t \qquad (8),$$

Where ΔYt represents the first difference of the dependent variable and can be expressed as $\Delta y_i = y_t - y_{t-1}$

The null hypothesis of the ADF-test states that the time-series variable has a unit root (H0: $\delta = 0$), hence, it is non-stationary. If the Augmented Dickey-Fuller Test's p-value exceeds 5% significance level, the null hypothesis about the non-stationarity of variables cannot be rejected. According to Augmented Dickey-Fuller Test results for the current study (Table 2), the p-value for all four variables of interest is higher than 0.05, which means that the null hypothesis cannot be rejected, hence, all variables are non-stationary.

Table 3. Augmented Dickey-Fuller Test Results

Variable	Dickey-Fuller Test Value	P-value	Result
Ln(CO2)	-2.0845	0.5404	non-stationary
Ln (GDP)	-2.5359	0.3597	non-stationary
Ln (NRE)	-2.9096	0.2102	non-stationary
Ln (RE)	-3.1837	0.1004	non-stationary

LAG LENGTH SELECTION (INFORMATION CRITERION)

After establishing the non-stationarity of all variables, the optimal lag length needs to be chosen. The wrong length of lag can inflate the standard errors and may result in estimation bias. The optimal lag could be estimated using an Information criterion. One of the widely used Information criterion is the Akaike information criterion (AIC). AIC can be expressed as follows (Stock&Watson, 2015, 595):

$$(p) = \ln\,[SSR(p)/T] + (p + 1)(2/T) \qquad (9)$$

Considering that sum of squared residuals will decrease while adding a lag in the OLS estimation process (the first term), the second term will increase while adding a lag. The Akaike information criterion finds the optimal tradeoff between these two terms to minimize the AIC which will be a consistent estimator of the true lag length (Stock & Watson, 2015, 595-596). According to the optimal lag length selection test estimations, the optimal lag number is 7, AIC(n)=7. In the VECM model “p-1” should be used, so the next calculations will use lag number = 6.

JOHANSEN CO-INTEGRATION TEST

The next step is to check variables on existing cointegration relations between variables. According to Stock & Watson (2015, 702-703), if time series have a common stochastic trend, they will be co-integrated and could have long-run relationships. Johansen’s test will be used for co-integration since the number of cointegrating vectors could be identified in multivariate time series (Johansen & Juselius, 1990).

For this aim, Johansen's test for co-integration with Trace and Maximal Eigenvalue Statistics will be applied. Both Trace and Maximal Eigenvalue are likelihood ratio test statistics, where the former represents the trace of the matrix, and the latter denotes the marginal eigenvalue of the matrix (Johansen & Juselius, 1990). If the Test value of Trace and Maximal Eigenvalue Statistics does not exceed the 5% critical level, the null hypothesis about the absence of co-integrating relationships (H0: the rank r of the matrix = 0) will be rejected. Both Trace and Maximal Eigenvalue Statistics results showed that there are 4 co-integrating relationships as test value is less than 5% critical value for rows r <= 4, r <= 3 and r <= 2).

Table 4. Johansen's test for co-integration results

Maximum rank	Trace Statistic		Maximal Eigenvalue Statistic	
	Test value	5% critical value	Test value	5% critical value
r <= 4	5.16	9.24	5.16	9.24
r <= 3	15.78	19.96	10.62	15.67
r <= 2	33.89	34.91	18.11	22.00
r <= 1	83.27	53.12	49.38	28.14
r = 0	145.01	76.07	61.73	34.40

VECTOR ERROR CORRECTION MODEL

As identified before, the current study is dealing with co-integrating variables which share the common stochastic trend. It means that the regular Vector Autoregressive Model (VAR) model cannot be used as it contains assumptions about stationarity I (0) of variables. Instead, Vector Error Correction Model (VECM) will be used, which is a modified version of a Vector Autoregressive Model (VAR), where long-term relationships between the variables are restricted. Vector Error Correction Model is highly useful for estimating both short- and long-run relationships. VECM equation is expressed in equation (3).

