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Energy Patents, CO_2 Emissions, CO_2 Intensity and Economic Growth:

Denmark and the Netherlands, 1976-2007

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Abstract: Denmark and the Netherlands had different approaches to deal with the repercussions of the oil crisis of 1973: Denmark focused on the development of renewables, and the Netherlands developed their natural gas sector. The varying approaches create the possibility to measure and generalize the dynamics of energy innovations on CO_2 output in small developed countries. This thesis relates the energy patents output of the Danish and the Dutch economy to the absolute and relative CO_2 output, through the use of a vector error correction model. The main finding is that for both countries an increase in energy patents has a negative association on the relative CO_2 output.

Key words: Energy Patents, CO_2 Emissions, CO_2 Intensity, Innovation, economic growth, Energy, Renewable Energy, The Netherlands, Denmark

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Abbreviations

ADF	- Augmented Dickey Fuller test
AIC	- Akaike Information Criterion
CBS	- Central Bureau of Statistics (Netherlands)
CO_2	- Carbon Dioxide
DEA	- Danish Energy Agency
DNK	- Denmark
E-Patents	- Energy Patents
GDP	- Gross Domestic Product
GHG	- Greenhouse Gasses
GPT	- General Purpose Techonology
GW-Yr	- Giga Watt Year
ICT	- Information and Computer Technology
IR	- Industrial Revolution
IRF	- Impulse Response Function
KPSS	- Kwiatkowski Phillips, Schmidt & Shin
kW	- Kilo Watt
kWh	- Kilo Watt Hour
MWe	- Megawatts Electric
NLD	- The Netherlands
OECD	- Organization of Economic Co-operation and Development
OPEC	- Organization of Petroleum Exporting Countries
PP	- Phillips Perron Test
R&D	- Research and Development
SBC	- Schwarz Bayesian Criterion
VAR	- Vector Auto Regression model
VECM	- Vector Error correction model

1 Introduction

This thesis analysis the dynamics between energy consumption, energy efficiency and energy patents in Denmark and The Netherlands (1976-2007). The decision to analyze these two specific countries has a historical and economic motive. The historical motive is that both countries were targeted by the OPEC and therefore had to create policies to overcome the repercussions of the oil boycott. The economic motive is that both countries have had a similar welfare level over time and are therefore comparable. The Danish government has been encouraging the transition towards sustainable energy since the oil crises, where the Dutch government decided to extract their gas reserves as a substitute for oil as a source of energy.

This thesis will shed light on the impact of energy innovation on the CO_2 output and the CO_2 intensity of the two developed countries with opposing energy policies. When there are similarities in the results, a generalization can be supported, with the possibility to gain understanding in the development of efficient energy policies. The research question that is used to support this gap-filling approach is stated as followed:

> *In what extent does innovation in the energy sector influence the CO_2 output, CO_2 intensity, and GDP of a developed country?*

The understanding of dynamics within the energy sector of the economy is increasingly important since our energy consumption behavior has long lasting consequences on the climate. The increasing temperature of the earth is causing unexpected climatological effects all over the world. Influential climatologist like Mann (et al. 2017) presented detailed reports stating that recent weather extremes are a cause of an anthropogenic impact on the climate. The ever increasing output of greenhouse gases (GHG) has reached a level that leads to a globally agreed upon reaction that rapid policy adjustments have to be achieved and maintained to prevent our society from catastrophically climate-related problems. The United Nations Climate Change Conference held in Paris (2015) was the latest and most encompassing act to guide countries towards an equilibrium in which humanity limits its impact on nature.

Climate change can and will have a resonating impact on economics and economic policies in the near future. The increasing knowledge concerning this topic has lead according to Bulkeley and Newell (2014) to a paradoxical twin process where the augmenting insights on the impact of climatological change are opposing policies issues for global governance. Therefore it is eminent to state the most compelling contemporary policy matters that are entangling our economic behavior to our energy consumption.

Our modern energy system has been developed since the first industrial revolution. The infrastructure and the way our economy is structured have been path depending on the general expectations towards the endless growth based on fossil fuels. For developed countries, it will be extremely costly to change their economic structure and infrastructure overnight. Despite the high financial costs, there is an increasing insensitive to invoke rapid shifts in the composition of the secondary sector.[1] The best example is the urge of the Port of Rotterdam to become completely CO_2 neutral and radically change the composition of their industries within the next 20 to 40 years (Rotmans, Duursma, & Postma, 2017).

The intentions of the Port of Rotterdam to completely adapt their port to meet the contemporary demands of sustainable industry and CO_2 output are a positive change and an example for other ports and industrial agglomerates in Europe. Unfortunately not every country or region has the financial or technological means to meet these new standards.

Therefore the second issue is the North-South dimension of the environmental problems and politics. The Greenhouse effect is borderless; this does not imply that the consequences are equally severe in the different regions of the world. Especially the countries around and south of the equator face ongoing and direct consequences of the GHG's. A cruel consequence if we reckon that these countries were historically least responsible for the GHG effects. Historically the West and contemporary China and East-Asia are the main polluters of the earth. This North-South dilemma implies that the increasing temperature of our ecosystem is not only an ecological disaster but also an issue of social injustice and inequality (Bulkeley & Newell, 2014, pp 37-40). Developed countries have the means to implement policies that can reduce their CO_2 output and can, therefore, contribute to solving the social injustice and inequality that is caused by global warming. This thesis is relevant since it provides a small piece in solving the problematic situation regarding the current pattern of our energy consumption.

Including this introduction, this thesis consists out of six parts. After this outline, the historical development of the global energy sector related to the Danish and Dutch energy sector will be described and followed up by the previous research on this subject. The historical background and previous research will be followed up with a theoretical framework. When the context is established the methodology will be explained with the main purpose to elaborate on the theoretical and methodological issues. Before proceeding with the analysis a description and insights on the data will be provided and reflected upon. After the data description, the results will be analyzed and followed up with the sixth part in which a conclusion will be stated and discussed.

[1] The Port of Rotterdam is the biggest port in Europe, with an average of 441.5 million ton of cargo a year. (Ship-Technology, 2017)

2 Historical background & previous research

2.1 Historical background

The differences in Danish and Dutch policies over time regarding the transition towards a sustainable economy vary. Before the 1980's both countries relied on fossil fuels and the encouragement of investments in renewables was not part of either Danish or Dutch policy makers. The oil crisis, however, changed the perception and policies of the Danish and Dutch government.

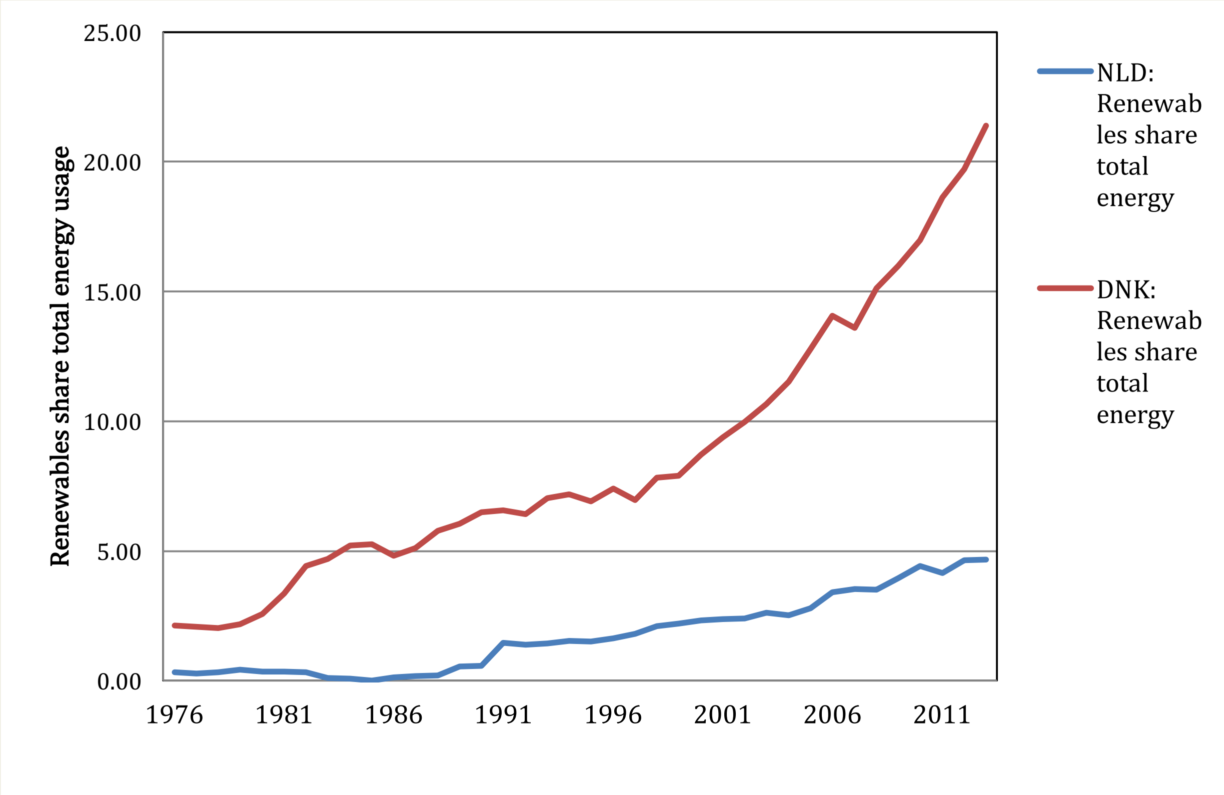
The Danish economy had suffered significant losses due to the oil crisis of 1973 caused by the cartel forming of OPEC. As a consequence of this crisis, the Danish government decided to shift towards a renewable energy system[2]. The Danish energy policy consisted out of a five-step packaging and sequencing action plan to stimulate wind power. The first phase of this scheme was a construction of financial and technical support contributed by the government. This financial and technical assistance was developed as early as in 1978 and lasted until 1989. Besides the financial aid, the government dared to set energy plans to guide the industry towards a dependency on wind energy. The first target was to produce at least 1000 MW wind power in 2000 and reach the level of 5500 MW from wind energy in 2030. The financial aid had the purpose of maturing the wind turbine technology. Furthermore the Danish government added an energy tax in 1981 and a carbon tax in 1992 next ensuring an improved grid connection and a feed-in tariff. To respect and guarantee the quality of the wind turbines the government enforced in 1990 a Danish Wind Turbine Certification. This policy was needed to ensure the safety, energy, and quality-related requirements of the wind turbines. The fifth tool of the Danish government to enforce the use of wind energy was a Green certificate. These green certificates are granted to the producers of renewable energy. These certificates are tradeable and therefore an interesting, encouraging measure to invest in sustainable energy. The active stimulation of the Danish government in renewable energy had led to an increase of renewables used during the observed period (United Nations, 2012).

The announced embargo of the OPEC caused economic and political tension in the Netherlands. The Dutch economy was relying on more than 50% of its total energy needs on oil. The general dependency was not the most urgent problem, but the specific requirements of the chemical industries and the transport sector were enforcing the Dutch government to develop active and encompassing policies to overcome the consequences of the oil crisis. The first short-term solution was the reduction of oil consumption, through rationing and to invoke in the summer of 1973 a Sunday ban on motoring (Hellema, Wiebes & Witte, 2004, pp.97-115). The short-term policies of rationing and Sunday bans of motoring were in the long term replaced by a shift towards the usage of the natural gas instead of oil for heating and electricity. Where the Danish government decided to become the leader in wind energy (Figure 2-1), the Dutch government decided to focus on becoming the expert on gas winning and gas technology in Europe (NAM, 2017).

[2] With the focus on wind

Figure 2-1: **Renewable energy in Denmark and the Netherlands (1976-2012)**

Source: World Bank (2016)



Besides the energy transitions from oil to cheaper/ more secure sources of energy, both the Danish and Dutch government supported international treaties[3] that had as main aim to reduce harmful gasses to the environment. These international policies had to lead to a hold on and a reduction of acid rain and ozone depletion. In paragraph: 2.1.2 till 2.1.5, CO_2 reducing technologies that were developed during the research period will be described and explained how they were implemented in Denmark and the Netherlands, but first, a general context of the technological development that enabled these innovations in the energy sector will be presented.

