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The relationship between renewable energy consumption, CO_2 emissions and economic growth in Denmark

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Abstract

This study utilizes a multivariate framework to test the causal relationship between renewable energy consumption, gross domestic product (GDP) and carbon dioxide (CO_2) emissions in Denmark using annual data from 1972-2012. The causal relationship between variables is examined using Granger causality test in VAR framework. Results of unit root tests show that all variables are non-stationary in their level form and stationary in first difference form. Cointegration analysis following Johansen (1992) approach, shows that there is no evidence of cointegration among the test variables. The empirical results from Granger causality Toda-Yomamoto test and Granger causality test using first differences strongly supports a unidirectional causality coming from renewable energy consumption to CO_2 emissions. The results of this study also indicate that there is no statistically significant causality between the economic growth and renewable energy consumption, which supports the neutrality hypothesis and implies that energy conservation policies should not have a significant impact on economic growth. The empirical results also reveal that there is no causality between economic growth and CO_2 emissions. This may be due to the fact that Denmark has one of the lowest energy intensities in the world, which allows to achieve one unit of GDP with a minimum input of energy and minimum CO_2 emissions.

Key words: Renewable energy, CO_2 emissions, economic growth, Granger causality, Denmark.

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Contents

List of Figures

List of Tables

Chapter 1

Introduction

Energy is the lifeblood of any modern economy. It is a crucial input to nearly all of the goods and services we have today. Stable and reasonably priced energy supplies are vital to maintaining and improving living standards of billions people across the globe. A recent World Economic Forum report on energy describes it as the oxygen of the economy “without heat, light and power you cannot build or run the factories and cities that provide goods, jobs and homes, nor enjoy the amenities that make life more comfortable and enjoyable”.

Multiple challenges in relation to energy exist, but in particular three topics drive today’s energy discussions. First, fossil fuels are a finite resource. Although there are still large supplies of coal, oil and natural gas, given the increasing demand and limited supply it is inevitable that one day supplies will run out. Thus, it is important to search for alternative energy sources.

Second, the energy security problem facing energy-importing countries. Large reserves of energy supplies located in particular parts of the world involves risks for many countries in terms of reliability of energy supplies. The Energy crises in 1970s was a wake up call for many countries and more recent uprisings that took place in the Arab world, once more showed that heavy dependence on energy imports is neither secure nor stable and can also be politically damaging.

Third, although different opinions exist it is very likely that using fossil fuels changes the climate. One of the biggest contributors to climate change is the increase of greenhouse gases (GHG) in the atmosphere in particular carbon dioxide (CO_2) that comes from the combustion of fossil fuels (coal, oil and natural gas). It is still generally believed that unless dramatic actions are taken to reduce global warming the world could face an environmental catastrophe (Apergis et al., 2010).

All of the topics are of course important but the most debated on a global scale is the issue of climate change. The prevailing threat of global warming and climate change has brought the attention on the relationship between economic growth, energy consumption and environmental pollution to a new level. Attempts have been made to reduce the share of emissions in the atmosphere. Strong emphasis on this issue was placed in 1997, under the Kyoto Protocol agreement. It obliged industrialized countries to limit their greenhouse gas emissions, mainly CO_2. Consequently many countries started to shift from dependence on fossil fuels towards the use of more renewable energy sources (RES).

The International Energy Agency (IEA, 2009b) suggests that current trends in energy supply and use are still economically, environmentally and socially unsustainable. It is projected that the primary energy demand will increase by 1.5 % per year between 2007 and 2030, with fossil fuels being a dominant energy source. It is expected that because of increasing energy demand the energy-related CO_2 emissions will more than double by 2050 whereas, the increased demand for oil will heighten the concerns over security of energy supplies (IEA, 2009b). The IEA executive director, Nobuo Tanaka summarized energy associated issues as follows: "The message is simple and stark: if the world continues on the basis of today's energy and climate policies, the consequences of climate change will be severe. Energy is at the heart of the problem – and so must form the core of the solution" (IEA, 2009a).

Many countries faced with energy security and environmental challenges are therefore forced to look for energy alternatives to fossil fuels. It is generally believed that renewable and nuclear energy are practically carbon free energy sources and are seen as major solutions to the problems associated with global warming and energy security (Elliott, 2009). Consequently many countries are making investments in these energy sources in order to reduce GHG and increase the supply of secure energy. Despite the slow speed of transition towards the non-carbon energy carriers there are also a number of other issues.

Firstly, although we all want to make a "difference" many things that allegedly make a difference simply do not add up. MacKay (2009) calculates that in order to satisfy British energy consumption and make a difference, renewable energy facilities have to be country-sized. For instance, for energy crops (biomass, biodiesel and etc.) to make a contribution that would satisfy $\approx 9\%$ of total energy demand, crops would have to cover $\approx 75\%$ of the country. Similarly wind farms would have to cover $\approx 12\%$ of the country to satisfy about $\approx 10\%$ of total energy demand.

Secondly, renewable energy sources are associated with high costs and are more expensive compared to conventional energy forms (apart from hydropower and geothermal). To make renewables attractive for investors a financial support through subsidies (usually known as feed-in tariff and/or feed-in premium) is provided. It guarantees investors a particular price or premium for each kWh produced for a particular period of time (usually 20 years). Typically a substantial share of the higher cost is transferred to the consumers and thus they have less income to spend on other goods and this may adversely affect economic activity. In addition, an increase in energy prices may also result in the loss of international competitiveness that could lead to lower wages and/or lower demand for labor (Ragwitz et al., 2009).

Finally, and most importantly the actual contributions of some renewables towards reduction of CO_2 can be questioned. Certain renewables like hydropower, geothermal and biomass are reliable and easily predictable and thus there is no doubts about their contribution towards reduction of GHG. However, other popular renewables like wind and solar power are associated with high intermittence and creates many challenges when it comes to balancing of their supply. White (2004) argues that the fluctuations in wind output have to be covered by operation of fossil-fuel fired plants bellow the optimum efficiency level to stabilize the grid (back-up reserve). Consequently, although wind-generated power itself is CO_2-free, the saving to the whole power system is not proportional to the amount of fossil-fuelled power that it displaces. The operation of fossil-fired capacity as back-up reserve emits more CO_2/kWh than if the use of that plant were optimized, thus offsetting much of the benefit of wind. This was confirmed by Denmark's Elsam and Jutland region power providers who at the meeting with Danish Wind Energy Association and Danish government stated that increasing wind power capacity does not decrease CO_2 emissions (White, 2004). Nevertheless it is important to note that renewables associated with high intermittency (wind and solar) form only a part of a bigger renewable energy system (biomass, hydro, geothermal) contribution of which is less questionable however it is also important to note that Denmark has one of the highest shares of stochastic renewables (wind) in its energy mix.

Given the importance of the above mentioned issues and challenges associated with them, it is not surprising that the relationship between the economic growth, environmental pollution and energy consumption has been amongst the most debated topics over the past few decades in energy economics. There is an extensive amount of research looking at the linkage between economic growth and energy consumption on the one hand and between economic growth and environmental pollution on the other. There is however a lack of empirical studies that investigates both relationships in one framework. Particularly, there is a significant lack of research that looks at renewable energy consumption instead of aggregate energy consumption using modern econometric techniques associated with causality testing. Thus, given the importance of renewable energy supplies as possible panacea for emission reductions necessitates a research that investigates the causal relationship between the renewable energy consumption, environmental pollution and economic growth

1.1 Objective of the Study

The principal aim of this study is to investigate the causal link between the renewable energy consumption, CO_2 emissions and economic growth in Denmark for the period between 1972-2012. The questions this thesis seeks to answer are formulated as follows: Is there a (Granger) causal link between renewable energy consumption and CO_2 emissions? and similarly is there a (Granger) causal link between renewable energy consumption and GDP? What is the direction of this causality?

1.2 Method and Sample

Vector autoregression (VAR) based Granger causality test is employed in order to determine the causal link between the chosen variables. Granger causality test has been the most common approach to determining the causal validity in energy consumption, economic growth and pollution models. A definition of a method can be given as "a variable X is said to Granger cause another variable Y if past values of X help predict the current level of Y given all other appropriate information".

Data used in the study comes from two sources. First, energy consumption and environmental data comes from Danish Energy Statistics and it covers the period from 1972-2012 and second economic data on GDP is obtained from World Bank database and it covers the period from 1972-2012. The variables considered in the study are the following: GDP per capita, CO_2 emissions per capita, renewable energy consumption (RE) per capita.

The choice of Denmark in this study is motivated because of the following reasons. Firstly, nuclear power was never seriously considered because of the opposition from politicians and civil society was always strong. So long before other countries, Denmark began developing renewables, and is now a world leader, particularly in the field of wind power. According to the latest figures renewable energy consumption accounts for a significant portion (16%) of overall energy consumption. Secondly, even though Denmark is still self sufficient for its all energy supplies and is a net energy exporter current oil and gas reserves in the North Sea are expected to run out by 2018 after which unless it reduces demand it will become a net energy importer (DEA, 2009). Finally, because of favorable geographical location and close proximity to the neighboring regions with strongly interconnected energy system allows Denmark to balance a stochastic electricity generation and thus it can be seen as seen as a perfect example for other countries.

1.3 Outline of the Thesis

After this introduction a background follows in Chapter 2 that provides a historical context together with an overview of country's energy sector. Chapter 3 gives a brief overview of main the theories and hypotheses related to the investigation of causal relationship between energy consumption, economic growth and environmental pollution. Chapter 4 looks at the main studies conducted in field. Chapter 5 and 6 describes in detail data and methodology used in the study and Chapter 7 presents the empirical results. In Chapter 8 the obtained results are discussed and various implications are considered. In final Chapter 9 an overview of the whole study is presented and conclusions with a suggestions for further research are provided.

1.4 Supporting information and technical details

This thesis is written in LaTeX with the help of LyX editor. All of the econometrics tests are performed using STATA and Eviews software packages. Figures and diagrams are made with the help of Excel.

It is possible to browse the PDF version of the report as hypertext. Headings in the table of contents, literature, chapter, figure and table references in the text are all clickable links. After clicking, to return to previous position push Alt + left arrow (cmd + [on Mac OS). To go forwards again, push Alt + right arrow (cmd +] on Mac OS).

Chapter 2

Background

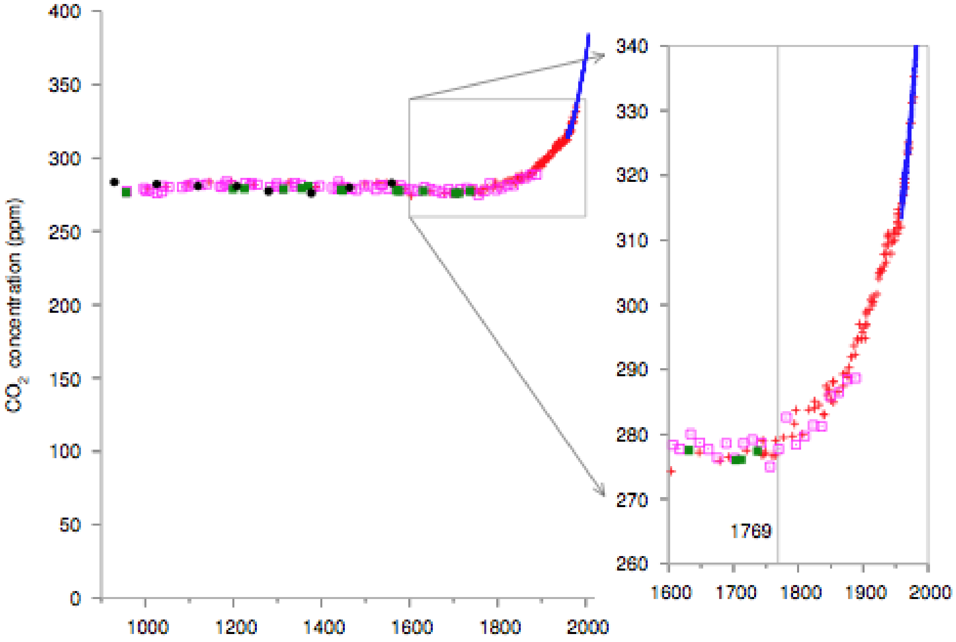
2.1 Historical Background

So, when, where and how did it all start? Probably as in many other economic history topics to answer these questions we have to go back to the 18th century, when Scottish scientist James Watt while repairing Newcomen's steam engine discovered how he could make it more efficient. In fact his improvements not only made the steam engine much more efficient and powerful, but also allowed it to drive many different types of machinery, making it a core part of the First Industrial Revolution.

One of the main steam engine applications was pumping water out of the mines and although the first steam engine was invented in 1698, it was Watt's more efficient steam engine, introduced in 1769 that took coal mining to the next level (MacKay, 2009). Starting from 1769 Britain's coal production rocketed and 30 years later by 1800 it had doubled, and then in next 30 years (1830) it doubled again. After 1830 coal production started to double within 20-year intervals, so it doubled by 1850 and then it doubled again by 1870. This brought not only prosperity and population growth, but also a significant increase in CO_2 emissions (see Figure 2.1 on the following page).

Followed by the invention of the steam engine and a growing use of coal, the other two key inventions that have completely reshaped the world we live in today emerged in the 19th century. If the First Industrial Revolution was mostly the story of steam engine and coal, the Second Industrial Revolution and the expansion of energy was built round two development blocks, one of which was electricity development and the second was the Internal Combustion Engine (ICE).

Figure 2.1: CO_2 Concentration, [ppm]



Source: MacKay, 2009

The use of electricity expanded in two phases. Firstly, it was introduced in the cities, initially as a substitute for other energy sources for specific applications such as light and cooking. While electric motors were used simply to replace the factory system with one big steam engine that operated several individual machines. Electric motors did not revolutionize the way factories were organized and did not provide any greater flexibility or any fundamental improvement in productivity, nevertheless they improved working conditions because they were operating much more silently and did not emit smoke. The second phase of the evolving electricity block was much more dynamic and had a greater impact on society. The market widening occurred because of the falling electricity price and much greater influence was made on infrastructure. Different from the first phase, electric motors in factories were installed to each individual machine. This allowed a greater flexibility of work and was highly economical, as the machines could be started or shut down when it was needed. Household electric appliances also diffused much quicker during the second phase and most of the appliances were new devices not substitutes as was common during the first phase. These appliances not only acted as labor saving tools, but also helped to improve quality of life and thus devices such as vacuum cleaners, refrigerators, washing machines and others rapidly diffused across households.

The other key part of the Second Industrial Revolution was the internal combustion engine, which affected the use of oil and corresponding CO_2 emissions to a considerable degree. Firstly, because of strong complementarity between cars (or ICE) and gasoline there was a demand pull or market suction on oil from cars. This simply meant that the growing use of engines increased the demand for the production of gasoline, similar to the scenario of the First Industrial Revolution where the core innovations in steam engine generated the demand for coal. As a result, the increase in the number of cars from the 1910 to 1950 affected demand for raw oil extraction. The other way of oil expansion was through the supply side, where market widening of the ICE technology, mainly in transportation led to lower freight. The lower costs were achieved because of the increasing size of oil tankers and their more powerful engines. As a result ocean transport costs divided by landed cost for crude oil, dropped from about 50 percent down to 5 percent between 1950 and 2000 (Kander et al., 2013). This implied a few things, firstly, the cost of freight was no longer a major issue and oil could now be delivered from the middle east to Europe without a significant effect on its price and secondly the lower price of oil meant that it could be used for wider applications, for example heating, where alternatives like coal and coke were available but now because of the cheaper oil, could be replaced.