When the mathematical formula is stated, it is possible to start estimating short- and long-run relationships between variables based on Vector Error Correction Model (VECM), since the pre-requisites for this model are satisfied. According to Augmented Dickey-Fuller Test and Johansen's test for co-integration all five variables CO_2 emissions per capita (metric tons), GDP per capita (constant 2015 US$), non-renewable and renewable energy consumption per capita (tonnes of oil equivalent), and dummy variable are non-stationary in their levels but are stationary in their differences as well as co-integrated. By restricting the long-run influence of co-integrating relationships in the model, and simultaneously allowing short-run adjustment changes towards the equilibrium, VECM results in reflecting information about short-term and long-term relationships between the variables (Mishra, 2011). As it had been discussed earlier, equation (2) of our Vector Error Correction Model contains the Error Correction Term (ECT) $\Pi Y t{-}k$, which represents long-run relationships between the variables in the dependent Y vector and measures the speed of adjustments in this vector. The VECM estimation for four variables of interest as dependent variables had been run in R sequentially.

For all variables, Error Correction term is negative and significant at a 5% level of significance (Table 6), which means there is long-run relationships between carbon emissions, economic growth, non-renewable and renewable energy consumption. Other coefficients represent short-run causality between target and other endogenous variables. Regarding short-run relationships, we got the following results:

- *Equation with carbon emissions as a dependent variable*

Positive short-run relationships were identified between carbon emissions and non-renewable energy consumption at a 1% significance level. The economic interpretation is that for every 1% increase in non-renewable energy consumption, carbon emissions will increase by 0.97% in 6 years, since we used a 6-year lag for the current model.

- *Equation with non-renewable energy consumption as a dependent variable*

Negative short-run relationships were identified between non-renewable energy consumption and carbon emissions at 1% significance level. Considering time lag = 6 which was chosen for the VECM model, we could make an assumption that increasing of carbon emissions by 1% leads to 2% will decrease of non-renewable energy consumption after 6 years.

- *Equation with renewable energy consumption as a dependent variable*

Positive short-run relationships were identified between renewable energy consumption and carbon emissions at a 5% significance level and negative short-run relationships between renewable energy consumption and non- renewable energy consumption at 1% significance level. The former positive sign of short-run relationships between CO2 and RE variables is also interesting. It can be interpreted that for every 1% increase in carbon emissions, renewable energy consumption will lead to 1.9% increase of renewable energy consumption after 6 years.

For the purposes of this study, estimators with less than 5% level of significance will be used, which is stated as a normal distribution (Stock & Watson, 2015, 82).

Table 5. Vector Error Correction Model estimation results

Dependentvariable	Error corr. term	Independent variable			
		lnCO2	lnGDP	lnNRE	lnRE
LnCO2	-0.9469	x	-0.0404	0.9490	0.0877
	(0.3883)*		(0.5245)	(0.2562)**	(0.4483)
lnGDP	-0.4744	-0.0836	x	0.2529	0.2536
	(0.1950)*	(0.2183)		(0.1287).	(0.2251)
lnNRE	-0.6149	-1.9950	-0.2106	x	-1.1298
	(0.2380)*	(0.5098)**	(0.6152)		(0.5258)
lnRE	-3.4521	1.8984	1.5503	-1.5455	x
	(0.7651)**	(0.6088)*	(0.7347)	(0.3589)**	

Note: * shows rejection of null hypothesis at 5% significance level, ** - at 1% significance

Granger Causality Test

The significance of short-run coefficients and error correction term in the conducted Vector Error Correction model identifies the existence of short-run and long-run relationships between variables of interest. With the aim to investigate short-run causal relationships between variables of interest, Granger causality test will be applied to identify if one of variables can be used for predicting another time-series variable. The null hypothesis of the Granger causality test is that estimator coefficients on all lags of one endogenous variable equal zero, which means that this variable has no predictive content for another variable (Granger, 1969; Stock & Watson, 2015).