2.1.1 Transformations in the energy sector

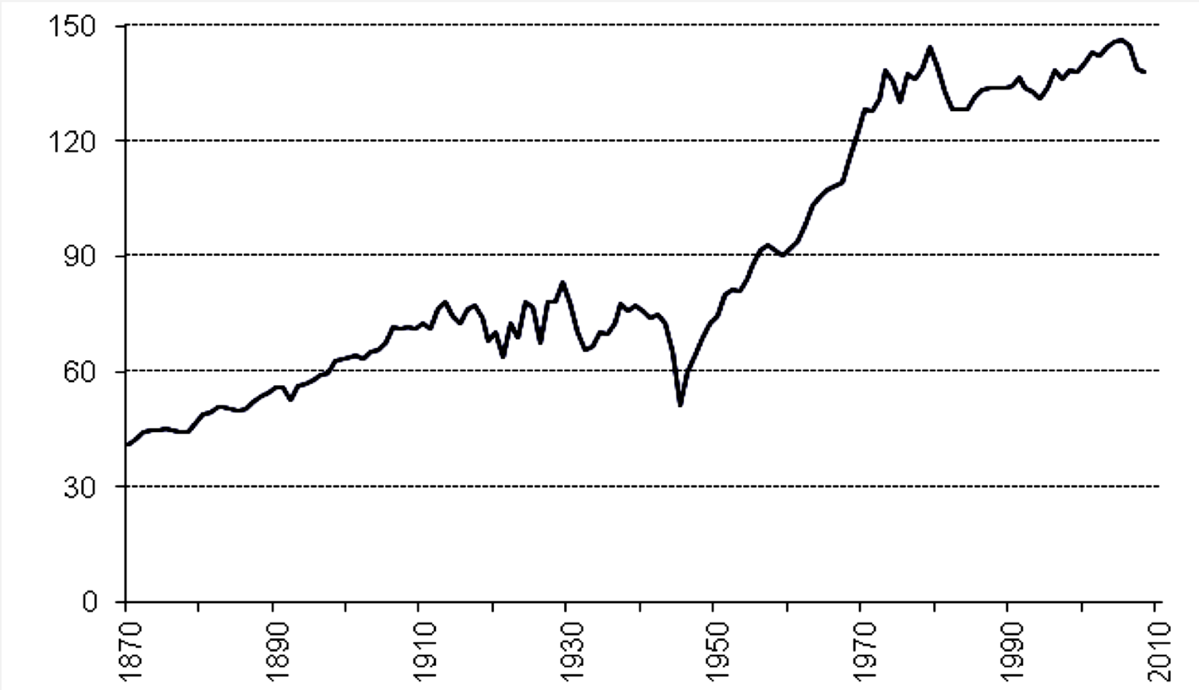
The invention of the microprocessor had such a tremendous impact on the composition of social and economic settings that contemporary economic historians described the process of the introduction and the maturation of this invention as the third industrial revolution (1970 onwards) (Schön, 2009). The development of the microprocessor and the expansion of the ICT development block enabled a growth spell that was less energy intense than the preceding two IR's (Figure 2-2). The development of the transistor enabled the existence of development blocks around information and communication technology. The direct impact on the energy intensity of the GDP was that these new development blocks shifted the dependency of the Western European economies from industry towards a service based economy. This shift eventually led to an energy intensity drop of 1.6% average a year in Western Europe (Kander et al. 2014, p.256).

[3] Rio de Janeiro (1990), Kyoto (2001) & Paris (2015)

Besides the effects on the labor market, the technology of the third IR enriched the energy sector with new conversion possibilities (Kander et al. 2014, p.259).

Figure 2-2: **Energy per capita in Western Europe, 1870-2008, in Giga Joules**

Source: Power to the People (pp. 254, 2014) (original: www.ergyhistory.org)



A new conversion possibility is a macro-innovation that fundamentally changes the way energy can be obtained out of an energy source. Examples of these macro-innovations are the steam engine for the first IR and the internal combustion engine for the second IR. In the twentieth century during the third IR, this macro innovation was the possibility to generate electricity from 'an increased variety of both energy carriers and energy converters' (Kander et al. 2014, p.259). Before the 1970's these innovations were focused on the optimization of the use of oil. The role of oil stabilized and remained prominent in the automotive and transport sector, the energy density of this fuel made it the optimal solution to travel cheap long distances. Where the use of oil was (until very recently) not contest in the transport branch, the situation for the role of oil in the electricity sector differed; after the Oil price increases in the 1970's the emphasis in Europe gradually shifted towards natural gas[4], nuclear energy[5] and renewable energy[6]. The shift towards other sources of power instead of oil within the electricity sector was a consequence of the modular character of the electricity. This modularity means that *'the system can be analyzed as separate modules and that each module can be replaced by a set of alternatives'* (Kander et al. 2014, p.266).

Electricity is modular on both the consumption and generating side. On the consumption side, the modularity of electricity lies in the fact that it is used for heating, major appliances (refrigeration, cooking, washing & drying and miscellaneous) and ICT (Computers, Smart-TV's

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[4] The Netherlands and Britain.
[5] France and Sweden
[6] Denmark

and portable devices). On the production side is electricity modular in the sense that it is generated by oil, gas, coal, nuclear energy and renewable energy (biomass, solar, hydro and wind).

2.1.2 Nuclear Power

Since the 1940's onwards the development of Uranium and Thorium as a power source has been actively researched. The Netherlands decided to invest in fission technology and construct a nuclear power plant site in Borssele (Zeeland). The fission reactor generates 4% of the Dutch consumption of electricity good for 452 MWe a year (Murray, 2009, pp.406-407). The Danish conception towards nuclear energy was consistent in a sense that since the 1980's the construction of nuclear reactors is forbidden in Denmark, and therefore nuclear energy is not contributing to the energy supply of Denmark (Table 2-1).

Table 2-1: **Nuclear energy in Europe**

Source: Without the hot air p.161

Country	kWh per day per person generated through nuclear fission (2007)
Sweden	19.6
France	19.0
Belgium	12.2
Finland	11.8
Netherlands	0.7
Denmark	0

2.1.3 Renewables: Wind

As a result of the struggle of European countries to battle CO_2 output, the development of renewable sources of energy has been widely researched and developed over the last fifty years. Renewable energy can be generated through: the burning of biomass, wind (offshore and onshore), solar, hydro, tidal & wave powered techniques. Since the Netherlands and Denmark are in a contemporary and historical sense not active in the hydro & wave and only 0.4%[7] of the renewables is generated through tidal energy (Stenkjaer, 2009), this thesis will emphasize on explaining the development of biomass, solar and wind energy.

Especially wind energy is an important source for both Denmark and the Netherlands. In the Netherlands the windmill enabled entrepreneurs to expand the amount of land available in an earlier unthinkable extend. Not only in the premodern era wind power played a significant role in a contemporary setting wind power started to become in the Netherlands, a financial and

[7]In the NLD (CBS, 2012), was still in test fase of tidal & wave energy during the observed time period DNK

ecological interesting alternative for fossil fuel, in Denmark it has already reached these proportions.

The consistency of the offshore turbines makes it possible to overcome over production problems through cross-border solutions; a good example is an initiative from Denmark and the Netherlands to connect their wind-energy grid (Climate Research Netherlands, 2017). This connected energy grid called COBRA will transfer all the energy that has been produced in Denmark but is not able to enter the Danish market due to over capacity on the grid to the Netherlands. Due to this construction 7000 households in the Netherlands will be enlightened through Danish turbines.

In the Netherlands the annual kWh wind power increased a total of 1978 kWh in the period between 1990 (56 million kWh) and 2005 (2034 million kWh), this helped the Dutch economy to evade 1198 kiloton of CO_2 in 2005 (CBS, 2012). Denmark started early with the building of wind turbines in 1979 the first Vestas turbine was constructed delivering only 30 kW a turbine. By the end of 2015, the Danish total wind energy output was 42836.4 million kWh (Ministry of Foreign Affairs of Denmark, 2017).

2.1.4 Renewables: Solar

Not only the use of wind turbines expanded during the last fifty years but also the efficiency and the utility of solar panels and solar heated boilers increased in this period. Solar energy is infinite and sustainable. In 2012 the Dutch government published a report in which the effects of renewable energy sources were discussed. In this report, they presented data that demonstrates that the use of Solar energy over time increased with 780,56 % (1990 compared with 2005) with the effect that 85-kiloton of CO_2 emissions were already evaded in the Netherlands only (CBS, 2012). The CBS (2012) state that the average solar panel sold and installed in the Netherlands is CO_2 neutral three years after installation.

Solar energy is still a sustainable option that is in development. In the contemporary composition of the Dutch generation of energy, it only accounts for 2% of the total renewable electricity gains. The use and application of solar energy in new build residential areas are strongly encouraged by the Dutch government. The Danish solar energy sector did not develop until 2012. There were attempts to start earlier with the construction of solar parks nevertheless the cumulative output never reached a significant level during the period observed (EurObserver, 2013). During the time span of this thesis the technology behind solar energy was developed into the promising opportunity, it is today (CBS, 2012).

2.1.5 Renewables: Biomass

Biomass can be used in many different forms and can be used both as a source of electricity and as fuel. Biomass has been the major energy source until the introduction of fossil fuels during the first and second IR. The interest in Biomass faded when there was an abundant supply of cheap and efficient energy in the form of coal, oil, and gas. Just as for the other carriers of sustainable energy the interest of policymakers in biomass revived as a result of the oil crisis and the search for CO_2 neutral forms of energy (Ptasinski, 2016, p.14).

Biomass contributes to the decoupling of our economic growth to CO_2, and the general output of emissions, the photosynthesis of the crops captures the amount of CO_2 created during the combustion of the biomass. The use of Biomass could be a closed system if the fuels to transport the materials needed for the crops were CO_2 neutral. Unfortunately was the transport and irrigation of the crops during the observed period still done on fossil fuel. Nevertheless, is the most bioenergy generated a result from the burning of already existing waste. Therefore is the additional energy created and CO_2 evaded a net win for the environment (Ptasinski, 2016, pp.14-19).

In the Netherlands, the burning of biomass is the largest source of CO_2 neutral energy. In 2012 biomass had a share of 73%[8] of the total generated renewable energy. In the observed period of this thesis, the total generating capacity increased to 7306 million kWh a year in 2005 (CBS, 2012). In the Netherlands, biomass was used to create domestic heating, fuel, and gas (CBS, 2012).

Denmark has been aware of the merits of the burning of biomass and since the 1980's the Danish energy sector has been investing in the optimization of combustion of residuals of the timber industry. Danish Universities have been providing new insights and methods to maintain Denmarks's world leading position in 'biotechnology, supply process technology, advisory and enzymes' (Danish Energy Agency, 2015 p.14). The aim of the DEA is to produce 'advanced biomaterials which can replace oil and chemicals in products such as plastic bottles and textiles' (DEA, 2015, p.14). The DEA managed in 2015 to generate 52% of all the district heating through biomass (DEA, 2015, p.4). The Danish biomass policies reduced the estimated Danish CO_2 output with 10.5 million tons over the period 1990-2020.

2.2 Previous research

The economics of energy and innovation have been the field of a wide range of previous research published since the 1980's onwards. Considering the economics of energy and sustainability the early work of Krafts & Krafts (1978) Yu & Whang (1984), Freeman (1996) and Stern (1993, 2000) provide useful insights when linking energy consumption to economic growth. In this paragraph first the previous research considering energy transitions and energy efficiency will be reflected on, and secondly, the earlier research conducted with similar methods will be evaluated and related to the aim and scope of this thesis.

Freeman (1996) noticed the problems related to the energy efficiency of economic growth and economic systems as such. Freeman (1996) argues that if a techno-economical system transition will be completed and a new model of innovation is developed in which both the linear and systemic innovation model are combined institutional tension can be overcome and sustainable economic growth will become a serious possibility. Freeman sees as the main problems for eventual transitions of the innovation system the diminishing returns of energy and material saving. The third industrial revolution initiated the introduction of computers into the general

[8] Nuclear Energy is not considered as sustainable energy by the Dutch bureau of statistics.

production process what lead to future big cuts in the energy costs of due to increased calculation capacity and therefore less energy was wasted. When Freeman wrote his essay, the initial big cuts in energy saving measurements had already been implemented. New energy-saving investments that would be initiated then (or now) are way more expensive in the sense that the returns in a financial perspective are diminishing. Freeman (1996) concludes that the transition towards a

> '*renewable energy system is not possible without some major institutional changes in public transport systems, tax systems, and automobile and airplane culture. Despite the important advances in wind power and solar power, it will not be possible either without some far greater R&D commitment in the public and private sector as well as procurrent policies. The long time lags involved in energy systems R&D and investment mean that these changes need to begin soon. (*Freeman, 1996, p.38).*'*

Previous research considering the environmental impact of structural change heavily relies on the theory considering the environmental Kuznets curve first labeled as such by Panayotou (1993). Panayotou (1993) argued that during the process of structural change the dependency of an economy on energy intensive industries decreases and therefore an economy can develop sustainable economic growth when shifting towards a service based society.