The Third Industrial Revolution with Information Communication Technology (ICT) in the center of it emerged in the 1970s. Arguably, the ICT revolution is more energy saving than any of the two central development blocks of the Second Industrial Revolution, however the degree of energy savings can still be questioned simply because the use of ICT stimulates the use of electricity.

The energy savings that come from ICT occur both directly and indirectly. First directly, the technologies produced by ICT can be applied for smart energy solutions like smart houses, smart grids and smart appliances. New trading options and various e-services (like e-bank, e-government) reduce the need for travel and for ordinary letter and invoices and thus lead to energy saving. The possibility to obtain music or film through the internet instead of going to shop and buying physical copy of CD or DVD saves about 40 to 80 percent of energy (Kander et al., 2013). While the indirect effects of ICT on energy saving are believed to be even higher. Automation of manufacturing based on semiconductors enabled large material and energy savings in traditional industries. The report by the American Council for an Energy Efficient economy has estimated that if the United States economy in 2006 still relied on the technologies of those seen in 1976 but had expanded at the same rate, the energy consumption would have grown by 20% (Kander et al., 2013).

There are also arguments made about the ICT block as energy expanding. One of the main arguments is that large resources are still needed to produce tiny microchips and thus embodied energy (which is the sum of all energy required to fold, spindle and mutilate materials) is still very large. Smil argued that today four cell phones equal one car in terms of embodied energy from manufacturing (Kedrosky, 2011). In addition, although most ICT devices use a relatively small amount of energy, the number of such devices is becoming so large that the energy consumption goes up. The lifecycle of most devices is also very short and thus they quickly become outdated and replaced. Although this stimulates economic growth it nevertheless also requires an increasing amounts of energy to keep up with the increasing demand. Therefore even if we achieve a much higher growth today with a lower energy input, it does not necessarily decrease CO_2 emissions. In relative terms we can see the decline, however in absolute terms CO_2 in most of the countries does not decline.

So, what does the history of all previous energy transitions teach us and what can be taken on board when we think about switching to the use of new energy sources. Firstly, it is important to understand that energy transitions encompass the time that elapses between an introduction of a new primary energy source e.g. coal or oil and its rise to a substantial share (20% -30%) of the overall market or even becoming the single largest contributor or an absolutely dominant energy source (with more than 50 %) in a national or global energy supply (Smil, 2010). The term also refers to the diffusion of new prime movers e.g. the steam engine and/or the internal combustion engine, the devices that convert primary energy into mechanical power that is then used to turn gigantic generators in order to produce electricity or to propel vehicles, ships and airplanes. Given all that, probably the most important thing that all previous transitions have in common is that they are multigenerational affairs that take many decades, rather than years to accomplish and the greater the use of a prevailing energy sources is, the longer the transition will take. The evidence of over 200 years also tells us that even though we have made significant energy-efficiency improvements, in the long run they are “eaten up” by increased consumption (Jevons Paradox[1]) and unless there is a shift towards non-carbon energy sources, there will be an increase in CO_2 emissions. Nevertheless, it of course does not mean that there should be no attention paid to more efficient use of energy in fact the opposite should be the true, simply because the growing use of energy without the efficiency improvements will result in even higher carbon dioxide emissions.

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[1] The Jevons paradox (sometimes referred to as rebound effect) suggests that as things become more efficient, we use more of them rather than less. A classical example is driving a bigger car or driving more miles as the fuel economy improves. This implies that technical improvement in efficiency will not lead "per se" to lower consumption of energy.

2.2 Country Background

2.2.1 Overview of Energy Sector

Denmark is a relatively small economy that continues to show remarkable economic development. Currently, it is still self-reliant for all energy demands and because of significant oil and gas production in the North Sea, it is a net energy exporter (European Commission, 2011). In fact Denmark is the only country in European Union that is regarded as net energy exporter and thus does not face any challenges yet associated with energy security. However, according to the DEA (2012b) estimations at the current level of production oil and gas reserves are expected to last until 2018 and 2020 respectively, after which unless the demand for energy is reduced, Denmark will become a net importer (see Figure 2.2 and Figure 2.3).

Figure 2.2: Oil Production and Possible Production Profile

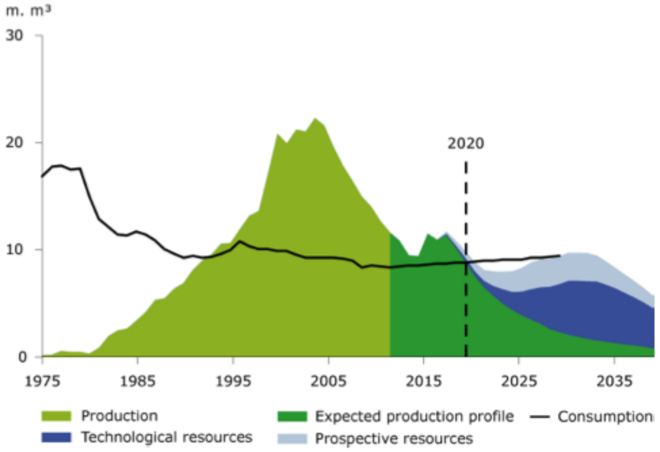
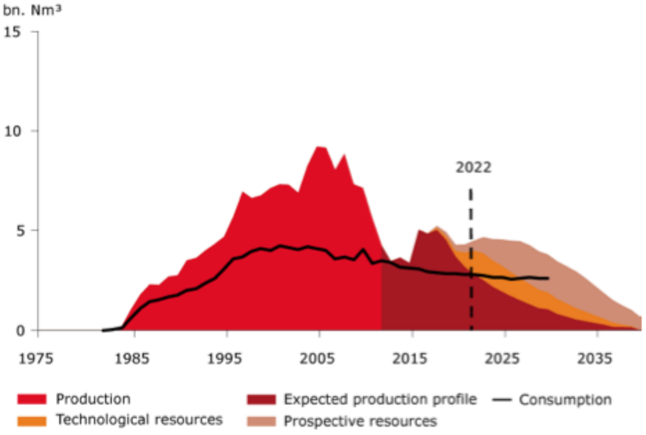


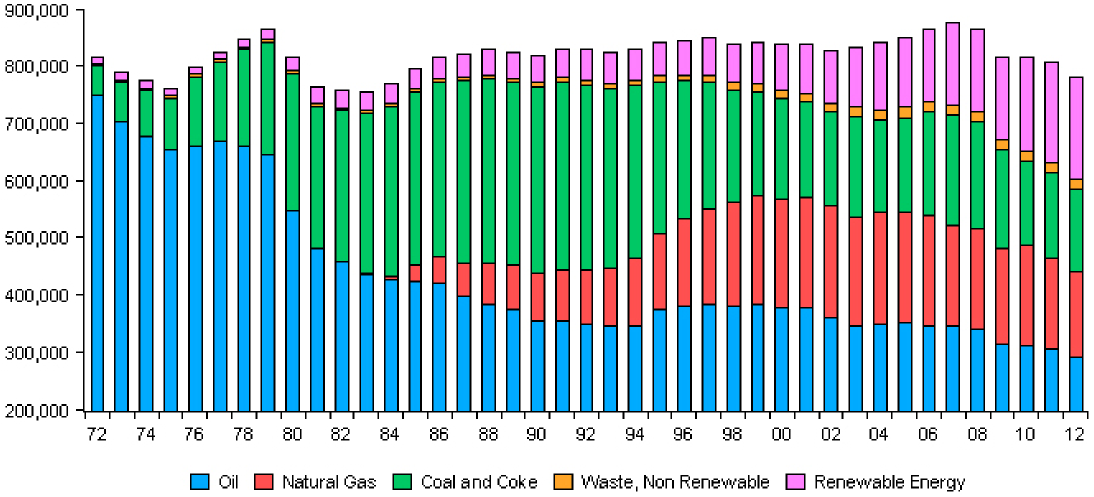
Figure 2.3: Gas Production and Possible Production Profile



Source: DEA (2012b)

Oil and natural gas represented respectively 38% and 20% of Denmark's total primary energy supply (TPES) in 2011 (DEA, 2012a). While the combined share of the two fuels in the supply mix has remained relatively stable over the past three decades, at around 60% of TPES, oil's share has been reduced dramatically from over 90% that it represented in the early 1970s. The decline in the oil share was largely attributable to the growing share of other fuels, mainly coal until the 1990s and then natural gas with renewable energy afterwards (see Figure 2.4). Furthermore, Denmark has one of the lowest energy intensities in the world, and thus despite remarkable economic growth, its energy use has remained almost unchanged over the period. It is important to note that Denmark not only introduced more renewables into its energy mix but also increased the share of less polluting fuels like natural gas[2].

Figure 2.4: Gross energy use by fuel type, Fuel Equivalent [TJ], 1972-2012.



Source: Danish Energy Agency (DEA). Author's construction

In addition to the oil and gas reserves, Denmark also has a well-developed electricity sector that continues to transform and introduce more renewable energy sources into its electricity generation. These major transformations started to take place since the oil crisis in the 1970's and as mentioned before at that time, most of the electricity was generated using oil (DEA, 2009). Throughout these transformations Denmark not only became a first large-scale user of wind power, but also a leader in the manufacturing of wind turbines.

As can be seen in Figure 2.4 the share of renewable energy (includes all renewables

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[2] Coal, Oil and Natural Gas have different CO_2 emission factors (kilogram CO_2/GJ). Coal emission factor is 95, Oil is 78; and Natural Gas (GJ/1000 Nm3) emission factor is 57, (DEA, 2012a). Thus by burning natural gas instead of coal we extract the same amount of energy but cut CO_2 emissions almost by half.

hydro, wind, biomass etc.) is increasing and in particular the growth speed up from 1997 (due to the Kyoto protocol agreement). Denmark's long-term goal is to become independent of fossil fuel use by 2050. In 2011, Danish government published Energy Strategy 2050, a ambitious policy document suggesting how to transform Denmark into low-carbon society with a stable and affordable energy supply. The first phase of strategy mainly focuses on the short term initiatives to reduce dependence on fossil fuels by strengthening and expanding existing policies in energy efficiency and renewable energy by 2020 (IEA, 2012).

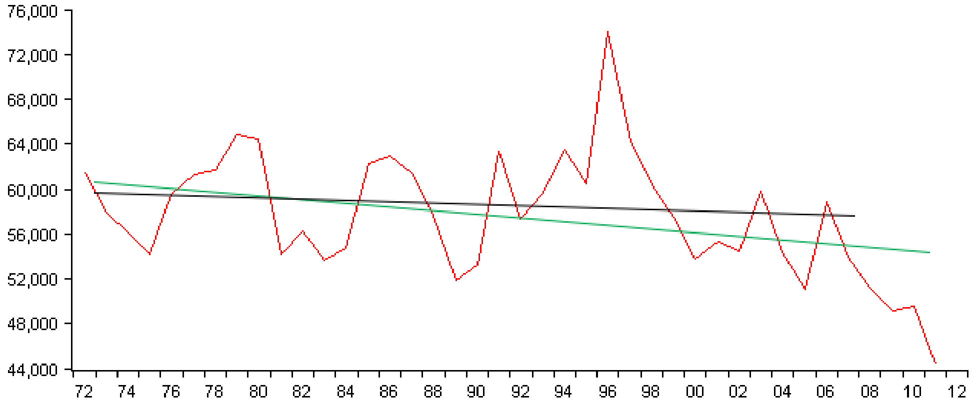
Doubts have been raised about the actual contribution of renewable energy sources (RES) towards the reduction of CO_2 (Sharman, 2009; Inhaber, 2011). The emerging renewable energy sources like e.g. wind or solar energy are very stochastic, intermittent and difficult to predict. In order to balance the supply and demand the conventional power plants must be present, otherwise when there is no wind or sun there will be no electricity. Such a relationship between RES and conventional power plants implies that even if the share of RES is increasing there may be no significant contribution towards CO_2 reduction (White, 2004). It is also important to note that even though Denmark has no electricity storage within its electricity sector, it is strongly interconnected with its neighboring regions Norway, Sweden and Germany. In particular Nordic countries with large hydroelectric systems, $\approx 95\%$ in Norway and $\approx 46\%$ in Sweden plays an important role in balancing stochastic variations in Denmark's wind power by continuously turning their hydropower stations up and down. Hydroelectric stations needs a little notice to start and stop generating and thus when "excess" of wind power is generated in Denmark hydropower can be rapidly turned down in Sweden or Norway, similarly when wind energy falls the "stored" electricity in Hydropower stations can be released (Sharman, 2009). In such a way, Sweden and Norway can be seen as Denmark's "electricity storage batteries". As could be expected, this kind of storage comes at a cost, because the price that the electricity is sold to Nordic countries and then bought back is different and most often it is bought back for more than it is sold.

2.2.2 Greenhouse Gas Emissions

Carbon dioxide (CO_2) is the main GHG, accounting for about 80% of the Denmark's total in 2010 and largest share of it comes from the burning of fossil fuels (DEA, 2012a). Although the renewable energy share has experienced a significant growth in Denmark's energy mix, due to the high presence of fossil fuels, CO_2 emissions are still above the EU average (IEA, 2012). Almost all energy-related CO_2 emissions come from three sources: the combustion of coal, used in the production of electricity and heat, oil consumed by the road transport sector; and to a lesser extent natural gas. The aggregate level of CO_2

emissions seems to fluctuate from year to year, some fluctuations are due to the weather changes (e.g. cold winter requires longer heating period) and electricity exports/imports. According to Denmark's National Inventory Report by Aarhus University (2009) in 1990 Danish electricity import was large resulting in relatively low fuel consumption and lower CO_2 emissions. Whereas, fuel consumption and constituting CO_2 emissions were high in 1996 (highest peak in Figure 2.5) mainly because of low rainfall in Norway and Sweden causing insufficient hydropower production in both countries. In addition some of the longer declines are attributable to global events e.g. decline since 2007 was mainly attributable to global financial crisis (see Figure 2.5). Two trend lines one up until 2007 (black line) and the other up until 2012 (green line) were drawn on the graph to show the overall trends in CO_2 emissions up until global financial crisis and during it. As it can be seen until 2007 trend line has only very marginal downward slopping pattern, while taking CO_2 emissions up until 2012 changes trend and a much more clear decline in CO_2 emissions can be observed.

Figure 2.5: Observed CO_2 emissions from total energy consumption, [ktoe], 1972-2012



Source: Danish Energy Agency (DEA). Author's construction

It is important to note that the CO_2 emissions stated in the Figure 2.5 concerns only emissions of CO_2 from energy use that account for about 80% of Denmark's overall GHG. Total GHG includes other CO_2 emissions from non-energy related activities nitrous oxide coming primarily from agriculture, methane coming primarily from agriculture and landfills, and the so-called industrial greenhouse gases, which stem primarily from refrigerants and from protective gas in larger electrical installations (Ministry of Climate and Energy, 2009).