Table 6. Granger Causality Test results

Null Hypothesis	F-statistic	Probability	Decision
ΔCO2 does not Granger cause ΔGDP	0.5976	0.7298	Accept

ΔCO2 does not Granger cause ΔNRE	4.2391	0.0004982 ***	Reject
ΔCO2 does not Granger cause ΔRE	3.6511	0.02059 *	Reject
ΔGDP does not Granger cause ΔCO2	0.6901	0.6592	Accept
ΔGDP does not Granger cause ΔNRE	1.1111	0.3792	Accept
ΔGDP does not Granger cause ΔRE	0.9548	0.4719	Accept
ΔNRE does not Granger cause ΔCO2	4.2391	0.003315**	Reject
ΔNRE does not Granger cause ΔGDP	0.2538	0.9538	Accept
ΔNRE does not Granger cause ΔRE	0.9974	0.4451	Accept
ΔRE does not Granger cause ΔCO2	0.4241	0.857	Accept
ΔRE does not Granger cause ΔGDP	1.6259	0.1745	Accept
ΔRE does not Granger cause ΔNRE	1.0895	0.3912	Accept

Note: * shows rejection of null hypothesis at 5% significance level, ** - at 1% significance level, *** - at 0,1%

The following short-run causal relationships are identified according to the results presented in the table 7:

- Bidirectional relationship between *carbon emissions* and n*on-renewable energy consumption*
- Unidirectional relationship between *renewable energy consumption* as a dependent variable and *carbon emissions* (as an independent variable)

Table 7. Results of investigation of long-run, short-run equilibrium and causal relationships between carbon emissions, gross domestic product and non-renewable and renewable energy consumption

Variable	Long-run eq relationships	Short-run eq. relationships				Causal relationships			
		CO2	GDP	NRE	RE	CO2	GDP	NRE	RE

CO_2	Exists between all variables	x	Absent	Exists, positive		x	Absent	Exists	-
GDP		Absent	x	Absent		Absent	x	Absent	Absent
NRE		Exists, negative	Absent	X		Exists	Absent	x	Absent
RE		Exists, positive	Absent	Exists, negative	X	Exists	Absent	Absent	X

The figure 4 represents causal relationships between variables of interest in the study.

Figure 4. Causal relationships between Carbon emissions, GDP, energy consumption

Post-estimation tests

Serial correlation

As the first step of post-estimation check, a test for serially correlated errors should be performed. Serial correlation, or autocorrelation, could arise in time series models when a variable is correlated with its lagged version. The issue caused by serial correlation is that the OLS estimator could be biased and misleading. (Stock & Watson, 2015, 574,652)

The multivariate Portmanteau- and Breusch-Godfrey test for serially correlated errors had been run to identify autocorrelation issue in the model. The null hypothesis of the latter test is that the model has no autocorrelation. According to the table 9, p-value is $< 2.2e-16$, which is less than 5%. Hence, the null hypothesis about the absence of autocorrelation can be rejected in the model and conclude that the model has a serial correlation issue.

Table 8. Portmanteau Test for serially correlated errors result

Indicator	Value
Chi-squared	120.15
df	5
p-value	< 2.2e-16

To identify serial correlation, correlograms had been built in R-studio for each time-series variable.