The environmental Kuznets curve dominated the energy efficiency paradigm, till Kander (2002, 2005) and Kander & Henriquez (2010) successfully argued that Panayotou (1993) had an overly optimistic view of the impact of deindustrialization on the energy efficiency of an economy. With their empirical research on a group of developed countries[9] and a group of developing countries[10], Kander and Henriquez (2010) show that the main cause of the increasing energy efficiency was a technological shift within the industrial sector. The service sector was of limited or non-importance to the gains in energy efficiency (1860 till 2000). Kander and Henriquez (2010) conclude that the shift towards a service industry has had only modest effects on the energy efficiency of an economy. The conclusions of Kander and Henriquez (2010) assume that increasing energy efficiency within a countries innovation system could contribute towards increasing energy efficiency within a country as such. They indicate that the general deindustrialization does not have the desired effect on energy intensity when measured in constant prices.

Kander (2005) based her argument that the service sector was not the main driver of energy efficiency of the last 170 years on the economic phenomenon called the Baumol disease. Baumol (1967) divides the economy into two sectors: the manufacturing sector and the service sector. He labeled the manufacturing sector as the technologically progressive sector and the service sector as the stagnant sector. Within the manufacturing sector, the value of the employee can be measured trough counting the physical output per hour. To increase this value, the addition of timesaving machines leads to rationalization. In the service sector, this increase of value is impossible. Since the hours worked are the final product itself. Within the manufacturing sector, the rationalization of labor leads to an increase in salaries. Due to the increase in wages in the manufacturing sector, the service sector will sooner or later demand a similar increase in wages to keep the same purchasing power. However, the productivity of the service sector has not

[9] (France, Germany, Italy, Japan, Netherlands, Portugal, Sweden, United Kingdom (UK) & United States of America (USA))
[10] (Brazil, India & Mexico)

increased on the same level as the manufacturing sector. Eventually, this resulted in relatively higher prices for services. Over time this inflation of service prices about manufacturing prices evolved constantly in the Western economies. This effect of service inflation is called the Baumol disease. The Baumol disease faces the misconception that the service sector has been increasing on a large scale in productivity as its share of the GDP. Kander illustrates these effects on the economy of Sweden and demonstrates therefore that the deindustrialization process will not be the engine behind energy efficiency (Kander, 2005).

This thesis is not the first research that investigates the association between energy/energy patents with the CO_2 output of an economy. The work of Whang, Yang & Zhang (2012), used as mentioned earlier similar methods to unveil the relationships between the variables in China. Whang, Yang & Zhang (2012) came to the conclusion that there are '*dynamic relations between energy technology patents, CO_2 emissions and CO_2 emissions intensity in China during 1985-2009'* (Whang, Yang & Zhang, pp8, 2012). They establish a significant positive long-run association between patents and CO_2 emissions, as well as a significant negative long-run association between energy patents and CO_2 intensity. Furthermore, they established a positive association between the CO_2 emissions and GDP growth. The last discovery is not surprising bearing in mind the transitional stage of the Chinese economy. The second conclusion provides the insight that a similar association might be existing in other countries/regions.

From a slightly different perspective Albino, Ardito, Dangelico & Petruzzelli (2014) use patents within the renewable sector to explain trends in the decarbonization of the economy in a global perspective. Albino, Ardito, Dangelico & Petruzzelli (2014) conclusions lead to the understanding that there lies an essential role at the stimulation of the commercial sector to shift towards low-carbon solutions. They encourage a stronger climate policy through economic motivations towards the commercial sector so that they can innovate and contribute to sustainability in that matter too. They state that:

> *'By taking into account what occurred for the development of some low-carbon energy technologies, such as nuclear plants and solar cells, the eventual push to full commercialization through the use of effective demand pull policies may significantly foster their spread and boost innovation. Accordingly, they allow the creation of new markets by protecting emerging technologies from the competition with established designs, hence again highlighting how commercial opportunities can enhance innovative efforts.'* (Albino, Ardito, Dangelico & Petruzzelli, 2014, p.849).

For the OECD Johnstone, Hašcic & Popp (2009) examined the effect of environmental policies on technological innovation with the focus on renewable energy. This approach is a mirrored version of the method used in this thesis. Therefore are the results of this research interesting concerning the research presented in this thesis. Johnstone, Hašcic & Popp (2009) found when using patents as a measurement of innovation that public policies play a role in the formation on patents. They concluded that 'More targeted subsidies, such as feed-in tariffs, are needed to induce innovation on more costly energy technologies such as solar power.' (Johnstone, Hašcic & Popp, 2009, p.149). For their research Johnstone, Hašcic & Popp (2009) use data considering all the OECD countries. Their econometric model consists out of cross-country analysis.

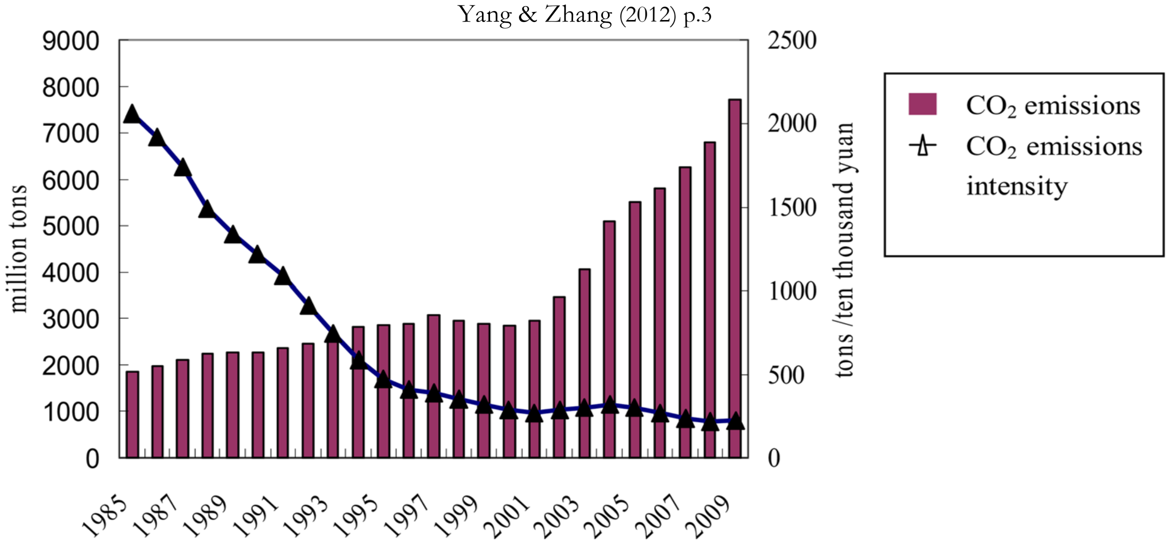
In a methodological perspective is it important to mention the previous research done with time series analysis by Stern (1993, 2000). Stern (2000) provided by using similar methods used as in this thesis a cointegration between the variables capital, labor, GDP, and energy output. Stern (2000) researched the situation of the United States from 1945 till 1995 during this period the CO_2 output of the United States. During the observed period by Stern (2000) there was an absolute increase in CO_2 emissions in the United States. In the scope of this thesis, the data of the Netherlands show an absolute increase in CO_2 emissions, where the Danish CO_2 output in absolute terms decreases with 42.81%.

2.2.1 Relative vs absolute decoupling

The measurement of energy and the use of energy data within economic research can be done through different perspectives and by bearing different theoretical considerations in mind. In this paragraph first, the ideas behind relative and absolute decoupling will be explained in a theoretical viewpoint. Secondly, the Kaya decomposition will be explained.

Decoupling of the emissions of an economy can be analyzed as a relative of absolute decoupling. There is a relative decoupling of CO_2 emission within a country when the units of CO_2 per unit of GDP is decreasing, but the general level of GHG emission within a country is still increasing. A good example of a country that managed to have a relative decoupling of the CO_2 emissions of GDP is China (Figure 2-3). A relative decoupling of CO_2 emissions and GDP is especially for developing countries a good step in the direction of becoming less and less polluting over time. Nevertheless will a global trend in relative decoupling not relieve the pressure on our ecosystem. Therefore is it necessary to not only measure the relative decoupling of CO_2 emissions and GDP but also the absolute decoupling of CO_2 emissions and GDP. Researching the absolute decoupling can provide insights in the long-term sustainability of an economy (Gupta, 2015). A good example of a country that manages to decouple on an absolute level is Denmark (Figure 2-4).

Figure 2-3: **CO_2 emissions and the CO_2 emissions intensity in China (1985 – 2009)**
Source: Relationships between energy technology patents and CO_2 emissions in China: An emprical study Wang, Yang & Zhang (2012) p.3

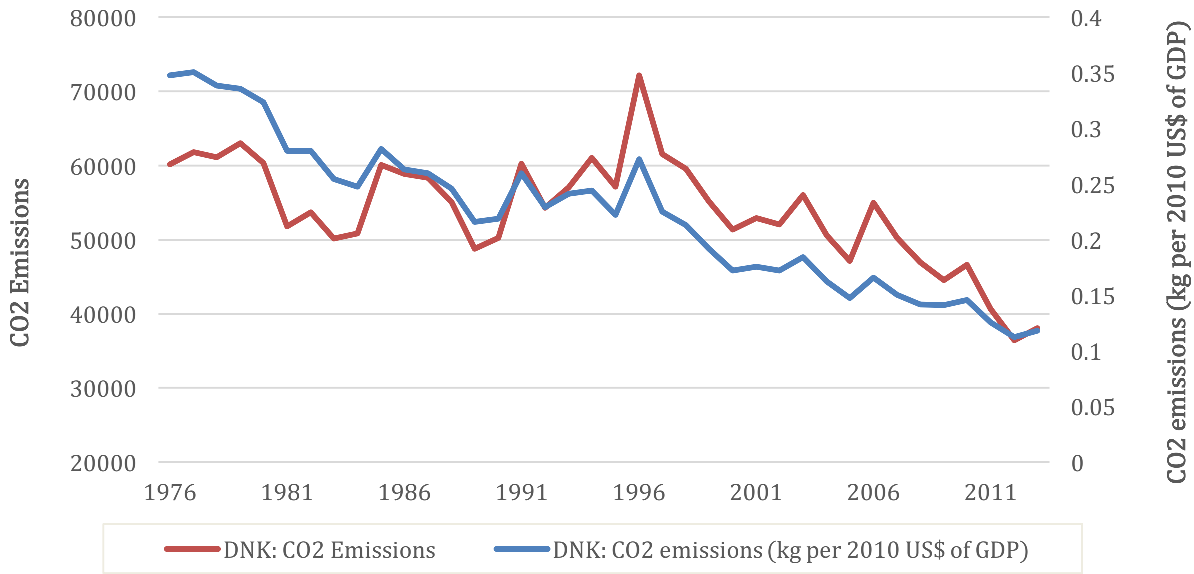


Bernstein (et al. 2006) argues that decoupling cannot only be achieved by energy saving innovations but that innovations, in general, are contributing to the development of the energy efficiency and general efficiency of a country (Bernstein et al. 2006). He also argues that there is a peak in the possibilities of a country to decouple their growth and energy in an absolute and a relative sense. The motivation of Bernstein's (2006) theory is best summarized in the following quote:

> *'With lower intensities, carbon emissions from new technologies grow more slowly. In the exponentially improving technology case, emissions from new technology eventually fall, despite the growth in the stock of new capital. Improvements in technology keep emissions below base case levels, but only the exponentially improving technology keeps emissions from growing...'* (Bernstein et al. 2006, p.755).

***Figure 2-4*: Decoupling in Denmark.**

Source: World Bank (2016) data



2.2.2 Decomposition methods

Besides the different ways to analyze the decoupling of energy consumption and growth is it also possible to decompose the energy intensity/consumption as such in different ways. Theoretically, it is important to decide whether to decompose the energy consumption of the analyzed countries or to maintain the macro statistics as presented for the researched economy. Decomposition can be used to measures the effects of structural and technological change within sectors. It can help to unveil historical trends with the aim to predict future energy demand and emissions.

The decomposition technique can be applied to the different sectors defined by classic economic theory: agriculture, industry and the service sector. Technological change is in this sense not measured as patents or R&D but as *'the change that increases the output of a sector by using the same amount of energy or that delivers the same output using less energy (efficiency, substitution, innovation)'* (Henriquez, 2017, p.4). Energy decomposition can be done in different ways it can be done through an approach based on the price indexes from Laspeyres, or it can be done by using a division index. Energy decomposition can be useful to gain new perspectives for policymakers. For example, results that indicate a strong energy dependency of the service sector can motivate policymakers to develop policies that can cut energy consumption in this specific sector (Ang, 2004).

Due to the importance of the decomposition techniques in the field of energy economics this technique had to be briefly explained, however, in relation to the scope of this thesis a decomposition of the consumption of Denmark and the Netherlands will not provide the most interesting insights on the data. The technological change measurement that is generated through decomposition techniques cannot help to provide insights on how innovation in the energy sector as such have an impact on the emissions on the economy in a macro perspective.