Under the Kyoto Protocol Agreement Denmark is committed to reducing average emissions of GHG in the period 2008-1012 by 21% (DEA, 2012a). Reviewing the latest available data two important conclusions emerge. Firstly, observed CO_2 emissions from energy consumptions were 44.3 million tons in 2011 which was 10.6% less than in 2010 and 16.8% less than in 1990. While adjusted (for import/export and climate variations) CO_2 emissions in 2011 were only 2.8% lower that those in 2010, but 25.2% lower when compared to emissions in 1990 (DEA, 2012a). Observed preliminary[3] statistics on CO_2 for 2012 were 39.8 million tons 10.2% lower than in 2011 and by 25% lower than in 1990. Therefore, if consider observed preliminary emissions it appears that Denmark managed to reach the "first commitment period" of Kyoto target to reduce its emissions by 21% of 1990 level. Nevertheless, it is important to note that this is based on preliminary statistics from DEA that are not yet confirmed.

2.2.3 Energy Prices and Public Service Obligation (PSO)

Denmark has one the highest taxes and charges on energy (European Commission, 2011). This makes electricity prices for Danish households by far the highest in the EU. However in order to keep the Danish industry competitive, electricity supplied to the industry is taxed at a lower rate (see Appendix B) . Even though the rate of taxation is lower for industry, the price paid for energy by industrial consumers is still amongst the highest in the EU (electricity price is bellow EU average but Natural gas price is the highest in the EU) (European Commission, 2011).

High electricity prices can be explained by the Danish PSO (Public Service Obligation) component in the electricity price, which is primarily used to provide support for the renewable energy sources and other environmentally friendly electricity generation (IEA, 2012). The PSO mechanism was introduced in 2001, mainly to provide subsidies for wind generators and for other environmentally friendly sources of electricity. Although from 2005 the PSO mechanism was slightly adjusted, but the idea behind it stayed the same i.e. support environmentally friendly electricity, primarily wind (IEA, 2006) see Figure 2.6.

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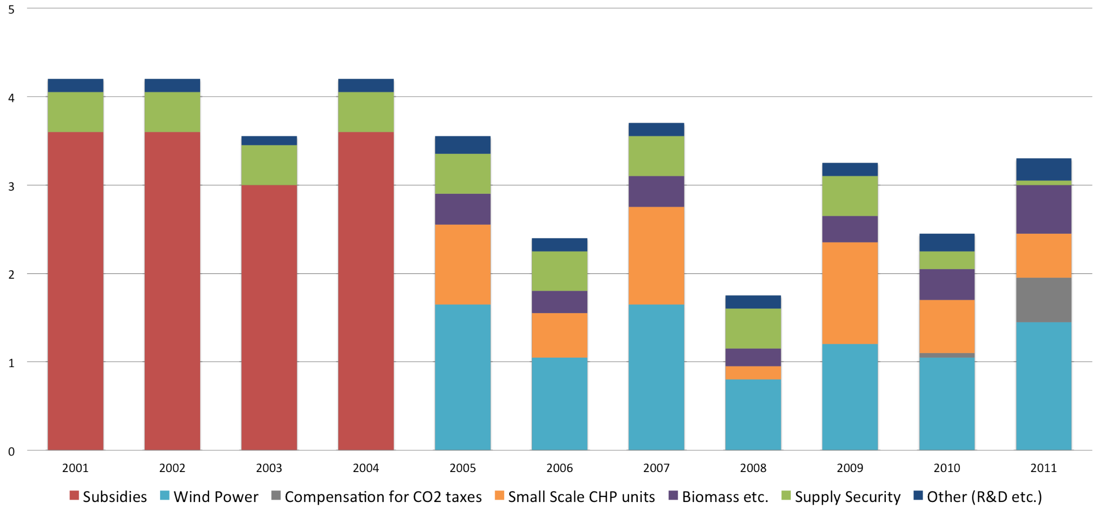
[3] The preliminary emissions statements are solely based on the preliminary energy statistics. Total greenhouse gas emissions are calculated by assuming that all emissions other than CO_2 emissions from energy consumption are constant at the values for 2010, as calculated by the DCE - Danish Centre for Environment and Energy (former NERI).

Figure 2.6: Expenses for (PSO) in the electricity area, Billion DKK (current prices)



Source: Danish Energy Agency (DEA). Author's construction

Renewable energy support mechanisms differ across the countries. The most popular and common support instruments can be subdivided into six categories: feed-in tariff, feed-in premium, quota obligation, investment grants, tax exemptions and fiscal incentives (de Jager et al., 2011). As can bee seen in Table 2.1 some Member States provide several different instruments to support electricity generation from renewable energy sources (RES-E) while others prefer the use of one particular support scheme. Denmark is one of the few countries that support it's electricity generation from RES mainly with the help of only one support instrument i.e. Feed-in premium (FIP). In a feed-in premium system, a guaranteed premium is paid in addition to the income producers receive for the electricity from renewable sources that is being sold on the electricity market. Compared to a feed-in tariffs (FIT), premiums are associated with higher uncertainty because returns on investments also depend on the electricity price in the market. Not all FIP systems are the same. Some are linked to the electricity price developments (e.g limited by cap and floor prices) this helps to provide more certainty for producers and also limit the possibility of over-compensation for investment. Denmark has put a cap on overall return for producers to minimize societal costs and ensure that adequate investment are made (Rathmann et al., 2011).

Table 2.1: Overview of RES-E support instruments in the EU-27

	AT	BE	BG	CY	CZ	DE	**DK**	EE	ES	FI	FR	GR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
FI-Tariff	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X			X			X	X	X
FI-Premium					X		**X**	X	X											X					X		
Quota obligation		X													X						X		X	X			X
Investment grants		X		X	X					X		X	X			X	X	X	X								
Tax exemptions		X							X	X		X						X		X	X			X		X	X
Fiscal incentives			X			X		X												X	X				X		

Source: de Jager et al. (2011)

Compared with RES-E there are relatively less incentives for the support of RES heat and cooling (RES-H&C). The available support instruments can be grouped into three categories: investment grants, tax exemptions and financial incentives (de Jager et al., 2011). In Denmark generation of RES-H is supported by tax exemptions (see Table 2.2). Biomass, being CO_2 neutral, is exempt from the CO_2 tax. Solar heating plants are exempt from both energy and CO_2 taxes (Rathmann et al., 2011). In general tax incentive or exemptions are highly flexible and powerful tools that can be used to target specific renewables or impact certain RE market participants in particular when they are used in parallel with other support instruments (de Jager et al., 2011).

Table 2.2: Overview of main RES-H&C support instruments in the EU-27

	AT	BE	BG	CY	CZ	DE	**DK**	EE	ES	FI	FR	GR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK
Investment grants	X	X	X	X	X	X		X		X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X
Tax exemptions	X	X					**X**				X	X			X	X				X				X			X
Fiscal incentives			X			X		X			X											X					

Source: de Jager et al. (2011)

The support for biofuel consumption (RES-T) in the European Union is often a combination of an quota obligation with tax exemptions. Only in a few member states, just one of these two instruments is used. In Denmark the main supporting measure for promotion of biofuels is the exemption from the CO_2 tax (see Table 2.3) that is imposed on ordinary petrol and diesel for transport since January 2005. The government is also working on change of vehicle taxation so that is transferred from ownership of a vehicle to its use. The main idea behind it is to encourage consumers to buy an energy-economical vehicle. In 2010 Denmark has also obliged oil companies to ensure that by 2012 at least 5.75 % of annual fuel sales for land transport comes from the biofuels (Rathmann et al., 2011).

Table 2.3: Overview of main biofuels support instruments in the EU-27

	AT	BE	BG	CY	CZ	DE	**DK**	EE	ES	FI	FR	GR	HU	IE
Quota obligation	X		X	X	X	X	**X**	X	X	X	X		X	X
Tax exemptions	X	X		X	X	X	**X**		X		X	X		X

	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	UK	
Quota obligation		X	X	X		X	X	X	X		X	X	X	
Tax exemptions	X	X	X	X	X		X	X	X	X	X	X	X	

Source: de Jager et al. (2011)

Chapter 3

Theory and Hypotheses

The standard economic theory while recognizes labor and capital as two crucial inputs in the production function does not consider energy *per se* as a factor of production and instead treats it as an intermediate input. Despite the fact that the traditional economic theories do not explicitly consider the relationship among energy and economic growth an empirical investigation on the relationship between these variables is one of the most attractive areas in energy economics.

Ever since the initial work on causal relationship between energy consumption and output by Kraft and Kraft (1978) the topic became widely discussed in the global scientific literature. Although no single agreement about the causation was found according to Payne (2009, 2010) the relationship between energy and GDP can be categorized into four hypotheses.

"*Growth*" Energy Consumption → GDP, (Unidirectional)

First the "growth" hypothesis indicates that energy contributes towards economic growth both directly in the production process and/or indirectly as a complement to labor and capital. In the Granger causality framework, the "growth" hypothesis is supported if the increase in energy consumption causes an increase in output. The implication of such a hypothesis is that policies aimed at energy conservation may potentially have a detrimental impact on economic growth. It is also important to note that increase in energy consumption may also have a negative impact on GDP. For example, it may occur when the economic growth is shifting from energy intensive production towards less energy intensive production (e.g service economy). The negative impact of energy consumption on GDP may also be attributed to either excessive energy consumption in unproductive industries, capacity constraints or an inefficient energy supply.

"*Conservation*" GDP → Energy Consumption, (Unidirectional)

Second the “conservation” hypothesis asserts that energy conservation policies that are aimed at reducing CO2 emissions, efficiency improvement and waste management do not necessarily reduce GDP. This type of hypothesis is supported if the increase in GDP Granger causes an increase in energy consumption. Although it is very unlikely (at least theoretically) but an increase in GDP may also Granger cause a decline in energy consumption. According to Payne (2010)this can occur when growing economy constrained by political, infrastructural, or mismanagement of resources generates inefficiencies and the reduction in the demand for goods and services, including energy consumption.

“*Feedback*” GDP ↔ Energy Consumption, (Bidirectional)

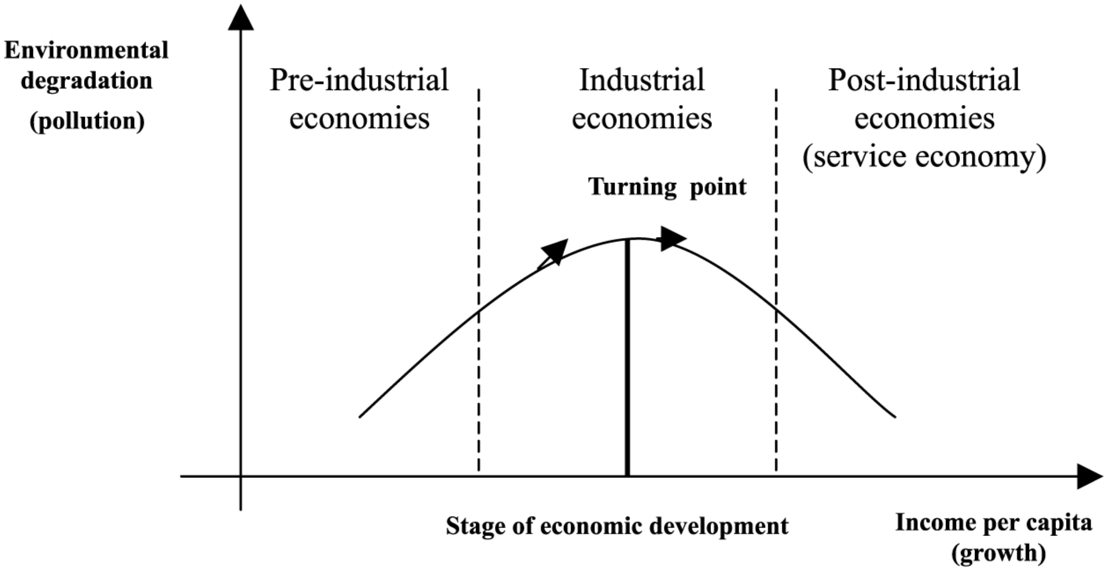
Third the “feedback” hypothesis implies the interdependent relationship between GDP and energy consumption where each component may act as a complement to each other. In the presence of such a relationship, increase (decrease) in energy consumption results in increase (decrease) in GDP and the other way round increase (decrease) in GDP may result in increase (decrease) in energy consumption. Therefore, feedback hypothesis is supported by the evidence of bidirectional Granger causality between GDP and energy consumption.

“*Neutrality*” GDP $\neq$ Energy Consumption, (No Causality)

Fourth, the “neutrality” hypothesis considers energy consumption to be relatively minor component of real GDP and thus energy consumption should have no significant impact on economic growth. Similarly as in the case of the “feedback” hypothesis, energy conservation policies may have little or no affect on GDP. The neutrality hypothesis is supported if there is no evidence of Granger causality between energy consumption and real GDP.

The hypotheses mentioned above were derived mainly from testing the relationship between the economic growth and energy consumption. While the studies examining the relationship between economic growth and environmental pollution tested the validity of the so-called Environmental Kuznets Curve (EKC) hypothesis. The EKC was first discussed by Grossman and Krueger (1992) who suggested that an inverted U shape relationship exists between the level of pollution and economic growth. Starting from the low base, the pollutant per capita and income per capita increase together until a certain point of income is reached at which growth of the pollutant flattens and reverses (see Figure 3.1). This implies that once a certain level of income has been reached the further growth can now be achieved without a proportional increase in emissions (Grubb et al., 2006). The corollary is that economic growth in itself is the solution to the environmental degradation (Taylor, 1993).

Figure 3.1: Environmental Kuznets Curve



Source: Panayotou (1993)

It is important to note that although this study looks at the relationship between the economic growth and environmental pollution it does not seek to test the validity of the EKC hypothesis. This is mainly because this study looks at renewable energy consumption instead of aggregate energy consumption and thus it would make no sense to test the environmental degradation. In addition, the methodology that is being applied in the study mainly relies on linear assumptions while testing the EKC hypothesis requires modeling of non-liner (usually its either quadratic or cubic) relationship.

The hypotheses to be tested are presented in the Table 3.1. Due to the nature of empirical methods applied in the study a total of twelve different outcomes is possible.

Table 3.1: Hypotheses to be tested and possible outcomes

RE $\rightarrow$ CO_2	GDP $\rightarrow$ RE	CO_2 $\rightarrow$ GDP
RE $\leftarrow$ CO_2	GDP $\leftarrow$ RE	CO_2 $\leftarrow$ GDP
RE $\leftrightarrow$ CO_2	GDP $\leftrightarrow$ RE	CO_2 $\leftrightarrow$ GDP
RE $\neq$ CO_2	GDP $\neq$ RE	CO_2 $\neq$ GDP

Chapter 4

Literature Review

There is an extensive amount of research that examined the relationship between economic growth, environmental pollution and energy consumption. Literature survey by (Payne, 2010) counted over one hundred empirical studies conducted up until 2005 on casual relationship between energy consumption and economic growth alone. Whereas, Stern et al. (2013) collected over 400 papers to conduct a meta analysis of this field of research. Most of the studies differ in the use of econometric methodologies, countries, time periods and findings and can be subdivide into three main lines of research.