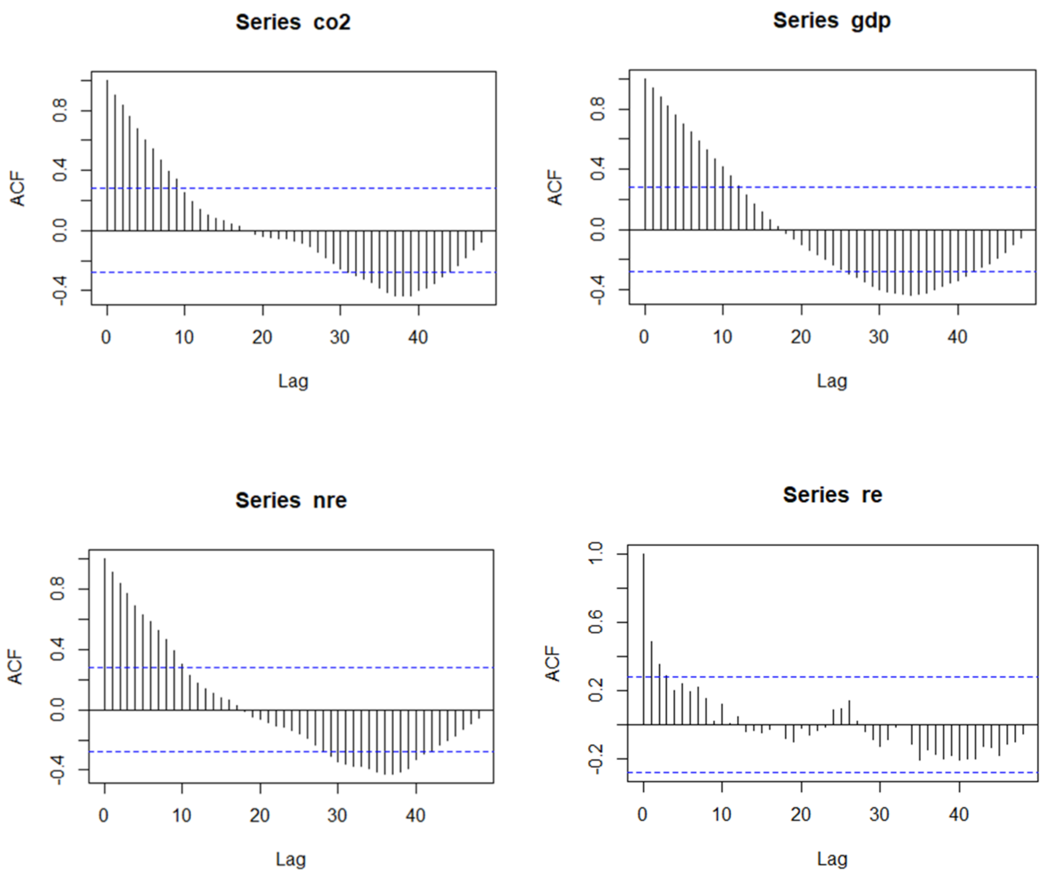

Figure 5. Correlogram of CO_2, GDP, NRE and RE time-series variables

According to the figure 5, the correlogram for CO_2 variable has peaks, exceeding the 95% confidence intervals (blue line) at lags up to 10, which means that the latter variable is lagged with its lagged versions up to 10^{th} lag. Correlogram for GDP variable exceeds the confidence bounds up to lag 13 and correlogram for NRE variable exceeds the confidence bounds up to lag 11. However, lag length selection according to AIC Information Criterion in table 4 showed that the optimal lag length for our VECM model is 6 years (p-1). Serial correlation issue may lead to possible biased OLS estimator, hence, unreliable results. (Stock&Watson, 2015, 574, 652).

ARCH ENGLE'S TEST

To test for heteroscedasticity, the ARCH Engles test will be applied. Heteroscedasticity arises when a standard variation of the dependent variable is not constant (Investopedia, 2020). Moreover, the presence of heteroscedasticity violates one of OLS's assumptions that the errors should be homoscedastic (Stock & Watson 2015, 203). The arch test performs Portmanteau Q and Lagrange Multiplier tests with the null hypothesis that residuals of the model are homoscedastic (RDocumentation, 2018). According to the table 8, p-value equals 1, which means that we cannot reject the null hypothesis, hence, the process is homoscedastic and there is no heteroscedasticity issue in the model.

Table 9. ARCH Engle's Test for Residual Heteroscedasticity result

Indicator	Value
Chi-squared	420
df	3375
p-value	1

JARQUE BERA TEST

The model should also be checked for the normality of residuals to satisfy one of the OLS assumptions: if the regression errors are homoscedastic, and normally distributed, then the OLS estimator is normally distributed. Moreover, the normal distribution of the populations is an essential assumption of the reliability of t-tests. (Stock & Watson, 2015, 212; Kim & Park, 2019). To test for the normality of residuals, a Jarque Bera test will be used. A normality test will be used in R, it computes multivariate Jarque-bera test and will be implied with null hypothesis that residuals are normally distributed. Since p-value of Jarque-Bera Test equals 0.7258 and exceeds a 5% level of significance (Table 11), the null hypothesis cannot be rejected and residuals in this model are normally distributed.