2.2.3 Technological waves and economic growth

Since this thesis relates an increase in technological activity (energy patents) with economic growth (GDP), the theory considering technological waves is added to the contextualization.

The essence of the theory of Schön (2009) lies the idea that economic growth spells are divided into two periods: a period of transformation and a period of rationalization. Between the end of a period of rationalization and the beginning of a new period of transformation, there is a structural crisis. The structural crisis is characterized as a stage of disequilibrium that can eventually lead to a new wave of innovation in a period of transformation. After the wave of innovation during the period of transformation the new technology will spread to the peripheral parts of the economy and the new technology will rationalize (Schön, 2009). A technological wave covers approximately a period of fifty years.

During the transformation period, a General Purpose Technology (GPT) will become a driver that has the strength to form development blocks within the economy. The theory of development blocks was developed by Erik Dahmén (1988) and provide the insights to understand how the diffusion of GPT's can reform the economy when it has been complemented with development blocks. During the period of transformation *'resources are reallocated between industries, and diffusion of basic innovations within industry that provides new bases for such reallocation'* (Schön, 2009, p.4). During the period of transformation, investments are directed to increase new production opportunities. These investments are costly and therefore done by bearing in mind a long-term strategy. Since these investments are made to conquer new markets is this way of investing resources based (Schön, 2009).

During the period of rationalization that there will be a *'concentration of resources to the most productive units within the branches and measures to increase efficiency in the different lines of production.'* (Schön, 2009, p4). In a period of rationalization, the economic growth is in general higher than during the period of transformation, and this leads to a different pattern of investments. In contrast to the investments in the transformation are the investments in the period of rationalization *'directed to reduce costs in the existing capacity'* (Schön, 2009, p.4). Investments during the period of rationalization are based on a short-term cost-cutting mindset and have a more direct impact on the productivity, growth and income statistics.

3 Theoretical framework & Methodology

3.1 Theoretical framework

As mentioned in the introduction is the main purpose of this thesis to unveil how innovations in the energy sector are affecting the absolute and relative energy usage of a developed country. The observed countries are Denmark and The Netherlands since they are both developed and had both radical shifts in their energy policies as a direct consequence of the oil crises of the 1970's. In the previous chapter's different views on previous research and a historical and technological context has been presented that function as the fundament of the theoretical framework that will be introduced in this paragraph.

The theory that will be reflected upon has as the main statement that: the development of innovation in the energy sector has been contributing to the decoupling between energy and GDP in the observed countries. Country specific innovations in the energy sector deliver the observed country, improvements in sustainability and efficiency applied to their social, economic and geographical settings.

Relating the energy patent data with energy consumption has already led to insights into the dynamics within the Chinese economy (Wang, Yang & Zhang, 2012) and it is not unlikely that in theory, an increase in energy patent could have a decreasing effect on the energy consumption per unit of GDP in developed countries as well. Since the dynamics of the economy of Denmark and the Netherlands diver from the dynamics in China is it necessary to apply this framework to two developed countries. When the results of the analysis concur with the results of the Chinese case, a general theory can be drawn up that: investments on innovations in the energy sector could lead to a decoupling of CO_2 and GDP. When this theory is supported by a variety of case studies the implication can ease policy makers in making investments in the R&D departments of the energy sector.

Out of theory the following hypotheses were developed:

1. Energy patents have a positive association with GDP.
2. Energy patents have no association with the absolute amount of emissions.
3. Energy patents have a negative association with the relative amount of emission output.
4. GDP has a positive association with energy patents.
5. GDP has a negative association with the relative amount of emission output.

3.2 Patents as a measurement tool

Patents are commonly used as a measurement tool in the field of the economics of innovation (Nagaoka et al. 2010). Even though patents are a prevailing measurement tool of innovation, it is important to name and recognize the specifications of this technique as well as the limitations of patents as an indicator of innovation. The first consideration when performing research with patents is the matter that patents are an output measurement, besides that, patents provide valuable insights on the aggregate of knowledge within an economy. Since the patent variable is an output indicator, there might be a possible high-tech and large firm bias against the use of patents.

This thesis will not focus on the R&D expenses instead it will link the output of patents with energy. Linking patents with CO_2 output will be done with the aim to provide insights on how energy efficiency can be achieved through expansion of the output of the innovation sector (Taalbi, 2014, p.51).

A returning critique (Van der Panne, 2007 & Borrás, 2016) on the use of patents as a measurement tool is the issue that countries have a different legal framework over time and that this legal framework differs between countries as well. This valid critique was taken into consideration when choosing for the dataset provided by the OECD. The OECD uses the same measurement technique for the entire period, for both countries and the different patent segments. Besides the possible measurement issues due to differences in legal systems, there are more fundamental issues when using patents as an indicator of innovation. Taalbi (2014, p.51) emphasizes that a patent not always represents an innovation since it can be an invention instead of a Schumpeterian innovation (Table 3-1).

***Table 3-1*: Schumpeterian perspectives on employment (elaboration on Taalbi's (2016) table)**

	Radical	Incremental
Product Innovation	New industries = Positive impact	Limited employment effects
Process Innovation	Negative Impact	Negative impacts
Invention	No impact	No impact

Another Issue mentioned by Taalbi (2014, p.51) is that *'Not all patented inventions will be commercialized and all innovations will not be patented.'* (Taalbi 2014, p.51). Besides the use of patents (output measurement) and the use of R&D spending (input measurement) is there a third way to measure innovation, this approach is called literature based innovation output. This method has the merit that it is more accurate than the other two methods, the biggest limitation of this third method is that there are not many databases constructed yet using this method and that the construction of a database using this technique is costly and time-consuming.

Since the literature based approach is not an option for this thesis due to accessibility issues, and R&D approach it not an option since the aim of this thesis focusses on output, therefore is the number of patents the most suitable and most realistic indicator to use. The limitations are not fundamental considering the research aim of this thesis, and therefore the researcher does not see any methodological issues to proceed using patents as an indicator of innovation.

3.3 Methodology

This thesis uses a quantitative method to gain insights on the association between innovations in the energy sector, emission output, and economic growth. To gain insights on these associations vector autoregression (VAR) and vector error correction (VECM) models were used. Using VAR and VECM models has as core merit that these models enable the researcher the possibility to identify an association between endogenous variables on both sides of the formula. The models will be tested for stationarity (ADF-, PP- & KPSS -test) and cointegration.

The output functions that will be presented in this thesis are impulse response function (IRF). The IRF has the aim to trace *'the effect that a one-standard-deviation-shock to one of the endogenous variables has on current and future values of all variables in the system.'* (Wang, Yang & Zhang, 2012, p.3).

For both countries, two models were constructed. The models will have two similar variables and one different variable. The two shared variables are GDP in Constant 2010$ (GDP) and energy patents (E-patents). The first model will include CO_2 emissions as the third variable. The second model has CO_2 intensity as the third variable. Therefore the first model will represent the influences of a GDP increase and energy patents on the absolute values of CO_2 emissions and the second model will represent changes in the relative output of CO_2 emissions. Since the models presented are VECM models both models shed light on the short and long-term dynamics of the variables.

Model I is expressed as the following VECM:

$$\Delta e_t=\alpha_e(\beta_1 e_{t-1}+\beta_2 p_{t-1}+\beta_3 y_{t-1}+\beta_3)+\lambda_{ee}\Delta e_{t-1\ldots}+\lambda_{ep}\Delta p_{t-1\ldots}+\lambda_{ey}\Delta y_{t-1\ldots}+v_t$$

$$\Delta p_t=\alpha_p(\beta_1 e_{t-1}+\beta_2 p_{t-1}+\beta_3 y_{t-1}+\beta_3)+\lambda_{pe}\Delta e_{t-1\ldots}+\lambda_{pp}\Delta p_{t-1\ldots}+\lambda_{py}\Delta y_{t-1\ldots}+u_t$$

$$\Delta y_t=\alpha_y(\beta_1 e_{t-1}+\beta_2 p_{t-1}+\beta_3 y_{t-1}+\beta_3)+\lambda_{ye}\Delta e_{t-1\ldots}+\lambda_{yp}\Delta p_{t-1\ldots}+\lambda_{py}\Delta y_{t-1\ldots}+n_t$$

Where y is GDP, e is energy, p is patents and v, u & n are the error terms. The notation for the lags is t.

Model II is expressed as the following VECM:

$$\Delta ei_t = \alpha_{ei}(\beta_1 ei_{t-1} + \beta_2 p_{t-1} + \beta_3 y_{t-1} + \beta_3) + \lambda_{eiei}\Delta ei_{t-1\ldots} + \lambda_{eip}\Delta p_{t-1\ldots} + \lambda_{eiy}\Delta y_{t-1\ldots} + v_t$$

$$\Delta p_t = \alpha_p(\beta_1 ei_{t-1} + \beta_2 p_{t-1} + \beta_3 y_{t-1} + \beta_3) + \lambda_{pei}\Delta ei_{t-1\ldots} + \lambda_{pp}\Delta p_{t-1\ldots} + \lambda_{py}\Delta y_{t-1\ldots} + u_t$$

$$\Delta y_t = \alpha_y(\beta_1 ei_{t-1} + \beta_2 p_{t-1} + \beta_3 y_{t-1} + \beta_3) + \lambda_{yei}\Delta ei_{t-1\ldots} + \lambda_{yp}\Delta p_{t-1\ldots} + \lambda_{py}\Delta y_{t-1\ldots} + n_t$$

In model II y represents again GDP and p is patents. In model II ei stands for CO_2 intensity and v, u & n are the error terms. The notation for the lags is t.

4 Data

4.1 Variables

The data used in this study covers the period from 1976 till 2007. In previous research Wang, Yang and Zhang (2012) used for China a time span stretching from 1985 till 2009 using a similar methodological approach as this thesis. That means that besides the historical considerations the length of the studied period has a long enough time span to overcome small sample and comparability issues.

The model exists out of the following variables:

1. **GDP in constant 2010 US$**: the data for this variables is acquired by the World Bank and published in the report: World development indicators (2017). The GDP per capita of the World Bank is composed out of the following sources: 'World Bank national accounts data, and OECD National Accounts data files' (World Bank, 2017). The GDP variable is chosen since it is the most accurate and inclusive measurement tool of economic growth.

2. **CO_2 Emissions in Kilo tons**: 'Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.' (World Bank, 2017). The World Bank acquired this data trough consulting: The Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States.

3. **CO_2 Emissions per GDP in constant 2010$**: Carbon dioxide emissions measured to indicate the energy intensity per GDP in constant 2010$ (World Bank, 2017). The World Bank acquired this data trough consulting: The Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States.

4. **Energy technology patents:** registered legal power over inventions and innovations within the energy sector. The variable energy technology patents are measured by the OECD in absolute values. The database fully covers patent applications handed in at the European Patent Office, US Patent and Trademark Office, Triadic Patent Families and the Japan Patent Office.

4.2 Database purposes

World Bank: The dataset global development indicators cover the period 1960 - 2015. This thesis reduced the span of the database from 1976 till 2013. The World Bank gathered these statistics to shape a '*compilation of internationally comparable statistics about global development and the quality of people's lives'* (World Bank, 2016, p.1). The objective of the dataset is to present material for researchers and policy makers to establish a global corporation and sustainable development. '*The sustainable development goals are 169 associated targets that build further on the Millennium development goals. The five leading themes are: people, planet, prosperity, peace, and partnership'* (World Bank 2016, p.1). The dataset is composed trough surveys and checks of the World Bank in association with private organizations and national/regional governments.

OECD: The OECD composed the 'Main Science and Technology Indicators' database with the aim to gain insights into *'the level and structure of effort in the field of science and technology'* (OECD, 2017). The database covers all the OECD countries and seven non-member countries. The data is composed with the help of local governments and authorities. The database covers research and development indicators, patent families, technology balance of payments and international trade in R&D-intensive industries.

5 Analysis

In this chapter, the results of the econometric models are presented and analyzed. This chapter is structured in the following way; first, the descriptive statistics and results for Denmark are presented when secondly, the same is done for the Netherlands.

5.1 Denmark

5.1.1 Descriptive statistics

In this paragraph the descriptive data of Denmark will be presented. The descriptive data gives a broad view of the underlying data of the variables. During the modeling process the data was transformed into a logarithmic series and from this logarithmic series the first differences were taken. All the variables have 32 observations since they run from 1976-2007, there were no missing data points so all the data points represent the values from the original data.