4.1 Output-Energy Nexus

The first line of research focuses solely on examining the relationship between economic growth and energy consumption. The main purpose of these studies is to examine whether the energy use is a cause of a economic growth or whether the level of energy use is determined by the level of output. The pioneers in this field were Kraft and Kraft (1978) who using the US annual data for the period between 1947-1974 analyzed the relationship between the GNP and energy consumption. Their findings showed that there is causality coming from economic growth (in this case GNP) to energy consumption. Such findings implied that energy conservation policies should not adversely affect economic activities. An extensive literature has followed. Not long afterwards Akarca and Long (1980) contested Kraft and Kraft (1978) findings. Using the data on the total employment and energy consumption for the period between 1950 and 1970 they found a unidirectional causality running from energy consumption to employment without feedback, such a findings were in support of growth hypothesis. Study by Stern (1993) supports such findings. Using multivariate VAR model of GDP, capital, labor and Divisia energy index he found that energy Granger caused GDP. While Yu and Hwang (1984) using similar technique to that of Kraft and Kraft (1978) with extended dataset for the USA found no causality between energy consumption and GNP in the USA for the period between 1947-1979. Yu and Choi (1985) studied several different countries and found different results for different countries. In their study they found no causality relationship between GNP and energy consumption for the UK, USA and Poland. Whereas, for the South Korea they found a unidirectional causality from GNP to energy consumption and for Philippines from energy consumption to GNP.

Most of the early studies were conducted in bivariate framework and relied mainly on Granger causality tests on unrestricted vector auto-regressions (VAR) in the level form variables. Following the advances in the time series new techniques have been applied to study the relationship between energy and output. The new technique that has emerged in a large number of studies was that of cointegration and the estimation of the corresponding error correction model.

First research to employ cointegration technique was conducted by Yu and Jin (1992). In their study using monthly data for the period between 1974-1990 on US energy, income and employment they found no long run relationship between variables implying neutrality hypothesis. Soon afterward an extensive amount of research using cointegration technique has followed. Similarly, as in the use of unrestricted VAR findings coming from use of cointegration method were inconclusive and differ according to the use of sample, region and variables. A study by Stern (2000) using the same variables as in Stern (1993) showed that there is a cointegrating relationship between all variables in the model and that energy Granger causes GDP in either unidirectional way or possibly in a mutually causative relationship. In a more recent paper using a Swedish data set of roughly 150 yearly observations, Stern and Enflo (2013) show that energy is more likely to cause growth in multivariate framework, while in bi-variate results are more mixed. While Chontanawat et al. (2006) analysis on GDP and energy consumption provides opposite findings. Although they use a shorter time period they find no cointegration among the variables and show that for the period between 1960-2000 there is no causal relationship between variables in the USA (neutrality hypothesis) while in Sweden GDP Granger causes energy consumption.

4.2 Output-Pollution Nexus

The second line of research focuses on examining the relationship between the economic growth and environmental pollution. Most of the studies from this branch of research are aimed at testing the validity of Environmental Kuznets Curve (EKC). The EKC concept emerged in the early 1990s with Grossman and Krueger (1992) path breaking study on potential impacts of NAFTA (North American Free Trade Agreement). The EKC postulates that the relationship between economic growth and the environmental degradation reassembles an inverted U-shape curve. Implying that when the country develops the pollution levels are increasing but begins to decline when rising income reaches an inversion point (see Figure 3.1 on page 20). If the EKC hypothesis is found to be true then economic growth instead of being a threat to the environment would actually be a source of environmental improvement.

The EKC literature is abundant in studies that test for linear, as well as quadratic and cubic relationships between per capita income and pollutant emissions. Similarly as in the studies between energy and output the results in this field of research seem to be inconclusive. Most basic EKC studies treat environmental degradation as dependent variable and income as independent. The key difference among these basic EKC models is the choice of different pollutants, time periods and countries. For instance, Grossman and Krueger (1992) estimated EKC for SO_2 (Sulfur Dioxide) using GEMS dataset[4]. Turning points for SO_2 were found to be at around \$4,000–5,000. Selden and Song (1994) estimated EKCs for four emissions series: SO_2 (Sulfur Dioxide), NO_x (Nitric oxide), SPM (Suspended Particulate Matter), and CO (Carbon Monoxide) using longitudinal data from developed countries. Compared to the Grossman and Krueger (1992) the estimated turning points in this study were relatively high. For SO_2 turning point was at \$10,391; NO_x, \$13,383; SPM, \$12,275; and CO, \$7,114. In general this study showed that turning point for emissions is likely to be higher that for ambient concentrations. Coondoo and Dinda (2002) test for the Granger causality between income and CO_2 in groups of countries using panel data. Their findings suggest that causality runs from income to emissions or there is no significant relationship in developing countries, while in developed countries causality runs from emissions to income. Other EKC studies also include additional explanatory variables, in order to model underlying or proximate factors, such as ‘‘political freedom’’ (e.g Torras and Boyce, 1998) or output structure (e.g., Panayotou, 1997), or trade (e.g., Suri and Chapman, 1998).

Although there is a very large number of studies testing the existence of EKC, the evidence suggest that there is no common agreement to support the existence of U-shaped curve. Nevertheless, it is important to note that local pollutants (e.g SO_2) are more likely to display an inverted U-shaped relationship with income than global pollutants like carbon dioxide. This evidence is also in line with environmental economics theory as local impacts are internalized within a single economy or region and are likely to give rise to environmental policies to correct the externalities on pollutees before such policies are applied to globally externalized problems (Stern, 2004).

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[4] The GEMS dataset is a panel of ambient measurements from a number of locations in cities around the world.

4.3 Output-Energy-Pollution Nexus

The third most recent branch of research combines the relationship between economic growth and energy consumption as well as economic growth and environmental pollution into one framework and analyses it simultaneously using advanced econometric techniques. One of the first studies to examine dynamic relationship between pollutant emissions, energy consumption and output was conducted by Soytas et al. (2007); In the study on the US for the period 1960-20004 they found that in the long-run economic growth was influencing the use of energy and growth of pollution. Ang (2007); Soytas et al. (2007); Soytas and Sari (2009); Hatzigeorgiou et al. (2011) followed this line of research and examined the relationship between economic growth, energy and environmental pollution for several different countries and periods. Although in general studies report similar results there are also some differences observed in the results that might be due to the choice of different countries, time period and methodology. Ang (2007) in the study on France for the period 1960-2000 found evidence to support causality coming from output growth to CO_2 emissions and energy consumption. Hatzigeorgiou et al. (2011) using a multivariate cointegration analysis to test the relationship between CO_2 emissions GDP and energy intensity in Greece during the period 1977-2007 reports similar findings. They find that there are unidirectional causalities running from GDP to EI (energy intensity) and from GDP to CO_2 as well as bidirectional causality between CO_2 emissions and EI. Whereas, Soytas and Sari (2009) using similar variables in their study on Turkey for the period between 1960 and 2000 find no cointegration among variables and use a Toda-Yamamoto procedure to test for Granger causality. Differently from previously mentioned studies they find a unidirectional causality running from carbon emissions to energy consumption.

4.4 Aggregate, Disaggregate and RE studies

The studies also differ in terms of how they treat energy consumption i.e. aggregate or disaggregate level. Most of the studies mentioned in previous sections looked mainly at aggregate energy data. However, the growing threat of global warming and importance of energy security led to the rise of interest in studies that seeks to investigate the impact of different energy carriers on economic growth and/or environmental pollution. One of the first studies to look at the disaggregate energy consumption data was conducted by Yang (2000). He argued that the use of aggregate energy data doesn't capture the extent to which countries depend on different energy source. In his study on Taiwan he found bidirectional causality between aggregate energy consumption and GDP. However, the direction of causality was inconclusive when he disaggregated energy data into coal, oil, natural gas and electricity. Findings suggested bidirectional causality between GDP and coal, GDP and electricity, GDP and total energy consumption, but unidirectional causality running from GDP to oil consumption and from natural gas to GDP.

Apergis et al. (2010) analyzes the relationship between GDP, CO_2, Nuclear and renewable energy using panel data of 15 countries for a period between 1984 and 2007. Their findings suggest that in the short-run nuclear energy has a negative and statistically significant impact on CO_2 emission, implying that nuclear energy plays an important role in reducing CO_2 emission. Whereas the sign of renewable energy was found to be positive implying that it did not contribute towards reduction of CO_2 emissions in the short-run. Menyah and Wolde-Rufael (2010) in a single country study on the US considering the same variables but longer time period 1960-2007 supports Apergis et al (2010) findings. The empirical evidence from the study suggest a negative unidirectional causality running from nuclear energy consumption to CO_2 emissions but no causality running from renewable energy consumption to CO_2 emissions, in fact opposite relationship was found to be true i.e causality coming from CO_2 emissions to renewable energy consumption. Such evidence suggested that unlike nuclear energy consumption, the renewable energy consumption did not help to mitigate CO_2 emissions. Possible explanations for such surprising relationship was that renewable energy could have not yet reached the threshold point when it actually starts to mitigate CO_2 emissions. Findings by Chiu and Chang (2009) suggest that renewable energy supply has to account for 8.39% (explain why there is a threshold) of the total energy supply before it starts to make any impact on reduction of CO_2 emissions. Whereas, in the US renewable energy accounted for only 7.3 % of total energy supply in 2008, and thus implied that the threshold required for renewable energy to make impact on mitigating CO_2 emissions has not been reached.

Vaona (2012) using several different methods and a large data set on Italy for a period 1861-2000 examined the causality relationship between energy consumption of (non) renewable energy sources and output. Although the study employed different methodologies (VAR, VECM) the results in general supported the same conclusions. One of the main findings in the study was bidirectional causality between non-renewable energy consumption and output. Which suggested that greater non-renewable energy consumption boosts economic growth but an increase in level of output depresses the growth rate of non-renewable energy consumption, which could possibly be attributable to greater efficiency in energy use. The study however did not find any evidence of causality between the renewable energy consumption and output.

Silva et al. (2011) examines the causal relationship between GDP, CO_2 and renewable energy sources (used for electricity generation) in a sample of four countries (Denmark, Portugal, Spain, USA) during the period 1960-2004. They found that for almost all countries except the USA, the increasing share of renewable energy sources have initially a negative impact on economic growth but positive impact on CO_2 emissions reduction. The general conclusion that can be drawn from Silva et al. (2011) study is that rather different countries in terms of size and energy structures have similar responses to the increase in share of renewable energy sources. However, observing all studies that used renewable energy mentioned in this section the evidence seems to be inconclusive

To best of the author's knowledge apart from the Silva et al. (2011) no other study have attempted to investigate causal relationship between renewable energy consumption, economic growth and CO_2 emissions for Denmark. Nonetheless, differently from Silva et al. (2011) in this study we consider all renewable energy consumption instead of the renewables used for electricity generation only. This is done because not all renewables are used for electricity generation even though the share is large, 65% of all renewables in 2011 were used for electricity and district heating. But we also use biodiesel, biogas, wood and etc to run our cars and heat homes and thus it is important to account for their contribution. In addition we also use different time period and employ a slightly different and more robust methodology i.e. we test for Granger causality using Toda Yomamoto approach and we also test for cointegration among the variables.

Therefore, this paper makes a contribution to the existing empirical literature by combining the two lines of empirical research in an emerging area of energy economics using relatively new time series methodologies that overcome some of the methodological concerns of other studies (e.g testing for cointegration and using T-Y Granger causality test). Finally, the empirical results of this single country study may be helpful in guiding policy makers in devising long term sustainable plans in Denmark.

Chapter 5

Quantitative Data

This study employs annual data covering the period from 1972 to 2012. This particular period was chosen simply because the required data was not available for earlier periods. The use of quarterly data could have allowed a more sophisticated analysis, however such statistics are not available for some variables. In order to account for changes in variables attributable to changes in population structure (e.g population growth) all variables were either obtained or transformed to per capita basis. The variables considered in the study are following:

- GDP per capita - is the main and mostly used growth indicator. GDP Series are PPP adjusted in constant 2000 US dollars. The data on this variable was obtained from World Bank database.
- CO_2 emissions per capita – is measured in metric tons and obtained from Danish Energy Agency (DEA). In general CO_2 is one of the most polluting gasses and accounts for about 80% of GHG in Denmark.
- RE per capita – represents renewable energy consumption, measured in kWh per capita, obtained from the Danish Energy Agency (DEA). Some studies tend to separate hydro power from the rest of renewables as it quite often may act as a main energy carrier in some countries e.g. Norway about 95% of electricity is generated by Hydro power, while in Sweden about half of all electricity comes from hydropower. However in Denmark only a tiny share of electricity is generated by hydropower and there are no signs that it would be growing and thus we do not separate it from other renewables. Therefore RE includes following energy source solar, wind, hydro, geothermal, biomass, biodiesel, biogas, and heat pumps.

The data on CO_2 emissions and RE consumption is available and can be obtained in two forms, observed and adjusted. Observed (or actual) energy consumption data represents the registered energy consumption for a given year and similarly observed CO_2 emissions represents the calculated emissions. Whereas adjusted data takes into account fluctuations in climate and foreign trade in electricity. In cold years or years with net electricity exports, the adjustments are negative, whereas in warmer years or years with net imports of electricity, the adjustments are positive (DEA, 2012a). The climate adjusted energy consumption is therefore the consumption that would have taken place, had the year been a normal year. Although adjusted statistics provides a good picture of overall developments in the energy field, in this study it has been decided to use observed statistics. This is mainly because they represent real and actual situations are more accurate and differently from adjusted statistics, there is no loss of information due to adjustments.

It is also important to note that observations for a year 1973 and 1974 were missing in the data (RE consumption and CO_2 emissions) obtained from DEA. The missing data was generated by taking the year 1972 (available from DEA) and applying RE consumption and CO_2 emissions growth rates obtained from the World Bank database (i.e 1973 = 1972 observation from DEA * growth rate from the World Bank and then a similar procedure for 1974).

Finally, all variables are transformed in natural logarithms as it helps to minimize the fluctuations in the data series and allows the measure of the approximate growth rates when taking logarithmic differences.

Chapter 6

Methodological Framework

In this chapter we present the details of the methods applied in this study. The number of tests required to perform a robust time series analysis is high and at some point can become confusing. Therefore, in order to help the reader follow the methodology used in this study a standard time series analysis procedure is provided in Appendix A.

6.1 Vector Autoregression

The Vector Autoregression (VAR) models were first proposed by Sims (1980) who argued that "it should be feasible to estimate large macro models as unrestricted reduced forms, treating all variables as endogenous". Today VARs are regarded as most flexible, successful and easy to use models for the time series analysis Wang and Zivot (2006). In this study VAR models are preferred because they allows us to analyze multiple relationship between variables in an accurate and simple way, without specifying which variables are endogenous or exogenous. Of course, the VAR methods outlined here have some disadvantages. On of the main limitations is that, without appropriate and correct modification, standard VARs miss nonlinearities, conditional heteroskedasticity, and drifts or breaks in parameters. Thus it is crucial to specify VAR model correctly. A critical element in the specification of VAR models is the determination of the lag length of the VAR. Three tests are used in order to choose the optimal lag length p in the VAR model, the Akaike (AIC), Schwarz (SBIC) and the Hanna-Quinn (HQIC) criterions. If the conflicting results are obtained then we choose a lag length suggested by majority of criterion tests. Post-estimation tests for skewness, kurtosis and normality of residuals are carried out after estimating each VAR model. In addition we also test for the serial autocorrelation in the residual if we find any evidence of autocorrelations we try to fix it buy adding or removing lags of our variables.

6.2 Unit Root Test

This study employs standard time series econometric procedures in order to analyze the dynamic relationships between economic growth, energy consumption and environmental pollutions. Firstly to identify whether time series contains a unit root, three tests are carried out an Augmented Dickey and Fuller (1981) (ADF), Phillips and Perron (1988) test (PP) and Kwiatkowski et al. (1992) test (KPSS).