Table 10. Jarque-Bera Test (multivariate) result

Indicator	Value
Chi-squared	6.9976
df	10
p-value	0.7257

CUSUM TEST

Time-series regression requires that coefficients are stable over time and did not have structural changes in the residuals (Stata, 2021). Structural changes can be due to exceptional happenings, such as weather and crises. To overcome such, a dummy was created for the model. Stability of coefficients of our model will be controlled by performing Empirical Fluctuation Processes which include CUSUM and MOSUM tests. Figure 5 represents the cumulative sums of residuals of the model. Since Recursive CUSUM Test results lie between red straight lines, which represents a 5% confidence level, the variables in the model are stable over time. Hence, the model is stable over time and does not have structural breaks.

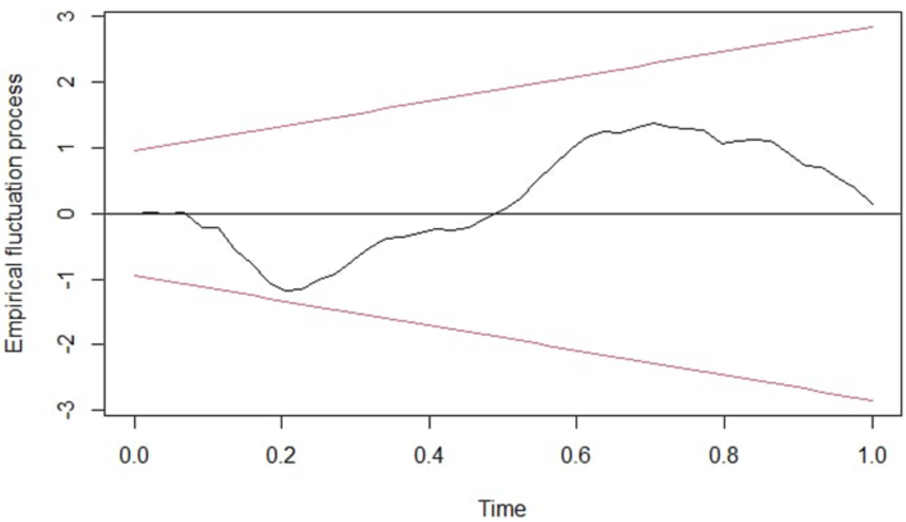

Figure 6. Recursive CUSUM test

Discussion

This study aimed at analyzing the relationship between energy consumption (renewable/non-renewable), economic growth (measured in GDP), CO_2 in Sweden for the period 1970-2018. The subject for the study is far known and well-studied; most famous by the Environmental Kuznets Curve, which initially through a focus towards the area of investigation. A Vector error correction model (VECM) was used as the main econometrical tool for the estimation. The relationships between the variables were then analyzed through a granger causality approach, which aimed at showing which variable was affecting the other, if any. The study proved the neutrality hypothesis, i.e. no causality is found between economic development and energy consumption. This result was strengthened by the results of Xu et al (2014), Acaravi & Ozturk (2010), both studied European countries using VECM or ECM, a granger causality hypothesis and found no causality between GDP and energy indicators. Thus, neither of those separated renewables or non-renewables in their studies. Neutrality hypothesis indicates that policies aiming at reducing carbon dioxide does not affect economic growth measured in GDP, and vis-à-vis that economic growth does not affect energy consumption either non-renewable or renewable. The result was supported by both Vector Error Correction model and Granger causality test, which resulted in absence of short-run relationships between GDP and non-renewable and renewable energy consumption, as well as absence of short-run causal relationships between the above-mentioned variables. However, VECM confirmed that there are long-run relationships between carbon emissions, economic growth, non-renewable and renewable energy consumption, since for all variables of interest the error correction term was negative and significant at a 5% level of significance.