Table 5-1: **Descriptive statistics Denmark**

Variable	Observations	Mean	Standard deviation	Minimal	Maximal
Energy patents	32	50.59	57.83	0	184.57
Emission	32	56185.66	5353.52	47095.28	72181.23
GDP (Billions)	32	245	4.97	173	334
CO_2 /GDP	32	.24	.06	.15	.35

For the patent data the maximal observed value represents the observation of 2007, and the minimal value represents the observation of 1976 (Table 5-1). The patent data had an especially sharp increase at the end of the 90's and beginning of the 0's (Figure A-1, Appendix I).

The Danish emission output slowly decreased until the end of the 1980's. At the start of the 90's the Danish emission output began to increase again until it hit it the maximal value in 1996 (Table 5-1). After 1996 the emissions began to decrease again until it hit the minimal value in 2005. In the last two observations, the Danish emissions stagnated around the minimal value that was reached in 2005 (Figure A-2, Appendix I).

The GDP at constant (2010 $) market prices of Denmark developed steadily over the observed period (Table 5-1). The only noticeable deviations of the growth line are the stagnations of growth during the Oil Crisis (1979), the Scandinavian banking crisis (1992-1993) and the dot-com bubble (the early 00's). The economic development stagnated during these crises but never plunged. The minimal value has been observed in the first year of the researched period and the maximal value represents 2007 (Figure A-3, Appendix I).

The CO_2/GDP variable decreases over the observed period (Table 5-1). The maximal value is observed in the first year of the series (1976), the lowest value was measured in 2007. The decoupling of the CO_2 emissions of the GDP stagnated during the mid-90's, but after 1996 the decoupling continued (Figure A-3, Appendix I).

5.1.2 Stationarity test results

The first step in the time series test procedure is the examination of the stationarity of the variables. To test the stationarity of the series the researcher looks for autocorrelation. When a variable is autocorrelated, the previous values of a series are determining the future values of that same series. Implying that the data is behaving like a random walk. Since we want to analyze dynamic relationships between the variables, it is essential to gain insights on the stationarity of series. Therefore multiple unit root tests were executed. The augmented Dickey-Fuller (ADF) test, the Phillips-Peron (PP) test and the Kwiatkowski Phillips, Schmidt & Shin (KPSS), are used in this thesis to gain insights on the stationarity of the series.

First, the ADF, PP and KPSS test are used to find out if the series are non-stationary in levels. If the test results indicate that the time series have a unit root the data has to be transformed into first differences. If the test statistics still imply that the data set is non-stationary after taking first differences a second differencing technique must be used to achieve a stationary dataset.

The research of Stern (2000) indicates that the variables emissions and GDP might be integrated. The earlier work of Wang, Yang & Zhang, (2012) suggests that the variables Energy patents and CO_2 intensity might be integrated. The stationarity test will indicate if the variables are stationary in levels or differences.

Table 5-2: **Stationarity test results for Demark in log**[11]

Methods	Specification	ADF	PP	KPSS
log E-Patents	Constant and trend	(2) 0.206 (-3.568)	(2) -1.519 (-2.972)	.239 (.146)[b]
Log Emissions	Constant and trend	(2) -1.233 (-3.560)	(2) -1.197 (-2.966)	.207 (.146)[b]
Log GDP	Constant and trend	(2) -0.279 (-3.723)	(2) -0.227 (-2.983)	.117 (.146)
Log CO_2 Intensity	Constant and trend	(2) -0.642 (-3.723)	(2) -0.637 (-2.983)	.183 (.146)[b]

[11] The first number presented in table 5-2 that is enclosed in parentheses is the amount of lags, the second number is the test statistic and the third number that is again enclosed in parentheses is the 5% critical value.
This order will be used in all the following tables.

[a] Indicates significance on the 1% level.

[b] Indicates significance on the 5% level

These indicators for significance will be used in all the following tables.

The stationarity tests for the variables considering Denmark indicate that the variables are not stationary in levels (Table 5-2). When the first differences were taken, the stationarity tests provided a concurring result indicating that for the ADF- and PP- test the null hypothesis of a unit root is rejected at the 5% level. The KPSS test has a different null hypothesis it *'postulates that the series is stationary and the alternative hypothesis is the presence of a stochastic trend'* (Stern, 2000, p.271). The KPSS test indicates that the variables are stationary after first differences. The variables are I1 and can be used for cointegration analysis (Table 5-3).

Table 5-3: **Stationarity test results for Denmark in differences**

Methods	Specification	ADF	PP	KPSS
Δ L-E-Patents	Constant no trend	(1) -4.696 (-3.696) [a]	(2) -16.049 (-3.689)[a]	.0522 (.463)
Δ L-Emissions	Constant no trend	(1) -5.386 (-3.682) [a]	(2) -7.857 (-3.675)[a]	.0616 (.463)
Δ L-GDP	Constant no trend	(1) -3.603 (-2.989)[b]	(2) -4.438 (-3.716)[a]	.0447 (.463)
Δ L-CO_2 intensity	Constant no trend	(1) -5.062 (-3.723)[a]	(2) -8.053 (-3.716)[a]	.029 (.463)

5.1.3 Model I (Log E-Patents, CO_2 Emissions and GDP) DNK

The first model relates the variables log energy patents, log emissions, and log GDP. Since the variables are all I1, it is possible to test for cointegration. For cointegration analysis the right amount of lags has to be chosen. The number of lags has been chosen by the guidance of the Akaike Information Criterion (AIC) score (Akaike, 1973).

The Johansen test procedure for cointegration was developed by Johansen and Juselius (1990). The first step in their procedure was to specify the number of lags of the model. This can be done by estimating the model in levels and testing different lags bearing in mind the guidelines of the Pantula Principle (Pantula, 1989). [12]

When the Pantula Principle indicates a suitable number of lags, a comparison with the AIC and the SBC should be processed. When the number of lags indicated by the AIC, SBC and Pantula principle concurs, the researcher has to decide to in- or exclude a trend and constant within the data and cointegration relation.

Even though the AIC indicates that the VAR model should include 3 lags, the model has been extended the number of lags to 4. The 3 lag model did not seem to fit the data at best after model fit testing. Not only the model fit testing indicated that there should be 4 lags, the earlier research of Stern (2000) includes 4 lags for a similar research topic (Table 5-4). Therefore is decided to proceed with a 4 lag model.

[12] Pantula principle: start with a large amount of lags, secondly reduce the amount of lags until you find H0 of no conintegration not rejected. (Pantula, 1989)

The Johansen test for cointegration was specified with a trend and constant including 4 lags. The Johansen test indicates that there are 2 cointegration vectors on a 5% significance level (Table 5-5). The residual of the VEC model including the variables log energy patents, log emissions, and log GDP indicate that there are no problems with normality or autocorrelation (Table 5-6 & 5-7).

***Table 5-4*: Optimal amount of lag testing (Model I DNK)**

Lag	AIC	HQIC	SBIC
0	-5.84084	-5.80027	-5.69458
1	-7.27234	-7.11006*	-6.68727*
2	-7.0278	-6.74383	-6.00395
3	-7.41166*	-7.00598	-5.949
4	-7.27193	-6.74455	-5.37049

***Table 5-5*: Johansen test (Model I DNK)**

Rank	Trace	5%
0	51.2441	29.68
1	17.1292	15.41
2	1.0158*	3.76

***Table 5-6:* Normality test result (Model I DNK)**

Jarque-Berra Test (ALL)	Kurtosis	Skewness	Normally distributed
0.70016	0.88375	0.36594	Yes

***Table 5-7:* Autocorrelation test (Model I DNK)**

Lagrange multiplier test: Lag	Chi^2	DF	Prob > Chi^2	Autocorrelation
4	6.9329	9	0.64411	No

5.1.4 VECM results Model I DNK

The coefficient of Ce1 and Ce2 represent the alpha values of the vectors. The value of the coefficient -1.22 in the log emissions indicates that the emissions will be moving towards the long-run equilibrium directly. The value 0.06 at the Ce1 column on Log GDP indicates that the development of the GDP will adjust each year to long-run equilibrium with 6% in this model. Within the short-run dynamics, the log GDP variable has a significant impact on the emission & energy patent variable and on itself (Table 5-8).

Table 5-8: **VECM Results (Model I DNK)**[13]

	Log E-patents	Log Emissions	Log GDP
Log E-patents (-1)	-.66(-1.94)	.16(1.47)	-0.35(-1.82)
Log E-patents (-2)	-.21(-0.64)	.17(1.56)	-.03(-1.65)
Log E-patents (-3)	-.33(-1.55)	-.01(-.16)	**-.04(-3.18)**
Log Emissions (-1)	-.99(-1.29)	.22(0.88)	-.02(-.43)
Log Emissions (-2)	-.13(-.20)	.42(1.98)	-.03(-.76)
Log Emissions (-3)	.26(0.44)	.37(1.92)	.04(1.27)
Log GDP (-1)	1.89(0.50)	1.39(1.13)	**.74(3.5)**
Log GDP (-2)	1.45(0.40)	**2.63(2.21)**	-.08(-.39)
Log GDP (-3)	-.63(-.18)	-1.49(-1.3)	.09(.47)
Constant	0.57(.18)	.05(.46)	**.08(4.35)**
Ce1	-.22(-.69)	.165 (1.57)	**.06(3.18)**
Ce2	1.01(0.98)	**-1.22(-3.61)**	.022(.38)

To gain insights in the dynamic interactions among log Energy patents log CO_2 emissions and log GDP impulse response function (IRF) were plotted:

[13] The bold numbers represent significant observations

Figure 5-1: **IRF E-Patents, Emissions, GDP (Model I DNK)**

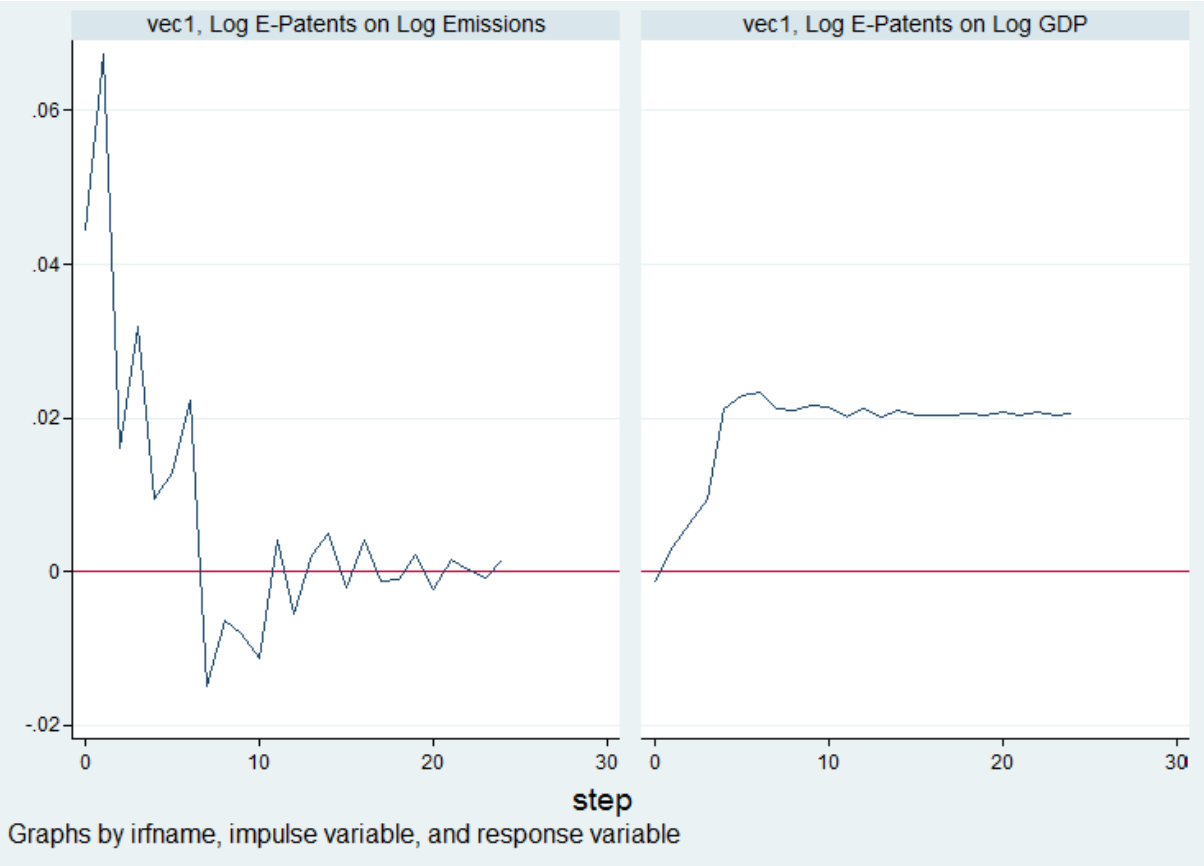
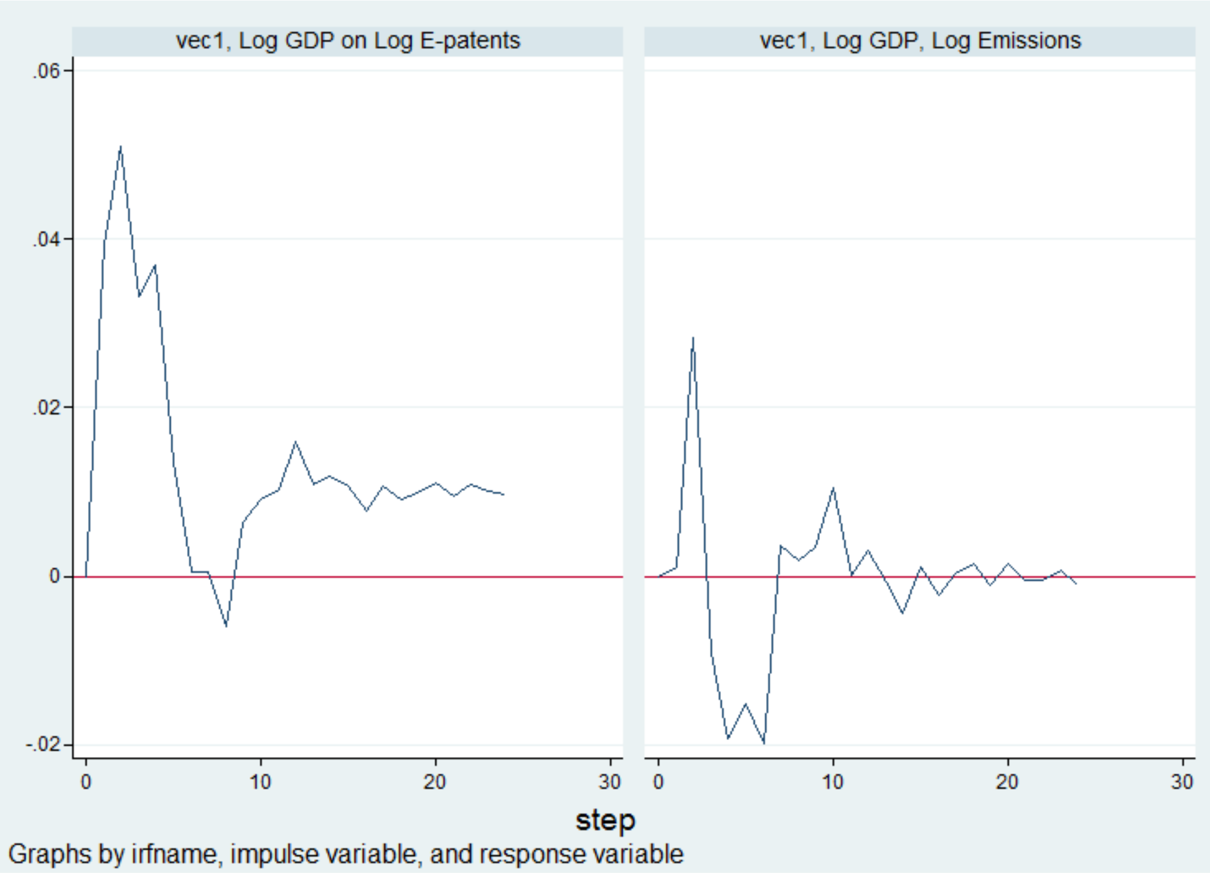