- Augmented Dickey-Fuller (ADF) regression model has a form:

$$\Delta y_t = \alpha + \beta t + \delta y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta y_{t-i} + \varepsilon_t \tag{6.1}$$

$$\Delta y_t = \alpha + \delta y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta y_{t-i} + \varepsilon_t \tag{6.2}$$

$$\Delta y_t = \delta y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta y_{t-i} + \varepsilon_t \tag{6.3}$$

where t is the time index, α is an intercept constant, β is the coefficient on a time trend, δ is the coefficient presenting process root (i.e. focus of the test), ε is an independently, identically distributed residual term, y_t is the variable of interest (GDP, CO_2, RE). The aim of test is to see whether the coefficient δ equals zero, which would imply that process is non-stationary, thus for the Eq 6.1 the null hypothesis is $H_0 : \delta = 0\ \beta{\neq}0$, y_t is non-stationary, against the alternative $H_A : \delta < 0\ \beta{\neq}0$, y_t is trend stationary, for Eq 6.2 $H_0 : \delta = 0\ \alpha \neq 0$, y_t is non-stationary, against the alternative $H_A : \delta < 0\ \alpha \neq 0$, y_t is level stationary and for Eq 6.3 $H_0 : \delta = 0\ y_t$ is non-stationary, against the alternative $H_A : \delta < 0$, y_t is stationary. It is important to note that Eq 6.1 represents a least restricted ADF model i.e. including trend and constant, while Eq 6.2 excludes trends and Eq 6.3 excludes both trend and constant. Adding irrelevant regressors into regression may reduce the power of the test, thus it is important to specify correctly whether to include a constant and linear trend, only constant or neither into the regression. One possible way to specify the model correctly is by ocular inspection of times series. If the plot of the series does not start from the origin and if there is some kind of visible trend then probably model should include constant and trend as in Eq 6.1 but if e.g the trend is not apparent (e.g differenced series) then it should not be included in the model as in Eq 6.2. Whereas in order to determine the lag length the correlogram will be inspected followed by a testing down procedure removing the lags that are statistically insignificant.

- Phillips-Perron (PP) regression model with a constant and trend has form:

$$y_t = \alpha + \beta t + \delta y_{t-1} + \varepsilon_t \tag{6.4}$$

where similarly as in ADF α is an intercept constant, β is the coefficient on a time trend, δ is the coefficient presenting process root, ε is an independently, identically distributed residual term, differently from ADF which accounts for serial correlation by including lags of the first differences of y_t, PP test ignores any serial correlation and heteroskedasticity in the equation and corrects for it non-parametrically by using Newel-West correction of standard deviations. The hypotheses to be tested are the same as in the ADF test i.e $H_0 : \delta = 0 \, \beta \neq 0$, y_t is non-stationary, against the alternative $H_A : \delta < 0 \, \beta \neq 0$, y_t is trend stationary and etc.

- Kwiatkowski et al (1992) KPSS regression model with a constant and trend has a form:

$$y_t = \alpha + \beta t + k \sum_{i=1}^{t} \xi_i + \varepsilon_t \tag{6.5}$$

where α is an intercept constant, β is the coefficient on a time trend, ε is stationary or more precisely $I(0)$ error process, ξ_i has expected value of 0 and variance of 1 and k is the coefficient presenting process root. Differently from ADF and PP test in KPSS under the null hypothesis series are assumed to be stationary. The hypothesis can be formulated as $H_0 : k = 0$, trend stationary and alternative $H_A : k \neq 0$, non-stationary.

Some of the tests like ADF and PP are known to suffer potentially severe sample size and power problems e.g process might be nearly non-stationary still meaning that it is stationary, but with a root close to the non stationary boundary. Therefore, all three tests are considered together to provide a robust conclusions about the time series properties.

6.3 Cointegration

The concept of cointegration can be described as a systematic co-movement among the selected time series over the long-run. If two or more series are each non-stationary, but a linear combination of them is stationary then it can be said that the series are cointegrated. It is necessary to test for cointegration if we want to provide robust and meaningful results.

One of the most widely used approaches to test for cointegration is VAR based Johansen (1992) test. Differently from other cointegration tests like e.g Engle-Granger test which permits only one cointegrating relationship, Johansen test allows for more that one co-integrating relationship to be tested and thus is more applicable in this study. General VAR (p) model can be written as

$$y_t = \alpha_o + \sum_{j=1}^{p} A_j y_{t-j} + \varepsilon_t \tag{6.6}$$

where y_t is our variable of interest GDP, CO2, RE. α_0 is a vector of constant terms or $[\alpha_{GDP}\ \alpha_{CO2}\ \alpha_{RE}]$, and A_j is a matrix of VAR parameters for lag j, ε_t represents vector of error terms $[\varepsilon_{GDP}\ \varepsilon_{CO2}\ \varepsilon_{RE}]$.

During the implementation of Johansen's test it is important to choose deterministic components (trend, constant, both or none etc) correctly. Johansen (1992) suggest the use of Pantula principle developed by Pantula (1989). The procedure involves the estimation of three models, starting from the most restrictive model (model 2) which includes restricted constant and no trends, to the least restrictive model (model 4) with unrestricted intercept and restricted trends comparing trace test statistic to its critical value at each stage. The test is complete when the null hypothesis is not rejected for the first time.

However, due to the small sample size (41 annual observations) used in this study it is possible that, the Johansen test statistics may be biased (Cheung and Lai, 1993). Therefore, we follow the approach Reinsel and Ahn (1992), who suggest multiplying the Johansen trace statistics with the scale factor N/(N-pk), where N is the number of observation, k is the number of variables and p is the lag parameter in the estimated VAR system. Such a procedure corrects for small sample bias and allows more appropriate statistical interferences to be made with small samples. If the co-integrating relationship is found then in order to account for non-stationary variables VECM model has to be estimated. General VECM can be denoted as:

$$\triangle y_t = \alpha + \sum_{i=1}^{p} \alpha_i \triangle y_{t-i} + \sum_{j=1}^{p} \beta_j x_{t-j} + \phi e_{t-1} + \varepsilon_t \tag{6.7}$$

where $\triangle$ is the difference operator, p is the number of lags, α and β are parameters to be estimated, ε is serially uncorrected error term, and e_{t-1} is the error correction term (ECM).

6.4 Granger (Non)Causality

Granger non-causality is one of the most widely used econometric techniques to investigate the relationship between two or more variables. The simple definition of Granger non-causality can be given as: " X is said to Granger-cause Y, if Y can be better predicted using the past values of both X and Y than it can be by using the history of

Y alone." In this study three Granger causality tests are considered. Firstly, Granger non-causality test is carried out following the Toda and Yamamoto (1995) (T-Y) long-run causality test. Which involves determining order of integration of times series, then adding additional lag for each variable based on their integration e.g if the both series are I(1) then we add 1 lag for each variable in the VAR model but not account for this additional lag in the Wald test[5]. This procedure involves testing for Granger non-causality in the levels of time series so there is no loss of information due to differencing. The VAR model to be tested has a form of:

$$y_t = \alpha + \sum_{i=1}^{m} \alpha_i y_{t-i} + \sum_{i=1}^{m} \beta_i x_{t-i} + \varepsilon_t \tag{6.8}$$

$$x_t = \alpha + \sum_{j=1}^{n} \alpha_j x_{t-j} + \sum_{j=1}^{n} \beta_j y_{t-j} + \varepsilon_t \tag{6.9}$$

we test for $H_0 : \beta_i \ (i = 1, 2...m) = 0$, against $H_A : Not\ H_0$, that "X does not Granger-cause Y" if the reject null it implies that variable X Granger-cause Y. In the same we we cant test for $H_0 : \beta_j \ (j = 1, 2...m) = 0$, against $H_A : Not\ H_0$, that "Y does not Granger-cause X" rejection of null in this case would mean that variable Y Granger-cause X. This Granger non-causality can be perceived as a pretest which allows for a cross-check of overall results. For instance, if we find that time series are cointegrated then there must be a causality between them in either one way, or in both directions (but the opposite is not true). This implies that if we find cointegration among variables but T-Y procedure reveals that there is none, then it is very likely that we could have misspecified the VAR model when testing for cointegration. Furthermore, the T-Y procedure involves testing for Granger causality in levels, thus there is no information loss due to differencing of the data.

In order to support the Granger causality test results obtained from T-Y approach and obtain some insights about the interaction between variables in the short-run we consider two other Granger causality tests. Which other Granger causality test will be carried out depends on whether the variables are cointegrated or not. If the variables are found to be cointegrated then causality can be tested in the following error correction models (ECM):

$$\triangle y_t = \alpha + \sum_{i=1}^{m} \alpha_i \triangle y_{t-i} + \sum_{i=1}^{m} \beta_i \triangle x_{t-i} + \phi_i e_{t-1} + \varepsilon_t \tag{6.10}$$

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[5] In depth explanation of this T-Y procedure can be found at: http://davegiles.blogspot.se/2011/04/testing-for-granger-causality.html

$$\triangle x_t = \alpha + \sum_{j=1}^{n} \alpha_j \triangle x_{t-j} + \sum_{j=1}^{n} \beta_j \triangle y_{t-j} + \phi_j e_{t-1} + \varepsilon_t \tag{6.11}$$

where $e_{t-1}$is the error correction term and (ECT). The short-run causality from x_t to y_t can be examined by conducting F-test, the null hypothesis of Granger non causality is $H_0 : \beta_i = 0$, $i = 1, 2...m.$ The long run causality from x_t to y_t is examined by conducting t-test, the null hypothesis of Granger non causality is $H_0 : \phi_i = 0$. To examine the strong (short and long) causality from x_t to y_t a joint F-test is conducted, the null hypothesis of Granger non causality in this case is $H_0 : \beta_i = 0$ and$H_0 : \phi_i = 0$. Similar procedure can be carried out to test causality from y_t to x_t in Eq 11. If the variables are found to be not cointegrated then we will test for causality by using differenced time series and testing for a Granger non causality in the following VAR model:

$$\triangle y_t = \alpha + \sum_{i=1}^{m} \alpha_i \triangle y_{t-i} + \sum_{i=1}^{m} \beta_i \triangle x_{t-i} + \varepsilon_t \tag{6.12}$$

$$\triangle x_t = \alpha + \sum_{j=1}^{n} \alpha_j \triangle x_{t-j} + \sum_{j=1}^{n} \beta_j \triangle y_{t-j} + \varepsilon_t \tag{6.13}$$

similarly as in T-Y approach we test for $H_0 : \beta_i \ (i = 1, 2...m) = 0$, against $H_A : Not\ H_0$, that "X does not Granger-cause Y" if the reject null it implies that variable X Granger-cause Y. In the same way we cant test for $H_0 : \beta_j \ (j = 1, 2...m) = 0$, against $H_A : Not\ H_0$, that "Y does not Granger-cause X" rejection of null in this case would mean that variable Y Granger-cause X.

6.5 Impulse Response Functions

In addition to Granger non-causality test we present the impulse response function graphs that could provide us some insights about the interaction between the variables in the short-run. In general IRF analysis in time series analysis is important in determining the effects of external shocks on the variables of the system. In general IRFs show us how an unexpected change in one variable at the beginning affects another variable through time.

Chapter 7

Empirical Results

7.1 Descriptive Statistics

It is evident from Table 7.1 that Standard Deviation (Std. Dev.) of renewable electricity consumption is highest and that of CO_2 is the lowest. Mean value of all variables is positive. The Jarque-Bera statistics shows that all variables used in the analysis have a log normal distribution. All variables have negative value of skewness indicating that the distribution is skewed to the left, with more observations on the right. Kurtosis show that the $lGDP$ has the distribution with thicker tails and a lower peak compared to a lCO_2 and lRE. In general there seems to be no extreme deviations from normal distribution.

Table 7.1: Descriptive Statistics for time series of concern (1972-2012)

Series	$lGDP$	lCO_2	lRE
Mean	10.1127	2.3860	7.8505
Median	10.1122	2.4054	7.9446
Maximum	10.3972	2.6428	9.0997
Minimum	9.7624	1.9638	6.4521
Std. Dev.	0.2063	0.1316	0.8156
Skewness	-0.2667	-1.0184	-0.3074
Kurtosis	-1.7036	4.4998	2.0854
Jarque-Bera	3.3571	10.9296	2.0744
Probability	0.1866	0.1866	0.3444
Observations	41	41	41

7.2 Unit Root Tests

Ocular inspection of the series in logarithmic form shows that there is an upward trend for GDP and renewable energy consumption series and downward sloping trend for

CO_2 emissions series (see Appendix C). A stationary data series has the property that the mean and variance do not depend on time or do not change over time. However, all the data series under consideration do not seem to fulfill these stationary properties in their level form (by ocular inspection). Whereas, plots of the series in first differences seems to fulfill these properties for all variables and thus such series could be described as a stationary. However, a formal unit root test needs to be employed to determine the order of integration.

Three unit root tests are implemented to determine the order of integration ADF, PP and KPSS. The obtained results presented in Table 7.2 suggest that the null hypothesis of a unit root cannot be rejected in either the ADF or PP test for series in their level form. Similar findings are obtained from the KPSS test, where we reject the null hypothesis of trend stationary series. Completely opposite findings are obtained when the differenced time series are tested. Both the ADF and PP test strongly reject the null hypothesis of a unit root. The KPSS test supports these findings and the null hypothesis of stationary series cannot be rejected. Since all series are non-stationary in their level form, but after taking the first difference we reject null hypothesis of non-stationary at the 5% level of significance.. We therefore can conclude that all our series i.e., $lGDP$, lCO_2 and lRE are integrated of order one I(1).

Table 7.2: Results of a unit root tests

Variable	Specification	ADF Z(t)	PP Z(t)	KPSS
lCO_2	constant and trend	(1) -2.09 (-3.53)	-2.01 (3.53)	0.217 (0.146)
$\triangle lCO_2$	constant no trend	(0) -7.192 (-2.94)	-7.278 (-2.94)	0.198 (0.463)
$lGDP$	constant and trend	(1) -1.051 (-3.53)	-0.763 (3.53)	0.216 (0.146)
$\triangle lGDP$	constant no trend	(0) -5.013 (-2.94)	-5.021 (2.94)	0.269 (0.463)
lRE	constant and trend	(1) -2.628 (-3.53)	-1.845 (3.54)	0.175 (0.146)
$\triangle lRE$	constant no trend	(3) -3.655 (2.95)	-3.436 (2.94)	0.076 (0.463)

Note: ADF test lag order is shown in parentheses, PP test lag order was set to the default of two lags, KPSS test two lags critical values reported in parentheses. All critical values in parentheses are at 5% level of significance.

7.3 Granger Causality (Toda-Yomamoto)

Granger causality test following Toda-Yomamoto approach requires augmenting VAR(k) (where k is the optimal lag length) with d (where d is the order of integration of the series) in our case $d = 1$, because our series (as the previous unit root test showed) is integrated of order I(1). To determine optimal lag length k, it is necessary to carry out an information criterion test (AIC, HQIC, SBIC). Obtained results are presented in Table 7.3, where all tests suggest inclusion of two lags in a VAR model and thus k =2.

Hence the final VAR(k+d) model that needs to be estimated is VAR(3).