The study showed interesting results regarding bidirectional causality between non-renewable energy consumption and carbon dioxide emissions and unidirectional causality from CO_2 emissions to renewable energy consumption, as shown in table 5 and 6. Hence, carbon dioxide emissions have a causal effect on the consumption of both renewable and non-renewable energy. The same result occurred in Zhang et al. (2017) in their study on Pakistan. On the other hand, Zhang et al (2017) found bidirectional causality between renewables and

CO_2 as well, which differs in the results for this paper. Here, only non-renewables have causal effect on CO_2, not renewables.

In this study it means that carbon emissions have a negative causal effect on non-renewable energy consumption, considering 6 years' time lag. Hence, an increase in CO_2 emissions will cause non-renewable energy consumption to decrease after 6 years. On the other hand, carbon emissions have a positive effect on renewable energy consumption, which means that an increase in CO_2 emissions will be a reason for renewable energy consumption also increasing 6 years later.

There is also a short run relationship between non-renewable energy consumption as independent variable and renewable as dependent, but not the other way around. This indicates that non-renewable energy consumption is a substitute for renewable (but renewables are not for non-renewables). This does make sense since renewables were introduced much later than traditional fossil energy sources. It also makes it possible to imagine that the Swedish government’s ambition to decrease carbon emissions by substituting the non-renewable sources for renewables is not yet met. By this analyze, it is possible to suggest an expansion of the renewables to meet the energy demand in Sweden, since it does not seem to affect the economic growth, at least not to a high extent.

The restraints this study met were most and foremost about limitations. With respect to the intended extent, different energy kinds were clustered into renewable and non-renewable. For future studies, it would be interesting to separate them. The results in this study can possibly be seen in the light of the 6 years’ time lag used. For further studies, with more time-series data available, it is recommended to use longer lags to overcome any serial correlation issues and investigate if the estimation result remains the same. More data could increase optimal lag length without degrading the degree of freedom. However, for this study the lag selection was done with respect to available years of data and in accordance with the AIC information criterion. This study avoided both heteroscedasticity and estimation errors when creating the model, but it could possibly meet other problems such as the choice of variables. Is GDP a good indicator of economic growth, or does it rather reflect income? The choice of using CO_2 as an indicator was due to the fact Stern & Cleveland (2004, 29) provided: that emissions of pollutants generally are linked to energy use, but was it enough to only include CO_2 as an indicator for emissions and hence environmental degradation? Carbon dioxide emission do account for around 80% of the emissions emitted, but should other indicators have been included as well for increased validity of the study? Further studies are therefore recommended to expand the model and include more variables. Moreover, it would be interesting to do a similar study in the future to analyze what effect the Paris Agreement would have. For this study, there was only data for three years after the agreements were signed, which is too little to evaluate any effect.

The overall conclusion, this study supports the neutrality hypothesis which indicates that the energy conservation policies do not affect economic growth, nor economic growth do not affect the energy conservation policies, at least not to a high extent. There was a positive relationship between GDP as dependent variable and non-renewable energy as independent, which meant that if NRE is increasing the GDP is also increasing, but this result was rejected due to the 10% significance level of normal distribution. Thus, energy conservation policies (improving energy efficiency and/or reducing CO_2 emissions) does not yet seem to fulfill its mission and need to be expanded to meet the demand, because when the level of carbon dioxide emissions change, the use of energy from non-renewable energy sources also change in a bidirectional relationship.

As stated in the introduction, studies like these are important for policymaking since they indicate how well policies fit to their targets. By this study, it is possible to conclude that policies aiming at energy conservation do not have by-effects on the overall economy, but that they also do not have reached their targets yet. This fact makes sense, Sweden aims for a carbon-neutral society by 2040 and is ongoing with the expansion of renewable energy sources. We will see if this pace is enough to reach the target of net-zero emissions, and if it will have any impact on economic growth before getting there.

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