Figure 5-1 shows on the left side the effect of log E-Patents on log emissions and the right side the effect of an increase in log E-patents on Log GDP. The impulse of an increase of E-Patents has during the first five adjacent years an increase in emissions as a result, until these changes into a slightly negative reaction during the 7th till the 11th year after the impulse. After the 11th year, the effects of an increase in log E-Patents on log Emissions dies out and becomes in the long run insignificant. The effect of log E-Patents on log GDP has been positive and significant especially during the first years after an impulse in the energy innovation sector there follows a growth in log GDP that remains significant on the long run.

In the Figure 5-2 the IRF's on the left side pictures the effects of log GDP on Log E-Patents are shown, and on the right side, the effects of Log GDP on Log Emissions are plotted. The function on the left side shows a significant response to an increase in energy patents when there is an increase in Log GDP. This response is especially strong during the first five years after a Log GDP increase and stabilizes after 12 years and becomes a significant long-term change. On the right side, the increase does not cause a significant increase in emissions over the long term. This indicates that the economic growth of Denmark is decoupled from the Danish energy consumption.

***Figure 5-2*: IRF GDP, E-Patents, Emissions (Model I DNK)**



5.1.5 Model II (Log E-Patents, CO_2 intensity and GDP) DNK

The second model includes the variables Log E-Patents, CO_2 intensity and GDP. The same procedure has been conducted to come to the best-fitted model as by model 1. Again the AIC indicates that 3 lags supposed to give the best-fitted model. Nevertheless, the model did better fit when 4 lags were included (Table 5-9). The Johansen test for cointegration pointed out there were at least two cointegrated vectors (Table 5-10). The residual of the VEC model including 4 lags a trend and a constant did not suffer any problems with normality or autocorrelation (Table 5-11 & 5-12).

***Table 5-9*: Optimal amount of lag testing (Model II DNK)**

Lag	AIC	HQIC	SBIC
0	-5.84084	-5.80027	-5.69457
1	-7.27233	-7.11006*	-6.68727*
2	-7.0278	-6.74382	-6.00394
3	-7.41165*	-7.00597	-5.949
4	-7.27193	-6.74455	-5.37048

***Table 5-10:* Johansen test (Model II DNK)**

Rank	Trace	5%
0	51.2441	29.68
1	17.1291	15.41
2	1.0158*	3.76

***Table 5-11*: Normality test result (Model II DNK)**

Jarque-Berra Test (ALL)	Kurtosis	Skewness	Normally distributed
0.41272	0.55659	0.25960	Yes

***Table 5-12*: Autocorrelation test (Model II DNK)**

Lagrange multiplier test: Lag	Chi^2	df	Prob > Chi^2	Autocorrelation
4	6.9329	9	0.64410	No

5.1.6 VECM results Model II DNK

Table 5-13: **VECM Results (Model II DNK)**

	Log E-patents	Log CO_2 intensity	Log GDP
Log E-patents (-1)	-.66(-1.94)	.19(1.8)	-.03(-1.82)
Log E-patents (-2)	-.22(-0.64)	.20(1.86)	-.03(-1.65)
Log E-patents (-3)	-.33(-1.55)	.03(.39)	**-.04(-3.18)**
Log CO_2 intensity (-1)	-.99(-1.29)	.23(.97)	-.018(-.43)
Log CO_2 intensity (-2)	-.13(-.20)	.44(.03)	-.03(-.76)
Log CO_2 intensity (-3)	.26(.44)	.33(1.71)	.04(1.27)
Log GDP (-1)	.91(.23)	.88(.7)	**.72(3.27)**
Log GDP (-2)	1.33(.36)	**3.15(2.62)**	-.11(-.51)
Log GDP (-3)	-.37(-.1)	-1.25(-1.07)	.13(.66)
Constant	.03(.11)	.03(.029)	**.07(4.34)**
Ce1	-.22(-0.69)	.11(1.04)	**.06(3.18)**
Ce2	1.01(.098)	**-1.23(-3.71)**	.02(.38)

Similar to the previous paragraph the coefficient of Ce1 and Ce2 represent the alpha values of the vectors. The values of Ce1 and Ce2 indicate the long-run relationships between the variables. Therefore the results indicate that log CO_2 intensity will return after a change directly to its equilibrium level. The value 0.06 at the Ce1 column on Log GDP indicates that the development of the GDP will adjust each year to long-run equilibrium with 6% in this model. Within the short-run dynamics log E-patents has a small significant impact on the development of the log GDP variable in the third lag. Log GDP has a short-run dynamic significant positive impact on itself in the first lag (Table 5-13).

Figure 5-3: **IRF E-Patents, CO_2 Intensity, GDP (Model II DNK)**

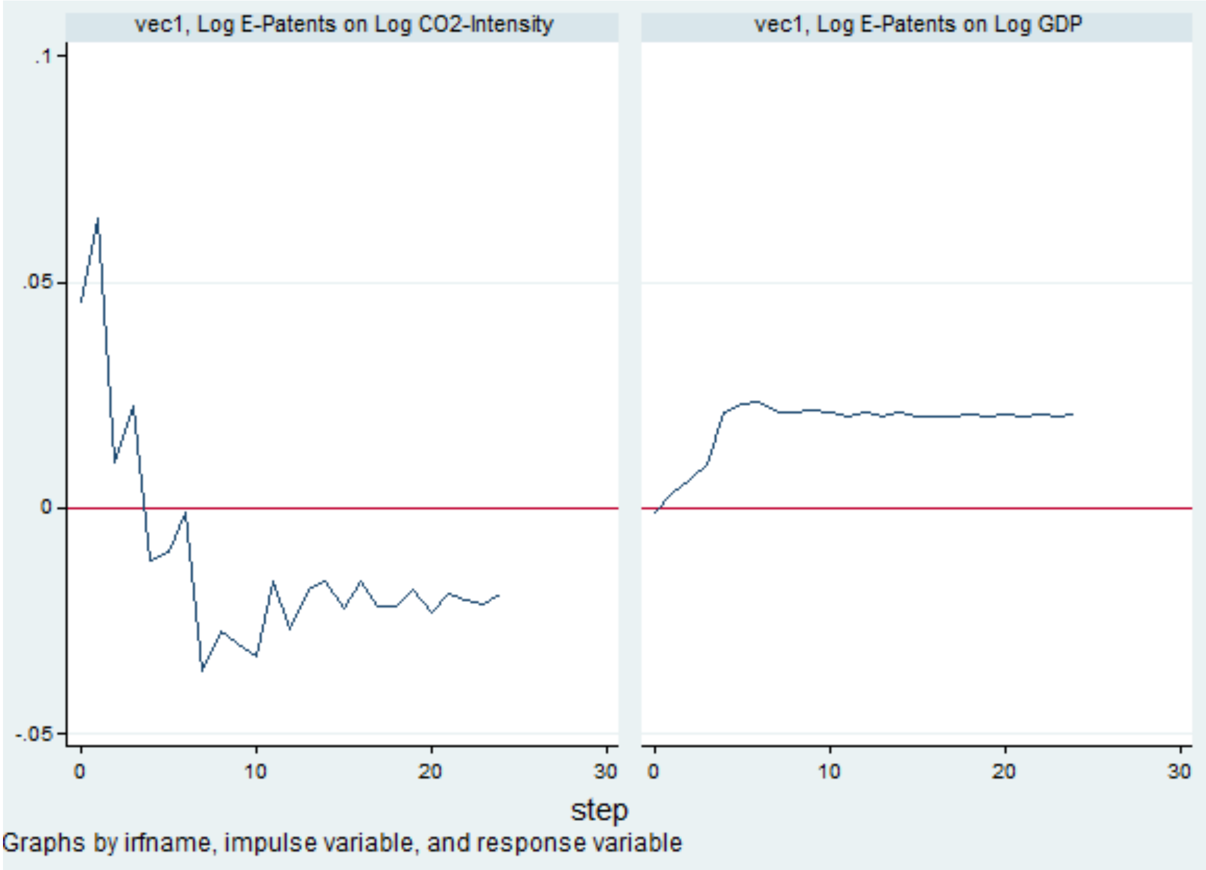
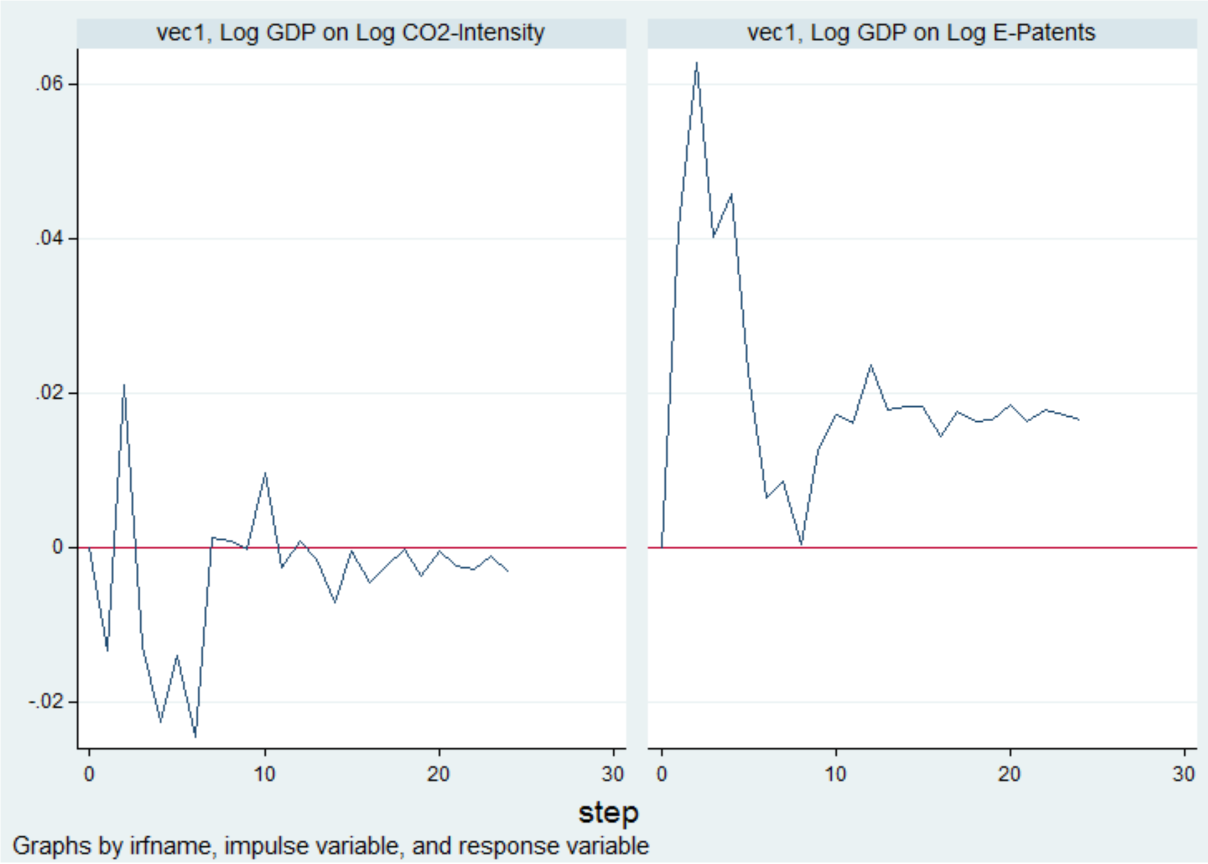