Table 7.3: Lag order selection criteria

Lag	AIC	HQIC	SBIC
0	-2.86727	-2.82122	-2.73665
1	-9.72538	-9.54118	-9.20292*
2	-9.94178*	-9.61944*	-9.02747
3	-9.88811	-9.42764	-8.58196
4	-9.77664	-9.17802	-8.07864

Note: * indicates lag order selected by the criterion

To ensure that the VAR model is well specified and does not suffer from any normality or serial autocorrelation problems, additional tests are carried out. Although the results are not reported in the paper, performed tests suggest that there is no problems in a VAR model with either skewness, kurtosis or normality of residuals, as well as no evidence of serial autocorrelation amongst the residuals. VAR(3) model to be tested can be presented as:

$$V_t = \alpha_v + \beta_1 V_{t-1} + \beta_2 V_{t-2} + \beta_3 V_{t-3} + \varepsilon_{vt} \tag{7.1}$$

Where, $V_t = GDP_t, CO_{2t}, RE_t$, α_v is a (3x1) vector of constants, $\beta_1, \beta_2, \beta_3$ are the coefficients to be estimated and ε_{vt} denotes the residuals. The results of multivariate T-Y Granger non-causality test are presented in the Table 3. The table reports the Wald test p-values, thus if we want to reject null hypothesis of "X does not Granger cause Y" at a 5% level of significance then the p value should be less than 0.05. The left column in the table represents the dependent variable and variables listed in the row are the independent variables (source of causation). In order to provide robust conclusions, both multivariate (CO_2, GDP, RE variables in the model) and bivariate (only two variables e.g RE and GDP, CO_2 and RE, etc.) are considered. Results of the Granger causality tests reported in Table 7.4 suggest that the null hypothesis "X does not Granger cause Y" can be rejected for a relationship between RE and CO_2 implying that renewable energy consumption Granger cause CO_2 emissions ($lRE \rightarrow lCO_2$). Intuitively it can be expected that the increasing RE consumption has a negative effect on CO_2 emissions but from the Granger causality test itself this can not be said and further tests are required in order to determine direction of causality.[6]

Similar results were observed in the study by Silva et al. (2011) who also found that renewable energy consumption Granger cause CO_2 emissions ($lRE \rightarrow lCO_2$). The

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[6] Granger Causality test is based on a VAR model with lags of particular variables as shown in equation (6.8) and equation (6.9). This dynamic structure of the model makes the interpretation of coefficients quite difficult because e.g. in the period $t-1$ we might have a negative coefficient while in the period $t-2$ positive, such relationship would tell us little about the sign.

results are however different from other studies (Apergis et al., 2010; Menyah and Wolde-Rufael, 2010; Vaona, 2012) that considered renewable energy in their models. It is also noteworthy to mention that despite the strong evidence of unidirectional causality from RE to CO_2 emissions there is no evidence of Granger causality in any direction between GDP and CO_2 emissions as well as RE consumption and GDP.

Table 7.4: Results of Granger non-causality test (Toda-Yamamoto approach)

Multivariate					Bivariate			
	Independent Variable					Independent Variable		
DV	$lGDP$	$lCO2$	lRE	—	DV	$lGDP$	$lCO2$	lRE
$lGDP$	–	0.7306	0.9247		$lGDP$	–	0.6694	0.8350
$lCO2$	0.2925	–	0.0363**		$lCO2$	0.3034	–	0.0457**
lRE	0.4224	0.3013	–		lRE	0.5593	0.4991	–

Note: Table reports Wald test p-values, DV= Dependent Variable, ***p<0.01, **p<0.05, *p<0.1

7.4 Cointegration

When testing for cointegration, the VAR model with two lags, as suggested by AIC and HQIC is considered. We adopt a Pantula principle in order to determine the appropriate restrictions in the model. We start by estimating three alternative models and move from the most restrictive, which includes restricted constant (model 2) to the least restrictive (model 4), which includes a restricted trend in the model. We compare the trace statistics with the critical values and stop only when the null hypothesis is not rejected for the first time. The results from three estimating models are presented in Table 7.5. It is important to note that in order to account for a small sample bias, the critical values were multiplied scale factor[7]. The obtained values are denoted as "Mod" in Table 7.5.

Table 7.5: Johansen test for cointegration

H_0	H_A	Model 2			Model 3			Model 4		
		Trace	5%	Mod	Trace	5%	Mod	Trace	5%	Mod
None	At most 1	31.9*	34.9	40.8	17.2*	29.7	34.8	23.2*	42.4	49.6
At most 1	At most 2	15.1	19.9	23.2	5.14	15.4	18.0	10.2	25.3	29.6
At most 2	At most 3	3.3	9.42	11.0	1.80	3.8	4.4	2.6	12.3	14.4

Note: Model 2 : Intercept in the cointegration but no intercept and constant in VAR, no linear trend in data. Model 3 : Intercept in VAR and cointegrating relationship but no trends in cointegrating or VAR. Model 4: Intercept in the VAR and cointegrating relationship. Trend in cointegrating and no trend in VAR .

As can be seen from Table 6, the Null Hypothesis of no cointegrating relationship against alternative of at most one cointegrating relationship cannot be rejected in any of the models at a 5% level of significance, suggesting that there is no cointegrating

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[7] $SF = \frac{N}{(N-pk)} = \frac{41}{(41-2*3)} = 1.17$

relationship among variables. Although the 5% critical values were adjusted (lifted up) in order to account for a small sample bias, the null hypothesis of no cointegration could not have been rejected even using none adjusted 5% critical values.

7.5 Granger Causality

Following the methodology presented in Section 6.4, the next step is to perform a Granger causality test using the first differences of the time series. Similarly, as in the Toda-Yomamoto approach, the optimal lag length is determined by the use of information criterion tests. In this case tests suggested inclusions of 1 lag in the VAR model. Tests for the normality of residuals suggested that the residuals do not suffer from any normality problems and there was also no evidence found of serial autocorrelation amongst the residuals. Both multivariate and bivariate models are estimated and the obtained results are reported in the Table 7.6. As it can be seen, the results are slightly different from the previous Granger causality test using the Toda-Yomamoto approach. The main difference is a reversed direction of causality in a multivariate model i.e. CO_2 emissions Granger cause renewable energy consumption ($\triangle lCO_2 \rightarrow \triangle lRE$). Meanwhile the results from the bivariate models support the same conclusions (as in T-Y test) of unidirectional causality coming from RE consumption to CO_2 emissions ($\triangle lRE \rightarrow \triangle lCO_2$). It is important to note that both the Granger non causality hypotheses were rejected at a lower 10% significance level.

Table 7.6: Results of Granger non-causality test

Multivariate					Bivariate			
	Independent Variable					Independent Variable		
DV	$\triangle lGDP$	$\triangle lCO2$	$\triangle lRE$	—	DV	$\triangle lGDP$	$\triangle lCO2$	$\triangle lRE$
$\triangle lGDP$	–	0.4319	0.5763		$\triangle lGDP$	–	0.5365	0.6599
$\triangle lCO2$	0.4018	–	0.1832		$\triangle lCO2$	0.3225	–	0.0774*
$\triangle lRE$	0.2432	0.0706*	–		$\triangle lRE$	0.4683	0.3209	–

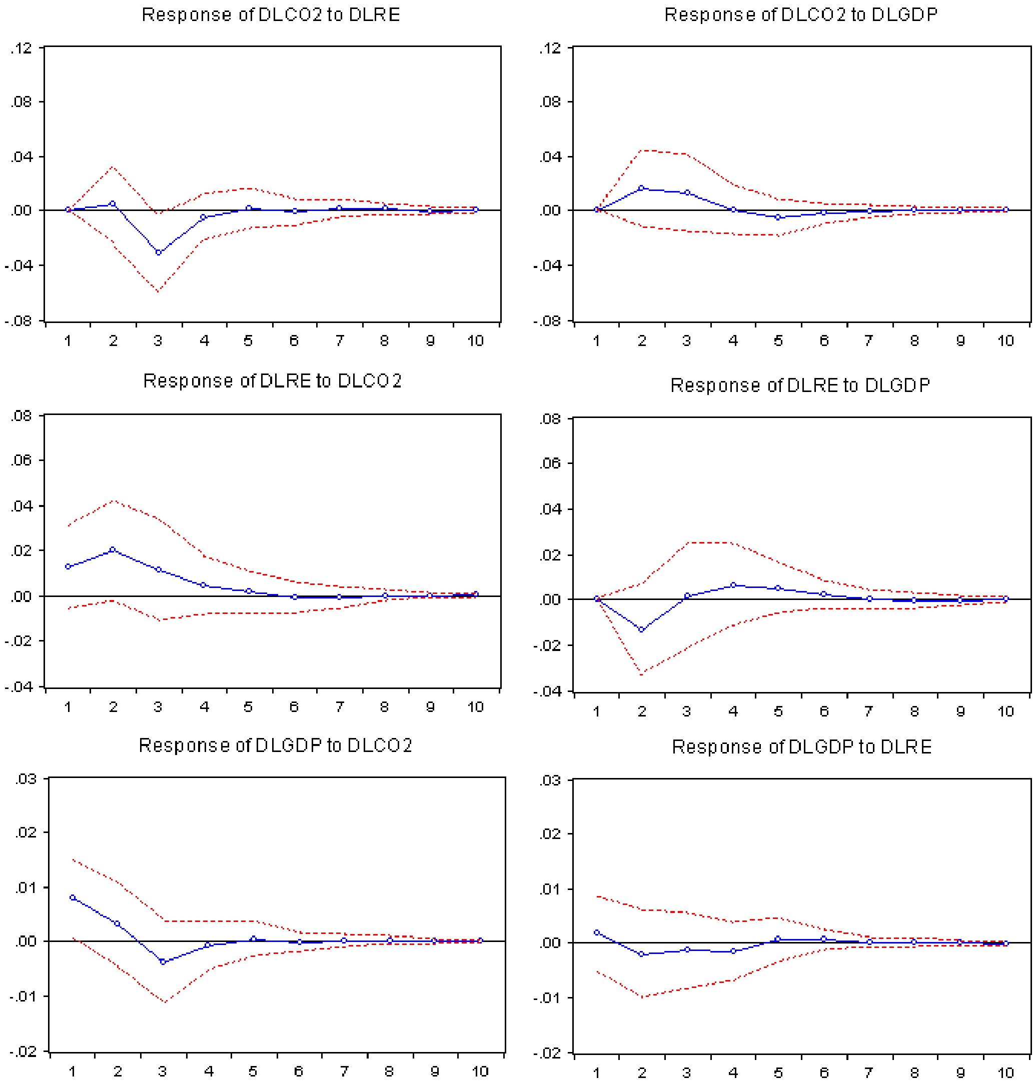
Note: Table reports Wald test p-values, DV= Dependent Variable, ***$p<0.01$, **$p<0.05$, *$p<0.1$

7.6 Impulse Response Functions

Impulse response functions (IRFs) contain valuable information on two important aspects. Firstly, graphs allow us to see how the shock in one of the variables influences the current and future values of another variable and secondly we can also observe the persistency of a shock, which may provide us with some useful insights about the relationship between variables in the short-run.

The first two graphs in Figure 7.1 on page 41 show the response of CO_2 emissions to a shock in RE energy consumption and GDP. Although there is some delay, in general, shock to RE has a large negative impact on CO_2 emissions. Whereas a shock to GDP has a longer and positive impact on CO_2 emissions, implying that if there is a rapid growth in the economy, increased level of production will result in higher CO_2 emissions. The second line of the graph represents the response of RE to the shocks in CO_2 emissions and GDP. The shock to CO_2 seems to have a relatively long and positive impact on RE, implying that the increase in CO_2 emissions drives the use of renewable energy consumption. While the shock to GDP has a negative impact on RE, after a few periods, it develops into very small but positive impact. Finally, the last two graphs indicate how the GDP responds to the shocks in RE and CO_2. It seems that shock to CO_2 has a positive effect on GDP, that later develops into a negative. Whereas a shock to RE seems to have almost no impact on GDP at all, suggesting that the use of more expensive renewable energy does not affect economic activity.

Figure 7.1: Impulse Response Functions



Chapter 8

Discussion and Implications

8.1 Renewable Energy Consumption and CO_2 Emissions

Granger causality test following Toda-Yomamoto approach revealed that there is a strong evidence of causal relationship between RE consumption and CO_2 emissions. Both multivariate and bivariate models indicate the existence of a unidirectional causality coming from RE consumption to CO_2 emissions ($lRE \rightarrow \triangle lCO_2$) at a 5% level of significance. A study by Silva et al. (2011) using slightly different method (SVAR model) and taking into account only the renewable energy sources used for electricity generation reported similar findings of causal relationship coming from renewable energy consumption to CO_2 emissions. However several other studies (Apergis et al., 2010; Menyah and Wolde-Rufael, 2010; Vaona, 2012) considering similar variables failed to find causality coming from renewable energy consumption to CO_2 emissions. The main difference between the countries considered in those studies and Denmark is the share of renewable energy sources in the energy mix. At the time of Apergis et al. (2010) and Menyah and Wolde-Rufael (2010) studies the share of non-hydro renewable energy sources in the US accounted for less than 3% of total energy consumption while in Denmark it accounts for around 20% of total energy supply. As pointed by Chiu and Chang (2009) in order for renewables to make impact on reduction of CO_2 emissions their supply has to account for nearly 10% of total energy supply.

Intuitively it can be expected that the increasing renewable energy consumption causes decline of CO_2 emissions. However, as mentioned in Section 7.3 on page 36, the Granger causality T-Y test itself does not provide information about the sign of causality and further tests are required. IRFs are believed to be a good tool, providing important information about the response of some variables to the shocks in other variables. Observing IRFs presented in section on page 39, it becomes clear that an external shock to RE has a negative impact on CO_2 emissions, implying that the increasing use of renewable energy sources helps to mitigate the carbon dioxide emissions.

Granger causality test using differenced time series provided empirical evidence indicating the opposite causality (but only at a 10% level of significance) coming from CO_2 emissions to RE consumption ($\triangle lCO_2 \rightarrow \triangle lRE$). However, such evidence was only observed in a multivariate framework, whereas evidence of bivariate models supported similar findings as in the T-Y approach (i.e. $\triangle lRE \rightarrow \triangle lCO2$). Such evidence further strengthens the claim that increasing renewable energy consumption has a statistically significant negative impact on CO_2 emissions.

In general empirical evidence indicates that in Denmark during the period from 1972 to 2012, consumption of renewable energy sources helped to mitigate CO_2 emissions. It is of course difficult to predict whether future developments in the RE field followed by an increase in RE consumption would result in a further reduction of CO_2 emissions, because as stated earlier in this paper, introduction of renewables (wind or solar) requires additional back-up capacity of conventional power stations to balance their supply. Nevertheless, other countries adopting similar policies and strategies have consider Danish experience of renewable energy (in particular wind) expansion with caution. It is in particular crucial to acknowledge the importance of neighboring regions (Sweden and Norway) that help to balance the stochastic energy supply (coming from wind) in Denmark (see White, 2004; Inhaber, 2011).

8.2 Renewable Energy Consumption and Economic Growth

Denmark has one of highest share of non-hydro renewables in its energy mix, as well as one of the highest energy prices in the EU. Therefore, it would not be a mistake to say that energy prices and the share of renewables in a country's energy mix have some kind of positive correlation. Looking from an economic point of view, the increased energy prices can have a number of different consequences. From a private household perspective, an increase in energy price implies a modified consumption pattern, most likely with a reduced consumption level arising from the substitution of other goods for energy (Ragwitz et al., 2009) The impacts might be stronger or weaker depending on a households' price sensitivity for consumption goods (elasticity). Furthermore, if the increased cost burden falls on energy intensive industries that are subject to strong international competition, the macroeconomic effects might be even greater, resulting in the loss of international competition. Most often the higher cost required to supply RES is supported from the public budget. This results in the reduction of other government expenditures or alternatively, the rise of tax revenues in other areas, reducing available budget for consumers or producers.

All these macroeconomic effects clearly indicate the existence of a strong relationship between the investments, consumption of RE and economic growth. However, Granger causality tests performed in this study suggest absence of any statistically significant causal relationship between the variables. Such evidence supports the neutrality hypothesis. Which indicates that the energy consumption is a relatively minor component of GDP and thus energy consumption should have no significant impact on economic growth. Nevertheless it is still important to discuss the main benefits and challenges that come from the investments in renewable energy sources.

Renewable energy proponents often claim that despite the higher cost (compared to conventional energy sources) associated with RES, it brings a number of other benefits to an economy and in such a way, compensates for an increase in spending and prices (Lund et al., 2011). One of the most notable benefits is the creation of jobs. Indeed large-scale renewable energy, electricity and biofuels for transport industries involve a large variety of jobs, which differ in skill levels required, and may also differ according to the supply chain of technologies. Some countries have significant employment across a wide range of renewable energy technologies whereas in others like Denmark, the employment is concentrated around a particular technology i.e. wind power (IRENA, 2011). Although no national studies have attempted to investigate the number of “green jobs” created, most of the international literature puts Denmark on top of the list. The study covering EU member states assessed the total employment generated by various “green” activities in Denmark to around 60,000 people in 2005 (Ragwitz et al., 2009). Most of these jobs were created in the production of equipment related to wind energy, where Denmark has had the ‘first mover’ advantage. Furthermore, studies applying a broader definition of “green” activities estimated the total number of employment in Danish eco-industries to be at 338 000 jobs in 2000, equivalent to 12.3% of total employment (GHK et al., 2007).

Others argue that the matter of employment and job creation in the renewable energy industry by the use of subsidies and other investments is often overestimated. According to a controversial study on Spain’s renewable energy sector by Alvarez et al. (2009), 2.2 jobs on average are “destroyed” elsewhere in the economy for each “green” energy job created. This is because average annual subsidy to renewables per worker (55,946€) is more than two times higher (2.2) than the average productivity per worker (25,332€) in other words “green jobs are paid double that of the average job in a wider economy. In Denmark the situation seems to be less dramatic, at least when we look at average subsidies per worker in the wind industry. According to Meyer (2009) the average subsidy per worker employed in the sector equaled 60,000-90,000 DKK ($9,000-$14000). However, Meyer also argues that when it comes to the creation of additional jobs, the evidence is not so convincing. By examining full employment rates, he suggest that the wind sector creates no additional jobs in the long run, but rather moves them away from other sectors of the economy.

The rationale of government support through subsidies, taxation of competing businesses for particular industries or sectors of economy like the wind industry can be highly questioned. Although the policies are likely to help the targeted industry, it is unlikely that such an approach is very feasible, as it is usually done at the expense of other competing industries. The risks and damages associated with such economic support schemes are very high. A perfect example could be one of leading companies in the Danish wind industry and one of the largest turbine makers by sales "Vestas". The company has expanded massively before and after the financial crisis, (especially in the US). However, the possible end of wind subsidies has caused panic in the market, leading to the decline of orders and job cuts (Milne, 2012). The company's share price has declined by nearly 90% from 600 DKK in 2008 May to 70 DKK in 2013 May (Google Finance, 2013). The headcount was confirmed to be reduced by 30% from 23000 jobs in 2011 to 16000 jobs by the end of 2013 (Milne, 2012).

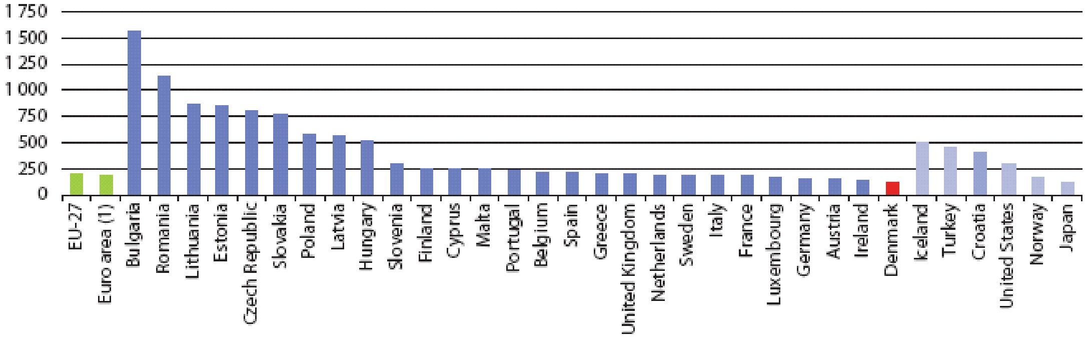
8.3 Economic Growth and CO_2 Emissions

The size and structure of the economy is fundamentally shaped by the environment. This is true for a local and national economies as much as the global economy (GHK et al., 2007). Economic activity in turn changes the environment through the use of resources and the generation of pollution and wastes. As presented in Subsection 2.2.1 on page 10, despite large growth of RES, most Danish energy ($\approx$80%) comes from the use of fossil fuels like coal, oil and natural gas. Given that we could expect to see some type of causal relationship between economic growth and CO_2 emissions, most likely a positive relationship between economic growth and CO_2. This expected positive relationship was to some extent confirmed by the IRFs, which indicated that after shock to GDP there is a positive (but very small) impact on CO_2 emissions. Interestingly, the evidence of the Granger causality tests performed in this study indicate that no statistically significant relationship exist between economic growth and CO_2 emissions and thus we can not reject the hypothesis that GDP does not Granger cause CO_2 emissions.

As presented in Section 4.3 on page 24 the most recent line of research that looks into the relationship between economic growth, energy consumption and pollutant emissions reports similar findings when it comes to economic growth and CO_2 emissions. However, conversely to this study, most studies mentioned in Section 4.4 find evidence of Granger causality between economic growth and CO_2 emissions. Apart from some minor methodological differences compared with other studies (some found cointegration and used VECM), there are also several countrywide characteristics that may have led to contrasting findings.

One particularly important aspect that should be mentioned is the energy intensity which is a measure of how energy efficient an economy is – it indicates how much energy it takes to create one unit of GDP[8]. Denmark has one of the lowest energy intensities not only among European countries but globally (see Figure 8.1) (OECD, 2012). This implies that in Denmark, one unit of GDP can be achieved with a lower input of energy than in many other countries. Often energy intensity is used interchangeably with energy efficiency. However it should be noted that energy intensity is only a poor proxy of energy efficiency, as the latter depends on numerous elements (such as climate, output composition, outsourcing of goods produced by energy intensive industries etc.) that are not considered by the simple energy to GDP ratio. According to Nordic Energy (2013) lack of energy intensive industries is one the main of reasons why Denmark has such low energy intensity.

Figure 8.1: Energy intensity of the economy, data up to 2006 (kgoe per 1000 EUR of GDP)



Source: Eurostat (2009)

According to Enerdata (2012) in the EU energy intensity tends to decline at the times when economic growth accelerates and in particular when it's above 2% a year. This happens because at the times of high economic growth, industrial facilities can be used more intensively. This allows a faster replacement of existing equipment for new, more efficient ones, which then contribute to energy efficiency. This then lowers energy intensity and the corresponding CO_2 emissions that occur from energy consumption. While at times of economic slowdown or in a recession, the intensity in general decreases less or even increases, as was the case in 2008. Such phenomena occur because part of energy consumption is not correlated with the GDP and remains stable regardless of the state of the economy.

In addition to energy intensity, Denmark has also reduced its CO_2 intensity[9]. This

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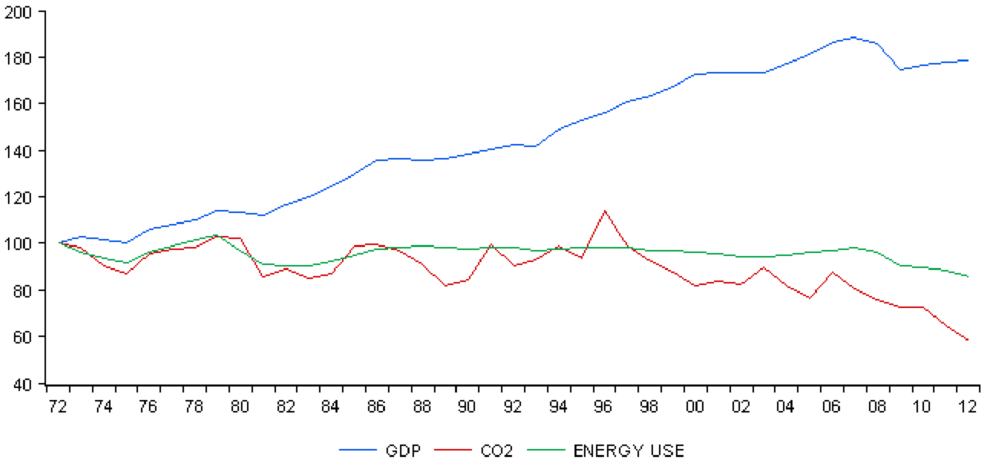
[8] The formula for energy intensity (i) can be denoted as $i = \frac{E_i}{Y}$, where E is total energy input and Y is GDP (taken from Kander et al.).

[9] Standard definition for CO2 intensity can be given as: kg of co2 per kg of oil equivalent energy use.

has been achieved mainly because of changes in energy mix, with the introduction of more low-carbon emitting energy sources (e.g. natural gas instead of coal as shown in Figure 2.4 on page 11). According to Enerdata (2012) in EU countries, on average 40% of the reduction in CO_2 intensity is due to the increased use of energy carriers with lower emission factors whereas, about 60% linked to the reduction in energy intensity.

There is of course no doubt that economic growth is a primary cause of CO_2 emissions. However, given the energy intensity decline which is to a large extent attributable to economic growth, as well as the introduction of more efficient energy carriers allowed Denmark to achieve a gradual decoupling of GDP from energy use and CO_2 emissions. As can be seen in Figure 8.2, economy over the past 40 years has grown by over 80%, while CO_2 and energy emissions did not increase, they even declined.

Figure 8.2: Economic growth, CO2 emissions and energy use, 1972-2012



Source: Danish Energy Agency (DEA). Author's construction.

Chapter 9

Conclusion

9.1 Summary

A number of challenges in relation to energy exist but above all the most important are those of climate change and energy security. These growing concerns have brought the importance of renewable and nuclear energy to the forefront of the wider energy usage debate. It is widely believed that both nuclear and renewable energy are virtually carbon free energy sources that can serve as a potential solution to both energy security and climate change problems. Denmark, although still self sufficient in its energy supply, has made a significant investment in renewable energy sources and is now regarded as one the leaders in the field. However, concerns have been raised about the actual contribution of some renewables towards the reduction of CO_2 emissions, as well as the impact of higher energy prices on economic activity. Given the importance of the topic and proposed further developments in the field, this research has therefore attempted to investigate the causal relationship between the renewable energy consumption, CO_2 emissions and economic growth in Denmark during the period from 1972 to 2012 using modern econometric techniques.

Literature review reveals that there is an extensive interest in studying the relationship between economic growth, energy consumption and environmental pollution. Most of the early researches focused solely on examining the relationship between energy consumption and economic growth on one hand, and between energy consumption and environmental pollution on the other. However, it seems that fashion is changing and there is a growing evidence of empirical research that investigates both relationships in a single multivariate framework. This is not surprising if we consider the growing challenges associated with energy security and climate change.

Firstly, from the analysis of a unit root test we found that all variables are non-stationary in their level form, but stationary after taking first differences. This indicates that the variables are integrated of order I(1), which also implied that one additional lag should be included in the T-Y test. The empirical evidence obtained from the Granger causality test using the T-Y approach within a multivariate model indicates that there is causality running from renewable energy consumption to CO_2 emissions ($lRE \rightarrow lCO_2$). tests for causality in bivariate models support these findings.

The VAR based Johansen test is applied to test for co-integration among variables. Test critical values are modified as suggested by Reinsel and Ahn (1992) with the scale factor (N/(N-pk)) in order to control for small sample bias. Obtained results suggest that there is no evidence of co-integration among the variables, even using the original (lower) none adjusted critical values. Thus, we do no to reject the null hypothesis of no co-integration at a 5% level of significance.

We then test for Granger causality in the VAR model using first differences of the series. Obtained results suggested that there is a unidirectional causality from CO_2 to RE ($\triangle lCO_2 \rightarrow \triangle lRE$) in the multivariate model, however this is only significant at a 10% level of significance. Whereas evidence from bivariate models support the existence of similar causality as in the T-Y test i.e. unidirectional causality coming from renewable consumption to CO_2 emissions ($\triangle lRE \rightarrow \triangle lCO_2$). Finally, in order to get some insights about the interaction between the variables, in the short-run we plotted IRF graphs. These supported the results of the previous granger causality test and indicated that there is significant interaction between the CO_2 and RE.

In general this study provided very strong evidence of a causal relationship between renewable energy consumption and CO_2 emissions. All of the performed Granger causality tests suggested (at a 5% level of significance) the existence of unidirectional causality coming from the renewable energy consumption to CO_2 emissions ($lRE \rightarrow lCO_2$). This finding is in line with those of (Silva et al., 2011) and implies that renewable energy consumption helps to mitigate CO_2 emissions. Nevertheless, other countries learning from Danish experience should not forget to consider the importance of its neighboring regions, who help to balance stochastic supply of electricity from renewable energy sources.

Interestingly the tests showed no evidence that would suggest a causal relationship between economic growth and CO_2 emissions, even though such a relationship was highly expected. This can partly be explained by the fact that Denmark has not only one of the lowest energy intensities in the world, but also has a relatively low CO_2 intensity, which in principal allows Denmark to achieve high economic growth with very low energy input and minimum CO_2 emissions.

There was also no evidence of causality in any direction between renewable energy consumption and economic growth. Such results support the neutrality hypothesis which implies that energy is a relatively minor component of real GDP and thus it should have no significant impact on economic growth. Although, the introduction of more RES into the energy mix requires substantial investments, that raise energy prices, it also brings numerous benefits, one of which is job creation. However, targeting and supporting specific individual industries or sectors (wind in Denmark) is risky and as it was highlighted with the case of the leading Danish wind turbine maker "Vestas", it can also be highly damaging.

9.2 Limitations of the Study and Future Research

Although this research has been carefully prepared and reached its aims, there are however a number of shortcomings that need to be mentioned. Firstly, it is important to consider the limitations associated with the data obtained from the Danish Energy Statistics (DEA), in particular the limitations associated with the renewable energy consumption statistics. The DEA provides statistics on gross energy consumption which are adjusted for foreign trade in electricity so what we have is RE consumption = RE production + imports - exports, e.g. in 2011 RE production was 134 447 (TJ) + imports 42 405(TJ) - Exports 2092 (TJ) = RE consumption of 174 256 (TJ). All electricity exports from Denmark are treated as those coming from conventional power plants, while all electricity from renewable energy is assumed to be consumed domestically and thus no electricity exports from RES appear in renewable energy balance sheet. Although it is impossible to determine what kind of electricity is exported because it simply cannot be traced i.e. we cannot tag electrons as "wind" or "coal" generated, however it is important to understand that such assumption is not entirely correct and potentially overestimates the renewable energy consumption in Denmark.