Figure 5-3, presents on the left side the IRF of log E-patents on log CO2 intensity and the right side the IRF of log E-Patents on Log GDP. The first graph shows that there is a significant long-run negative impact of log E-patents on log CO_2 intensity and a short-run positive effect of log-E patents on log CO_2 intensity. The impulse of an increase in log CO_2 intensity divers in the long run from zero, this indicates that an increase in log E-patents has a long run negative influence on the CO_2 used to create a unit of GDP. The IRF of log E-patents on Log GDP follows the same line as for model I. An impulse in log E-patents has still a positive long-run effect on the development of the GDP for Denmark.

The final IRF for Denmark is presented in Figure 5-4. This last IRF shows the impulse of a unit increase in log GDP on log CO_2 intensity and from log GDP on Log E-patents. The IRF of log GDP on log CO_2 intensity demonstrates an interesting finding, an impulse in log GDP seems to have a long-run small significant negative response of the log CO_2 intensity. This indicates that when the absolute level of the GDP in Denmark increases the decoupling with energy could according to this test result develop (Figure 5-4).

Another interesting finding that is provided by the information presented in figure 5-4 is the effect that an impulse of log GDP has on the log E-patents variable. A unit increase in log GDP is having a significant and lasting positive effect on the number of log E-patents. This tells that the energy innovations in Denmark are expanding when the size of the economy is expanding in absolute terms.

Figure 5-4: **IRF GDP, E-Patents, CO_2 Intensity (Model II DNK)**



5.3 The Netherlands

5.3.1 Descriptive statistics

In this paragraph, the descriptive data of the Netherlands will be shown. The descriptive data of the Netherlands give the reader the possibility to get a broad view of the underlying data of the variables included in the models.

Table 5-14: **Descriptive statistics Netherlands**

Variable	Observations	Mean	Standard deviation	Minimal	Maximal
Energy patents	32	317.61	399.22	0	1343.1
Emission	32	163556	11974.25	134322.2	187812.7
GDP (billion)	32	573	14.4	391	843
CO_2 / GDP	32	.30	.07	.20	.45

The created variables for the Netherlands have the same amount of observations as Denmark: 32. The observations run from 1976-2007 there were no missing data points, the variables only contain original data.

For the patent data (Table 5-14), the observation with the highest value represents the observation of 2001, and the minimal value represents the observation of 1976. The patent data increased in a constant growth rate until the second half of the 1990's when the number of patents doubled within five years. The patent data plunged after 2001 and returned to the original growth pattern from 2002 till 2005. In 2005 the growth stagnated until the end of the observed period (Figure A-5, Appendix I).

The Dutch emission output (Table 5-14), rapidly decreased in the three years after the 1979 (max observation) oil crisis until 1982 (min observation) when the absolute output of emissions started to gradually develop into the direction of the output level of 1979. At the beginning of the 00's the Dutch emission output came close to the maximal value of 1979 in 2004. After 2004 the emissions started to decrease again until it stagnated around the mean value from 2005 till the end of observed period (Figure A-6, Appendix I).

The GDP at market prices of the Netherlands (Table 5-14), followed a constant growth pattern over the observed period. The only noticeable deviations of the growth line are the stagnations of growth during the Oil Crisis + aftermath (1979-1982), the recession of the early 1990's (1990-1992) and the dot-com bubble (the early 00's). The economic development stagnated during these crises but never plunged. The minimal value has been observed in the first year of the researched period, and the maximal value represents 2007 (Figure A-7, Appendix I).

The CO_2/GDP variable decreased over the observed period (Table 5-14). The maximal value is observed in the first year of the series (1976), the lowest value was measured in 2007. The decoupling of the CO_2 emissions of the GDP stagnated during the last five years of the 80's but nevertheless kept on decreasing, and the decoupling continued in the 17 years after the ending of the 80's (Figure A-8, Appendix I).

5.3.2 Stationarity test results

The stationarity tests for the Netherlands will again indicate if the variables are stationary in levels or differences. The stationarity tests for the variables in levels are not significant on a 5% level, and therefore the data had to be tested for stationarity in differences (Table 5-15). The ADF and PP tests show that the null hypothesis of a unit root is rejected at the 5% level for all the four variables (Table 5-16). The KPSS test indicates that the variables are stationary after first differences. The results of the stationarity tests are encompassing and provide the information that the variables are I1 and can be used for cointegration analysis.

Table 5-15: **Stationarity test results for the Netherlands in log**

Methods	Specification	ADF	PP	KPSS
log E-Patents	Constant and trend	(2) -1.123 (-3.596)	(2) -0.739 (-3.730)	.319 (.143)[b]
Log Emissions	Constant and trend	(2) -2.423 (-3.580)	(2) -2.235 (-3.709)	.217 (.143)[b]
Log GDP	Constant and trend	(1) -3.003 (-3.580)	(1) -0.171 (-3.709)	.277 (.143)[b]
Log CO_2 Intensity	Constant and trend	(2) -3.5003 (-3.584)	(2) -0.770 (-3.709)	.132 (.143)

Table 5-16: **Stationarity test results for the Netherlands in differences**

Methods	Specification	ADF	PP	KPSS
Δ L-E-Patents	Constant no trend	(2) -3.823 (-3.6)[b]	(2) –4.881 (-3.736)[a]	.144 (.463)
Δ L-Emissions	Constant no trend	(2) -5.212 (-4.352)[a]	(2) -5.342 (-3.716)[a]	.0524 (.463)
Δ L-GDP	Constant no trend	(1) -3.576 (2.989)[b]	(2) -2.559 (-2.986)	.156 (.463)
Δ L-CO_2 intensity	Constant no trend	(2) -5.190 (-3.739)[a]	(2) -5.869 (3.716)[a]	.04 (.463)

5.3.3 Model I (Log E-Patents, CO_2 Emissions and GDP) NLD

The first model considering the Netherlands relates just as for Denmark the variables log energy patents, log emissions and log GDP. Since again all the variables are I1 cointegration can be tested for according to the principles of the Johansen testing procedure.

The AIC indicates that the VAR model should include 3 lags, the model has been tested and a 3 lag model was the best fit. Therefore the AIC lag length indicated by the AIC score was followed and used (Table 5-17).

The Johansen test for cointegration was specified with a trend and constant including 3 lags. The Johansen test indicates that there was 1 cointegrating vector on a 5% significance level (Table 5-

18). The residual of the VEC model was normally distributed and did not suffer from autocorrelation (Table 5-19 & 5-20).

Table 5-17: **Optimal amount of lag testing (Model I NLD)**

Lag	AIC	HQIC	SBIC
0	-8.27722	-8.23815	-8.12996*
1	-8.71238	-8.55611	-8.12335
2	-8.81349	-8.54002	-7.78269
3	-9.0471*	-8.65643*	-7.57453
4	-8.9105	-8.40262	-6.99616

Table 5-18: **Johansen test (Model I NLD)**

Rank	Trace	5%
0	40.723	29.68
1	4.813*	15.41

Table 5-19: **Normality test result (Model I NLD)**

Jarque-Berra Test (ALL)	Kurtosis	Skewness	Normally distributed
.48745	.156	.974	Yes

Table 5-20: **Autocorrelation test (Model I NLD)**

Lagrange multiplier test: Lag	Chi^2	df	Prob > Chi^2	Autocorrelation
3	12.2699	9	.199	No

5.3.4 VECM Results Model I NLD

Table 5-21: **VECM Results (Model I NLD)**

	Log E-patents	Log Emissions	Log GDP
Log E-patents (-1)	.2(.9)	**.03(2.34)**	.00(.09)
Log E-patents (-2)	.02(.1)	.01(.6)	.00(.84)
Log Emissions (-1)	-2.42(-1.02)	.23(1.6)	-.04(-.91)
Log Emissions (-2)	-3.6(-1.76)	**.36(2.94)**	.00(.08)
Log GDP (-1)	-4.0(-.36)	-.22(-.34)	**.96(4.29)**
Log GDP (-2)	5.5(.55)	-.21(-.34)	**-.47(-2.29)**
Constant	.01(.02)	**.03(1.99)**	**.01(2.52)**
Ce1	-.83(-1.79)	**.015(5.64)**	.00(.12)

The results of the VECM considering the variables Log E-patents, Log emissions and log GDP deliver one significant return to long-term equilibrium result and four short-run results (Table 5.21). The value 0.015 at the Ce1 column on Log emissions indicates that the development of the emissions will adjust each year to long-run equilibrium with 0.015% in this model. The four short run interactions are divided between the log emissions and the log GDP. The variable log emissions have a short-run association with the first lag of E-patents and on the second lag with itself. The variable Log GDP has a positive impact on itself in the first lag and a lower negative impact on itself in the second lag.

For a better understanding of the interactions and responses of the variables on each other, IRF's were plotted for the Netherlands. The IRF's in figure 5-5, show on the left side the effect of an increase of log E-patents on log emissions and the right the effect of an increase in log E-patents on log GDP. Both IRF's show a significant positive response of the variables when there is an impulse in log E-patents. This indicates that investments in the development of E-patents might not have the desired effect on the absolute output of emissions. This result is not strange in comparison with earlier research, Wang, Yang, and Zhang (2012) find a similar IRF for China. Log E-patents has a significant positive effect on the variable log GDP. This could indicate that investments in innovations in the energy sector could result in a lasting positive impact on the development of the absolute level of GDP. Figure 5-6, on the other hand, indicates that an increase in GDP does not necessarily have a positive impact on the development of E-patents.

The IRF on the left side of Figure 5-6 shows that an increase in the log GDP variable has a negative effect on the amount of E-patents. This can explain why the influence of log E-patents on log GDP stagnates after approximately five years. The negative relationship of log GDP on log E-patents is not strange bearing in mind that during periods of rationalization the investments are in general done in saving labor costs and production optimization. This effect could force the variables to develop the way they do on the left side of Figure 5-6. On the right side of Figure 5-6, there is a short and a long-run significant relationship between an impulse in log GDP and response in emissions. In the short run an increase in log GDP seems to have a negative impact on the absolute amount of emissions, but after three years this negative impact gradually moves over the 0-line and becomes a positive impact what indicates that the association between log GDP and log Emissions in the Netherlands is on the long-run positive. This suggests that Dutch economic growth has been a small significant negative effect on the environmental circumstances of the country.