Other limitations that need to be mentioned are a relatively small number of observations. It is generally admitted that the higher the number, the more robust results of a study will be, and usually it is accepted that the minimum number of observations required for this kind of econometric test is around 40. In this study we had 41 observations, which is only about the required minimum and thus there is room for improvement. Although for this particular study it would be difficult to use a time series over a longer period simply because renewable energy was not seriously considered as a possible source of energy before the 1970s, hence there was no data available before this time. Nevertheless, it is important to note that this study could be potentially improved by using a more frequent data set i.e quarterly or monthly data that would give a much larger number of observations. However, the attempt to obtain a more frequent series showed that even if such were available, for certain variables they are only available over a much shorter time period. For instance, quarterly or monthly data on energy consumption was only available from 2005, while for CO_2 emissions, it was not available at all.

The other shortcoming is associated with the omitted variable bias. Many studies of this type include variables that significantly contribute towards GDP e.g. labor, capital, foreign trade, etc., in order to account for the omitted variable bias. However, it was not done so in this study and hence it could be further improved by including additional variables.

Finally, this study was based on in-depth investigation of a single country (case study). The main problem with such studies is generalization. Which means that it is problematic and can be inaccurate to make broader and more general suggestions for other countries or regions. If something occurred/worked in Denmark does not necessarily mean that it will work elsewhere. Thus anyone learning from the results of this study has to take into account many other aspects related to individual characteristics of the country e.g. geographical location and close proximity to neighboring regions with strongly interconnected electricity systems, low energy intensity, lack of energy intensive industries and etc. The study can be improved by investigating more countries in a panel framework. This would not only improve analysis in terms of number of observations (e.g. 10 countries x 41 observations = 410) that would allow to draw a more concrete conclusions but also it would allow to draw a more generalized conclusions from results about the relationship between renewable energy consumption, CO_2 emissions and economic growth.

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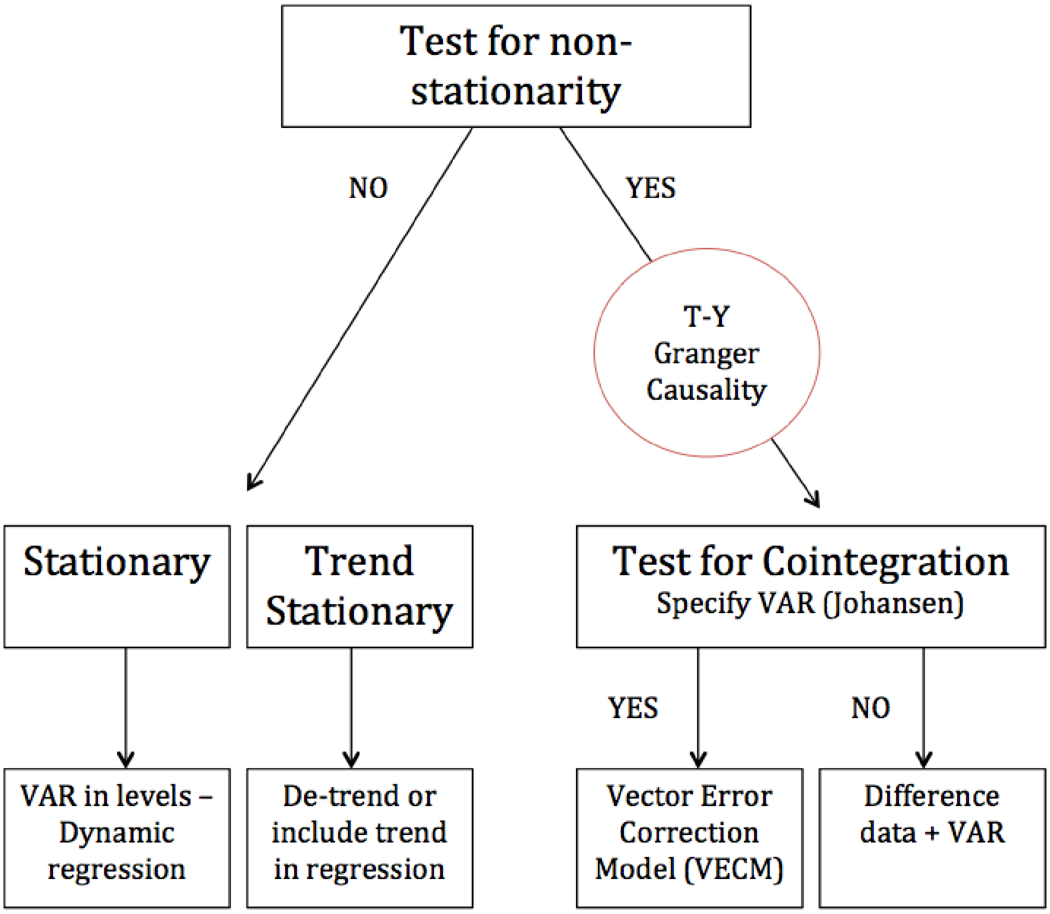
Appendices

Appendix A

Figure A.1: Standard time series analysis procedure



Appendix B

Electricity and natural gas price statistics

Figure B.1: Electricity prices for household consumers, 2012s2 (EUR/kWh)

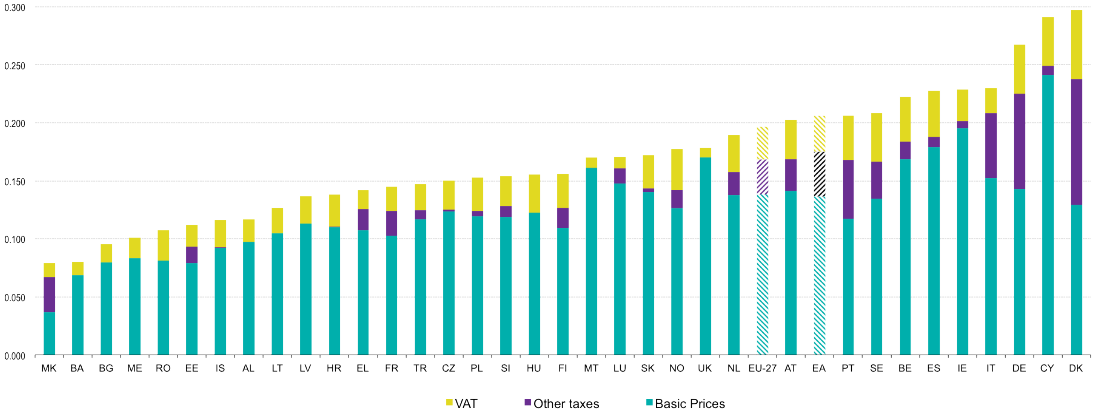
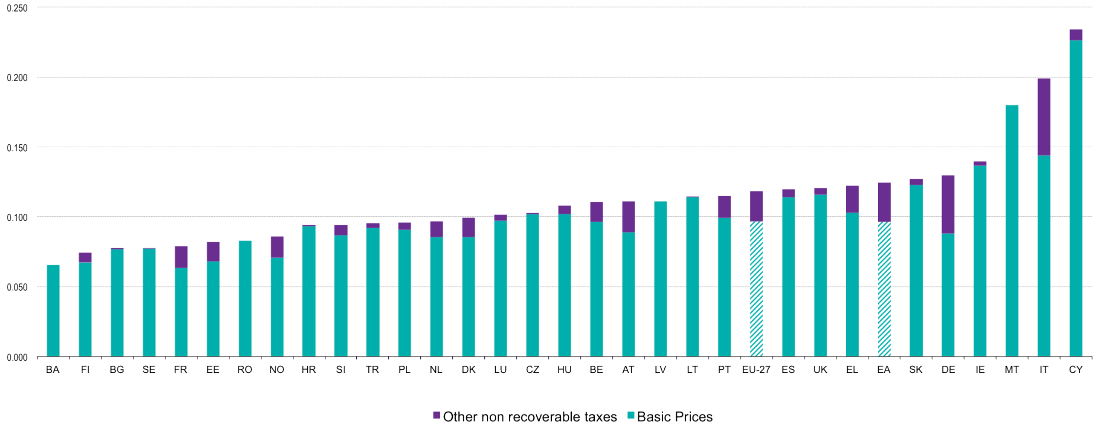


Figure B.2: Electricity prices for industrial consumers, 2012s2 (EUR/kWh)



Source: Eurostat (2013)

Figure B.3: Natural gas prices for household consumers, 2012s2 (EUR/kWh)

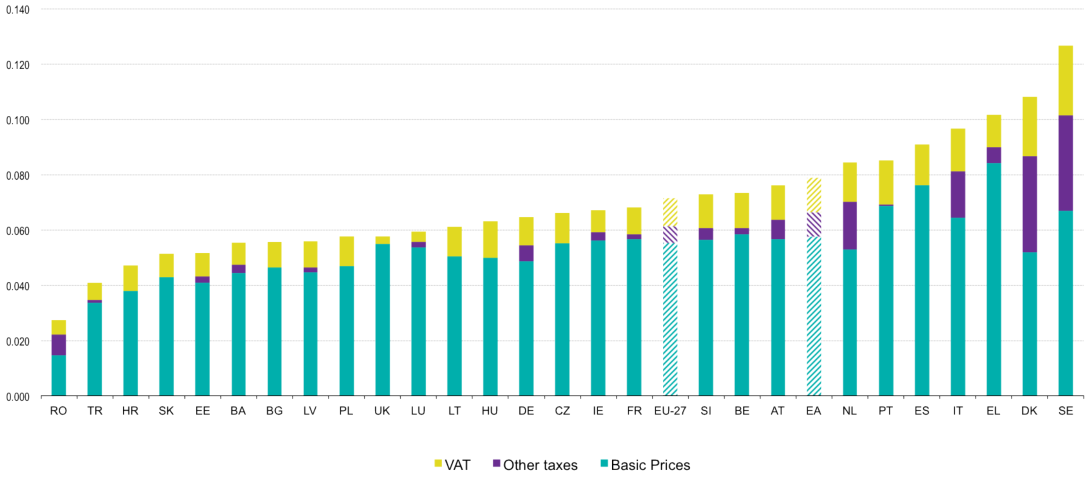
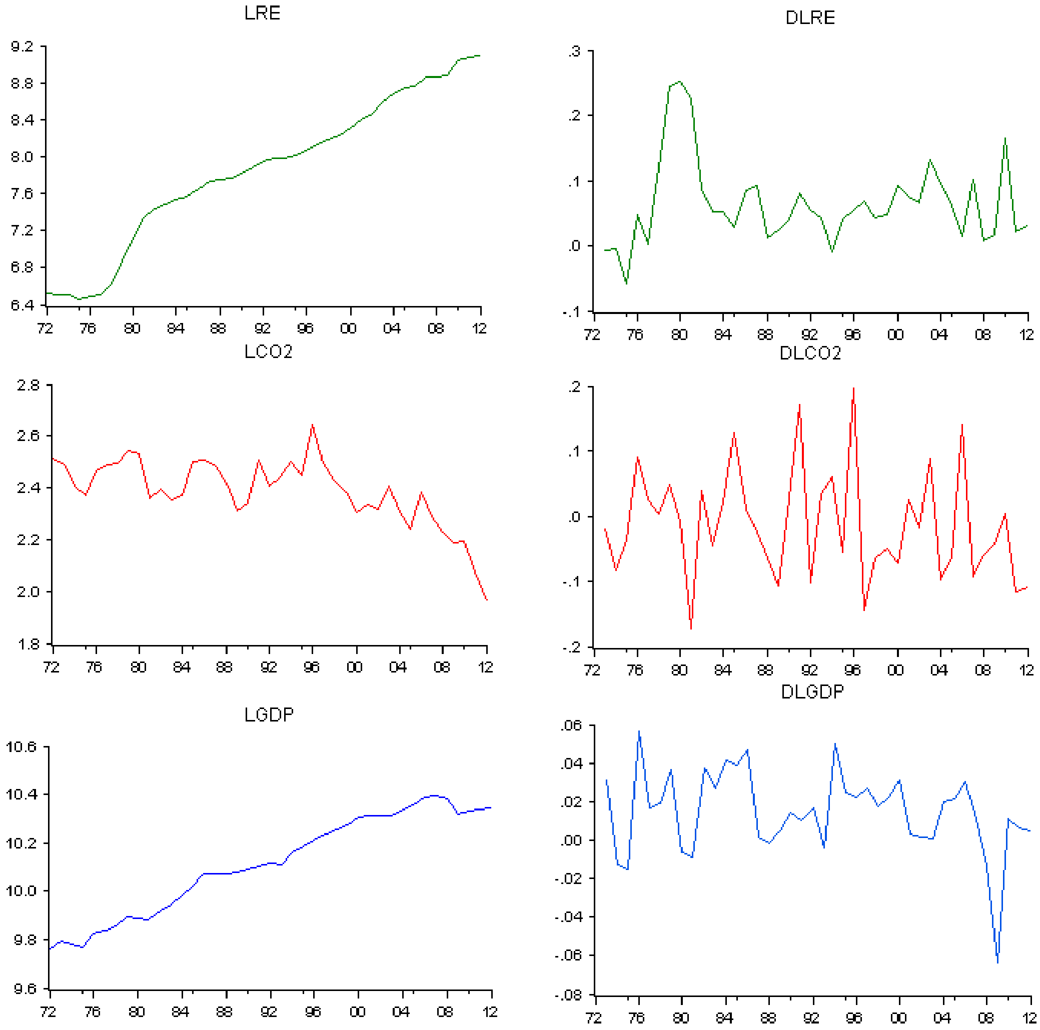


Figure B.4: Natural gas prices for industrial consumers, 2012s2 (EUR/kWh)

Source: Eurostat (2013)

Appendix C

Figure C.1: Time series of interest in log levels and first differences



Appendix D

Glossary and abbreviations

CO_2 Carbon dioxide the most common greenhouse gas, emitted from the burning of fossil fuels (e.g. coal, oil, natural gas)

DEA Danish Energy Agency

EC European Commission

EI Energy intensity. It can be denoted as: energy intensity $(i) = \frac{E_i}{Y}$, where E is total energy input and Y is GDP.

EKC Environmental Kuznets Curve. A hypothesis saying that that environmental degradation as a function of economic level, will take an inverted U-shaped form.

EU European Union

FIT Feed-in tariff. It is a fixed and guaranteed price paid to the eligible producers of electricity from renewable sources, for the power they feed into the grid.

FIP Feed-in premium. It is a guaranteed premium paid in addition to the income producers receive for the electricity from renewable sources that is being sold on the electricity market.

GDP Gross domestic product

GHG Greenhouse gases

GJ Gigajoule. 1 gigajoule = 10^9 joules. 1 GJ = 277.777777778 kWh

GNP Gross National Product

IEA International Energy Agency

IRENA International Renewable Energy Agency

ktoe Thousand tons of oil equivalent. 1 ktoe = 11630000 kWh

kWh kilowatt hour. 1 kWh = 3600000 joule.

OECD Organization for Economic Cooperation and Development

ppm Particles per million. A common way of expressing very dilute concentrations of substances. Just as percent means out of hundred, ppm means out of million.

PSO Public Service Obligation

RE Renewable Energy

RES Renewable energy sources

RES-E Renewable energy sources for electricity

RES-H&C Renewable energy sources for heat and cooling

RES-T Renewable energy sources biofuels

T-Y Toda and Yamamoto Granger causality test

TJ Terajoule. 1 terajoule = 10^{12} joules. 1 TJ = 277777.777778 kWh

TPES Total primary energy supply

VAR Vector auto-regression

VECM Vector error correction model