***Figure 5-5:* IRF E-Patents, Emissions, GDP (Model I NLD)**

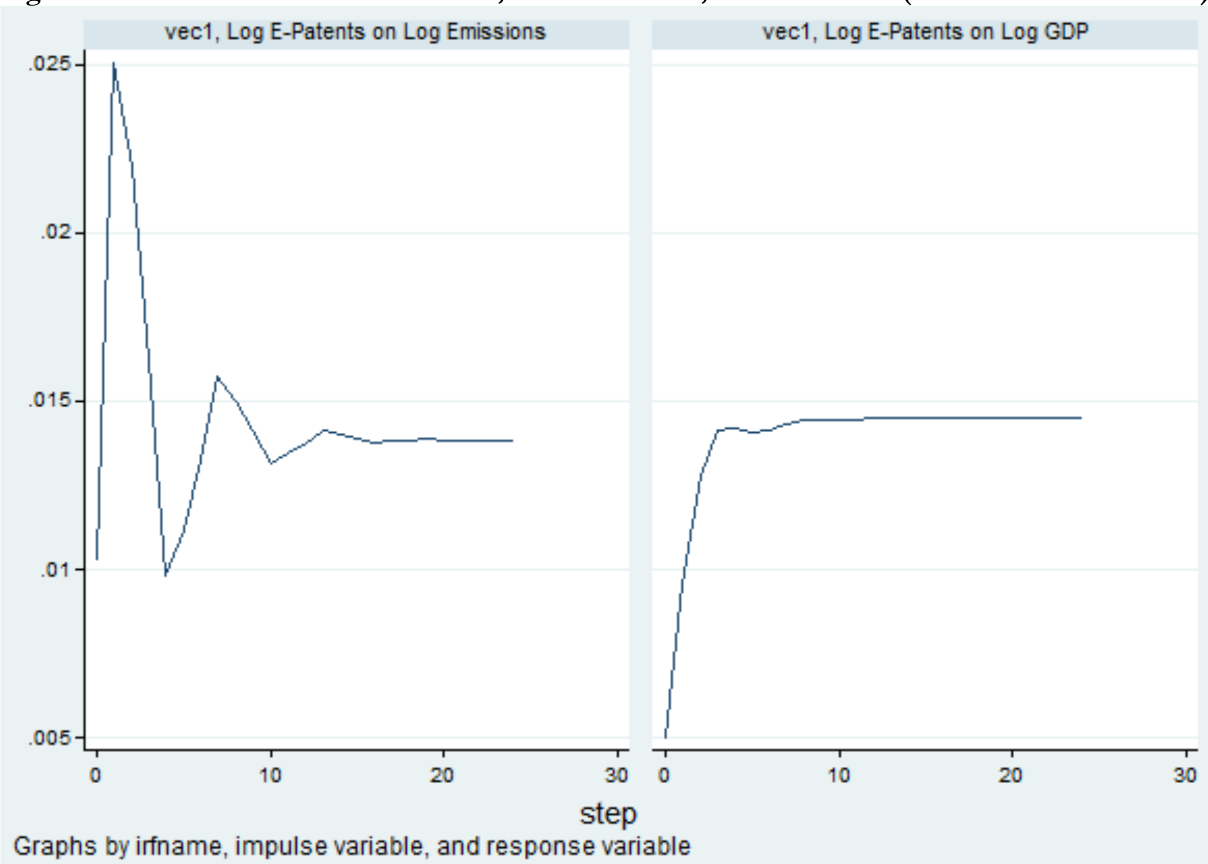
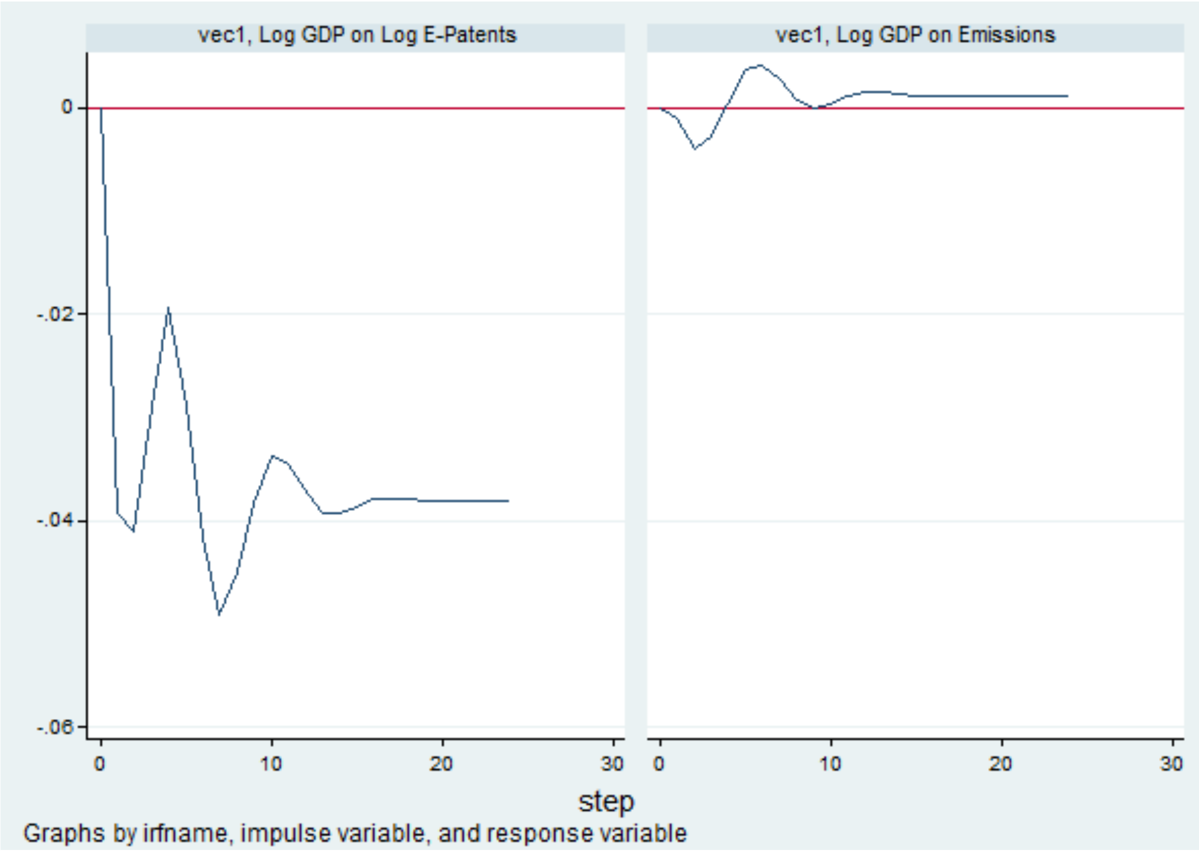


Figure 5-6: **IRF GDP, E-Patents, Emissions (Model I NLD)**



5.3.5 Model II (Log E-Patents, CO_2 intensity and GDP) NLD

The second model used to measure the developments in the energy use and innovation in the Netherlands relates just as for Denmark the variables log energy patents, CO_2 intensity and log GDP with each other. These variables were tested for cointegration following the Johansen test procedure.

Model 2 will have 3 lags, these 3 lags were added after consulting the AIC score which indicated that a model with 3 lags would have the best fit (Table 5-22). The Johansen test for cointegration was specified with a trend and constant including 3 lags. The Johansen test indicates that there was 1 cointegrating vector on a 5% significance level (Table 5-23). The residual of the VEC model was normally distributed and did not suffer from autocorrelation (Table 5-24 & 5-25).

Table 5-22: **Optimal amount of lag testing (Model II NLD)**

Lag	AIC	HQIC	SBIC
0	-8.27722	-8.23816	-8.12997*
1	-8.71239	-8.55612	-8.12336
2	-8.81348	-8.54001	-7.78268
3	-9.04708*	-8.65641*	-7.57451
4	-8.91048	-8.4026	-6.99614

Johansen test (trend + constant)

Table 5-23: **Johansen test (Model II NLD)**

Rank	Trace	5%
0	40.7231	29.68
1	4.8135*	15.41

Table 5-24: **Normality test result (Model II NLD)**

Jarque-Berra Test (ALL)	Kurtosis	Skewness	Normally distributed
.48926	.975	.156	Yes

Table 5-25: **Autocorrelation test (Model II NLD)**

Lagrange multiplier test: Lag	Chi^2	df	Prob > Chi^2	Autocorrelation
3	12.2696	9	0.19853	No

5.3.6 VECM Results Model II NLD

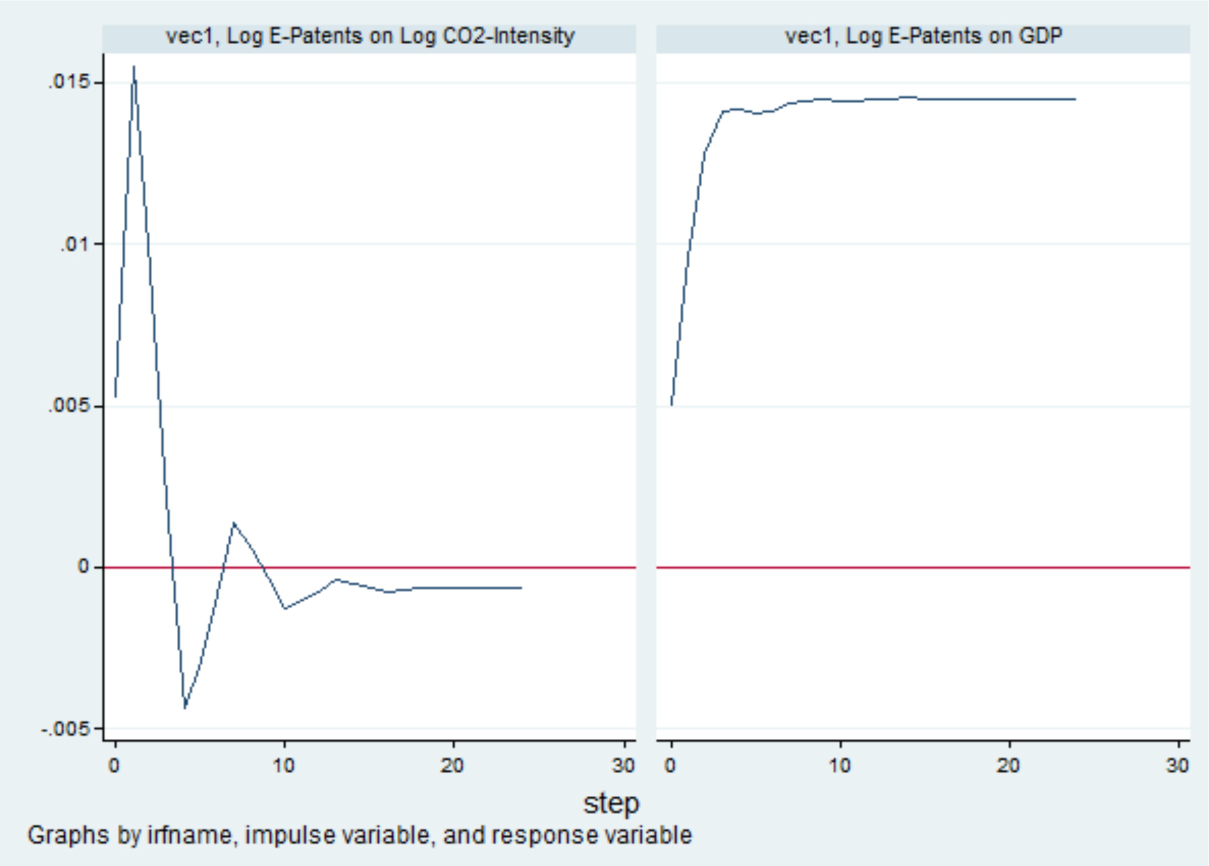
***Table 5-26:* VECM Results (Model II NLD)**

	Log E-patents	Log CO_2Intensity	Log GDP
Log E-patents (-1)	.19(.9)	**.029(2.21)**	.00(.09)
Log E-patents (-2)	.02(.1)	.00(.30)	.00(.84)
Log CO_2Intensity (-1)	-2.41(1.02)	.27(1.83)	-.04(-.91)
Log CO_2Intensity (-2)	-3.6(1.76)	**.36(2.78)**	.00(.08)
Log GDP (-1)	-6.43(-.61)	-.91(-1.4)	**.92(4.29)**
Log GDP (-2)	1.98(.2)	.62(1.02)	**-.47(-2.38)**
Constant	.00(.01)	.018(1.1)	**.01(2.51)**
Ce1	-.08(-1.79)	**.015(5.36)**	.00(.12)

The VECM results of the second model representing the Dutch situation show similarities with the earlier presented VECM for the Netherlands. The results of the second model indicate that the Dutch log CO_2 intensity slowly returns to a long-run equilibrium (Table 5-26). The coefficients of the other two variables are insignificant for the long run, but there are effects measured on the short run dynamics. On the short run, Log E-patents has a significant positive effect on the log CO_2 intensity, this is not a surprising result since Wang, Yang and Zhang (2012) have a similar result for China. Their explanation for this result is that *'The number of energy technology patents rise rapidly in the short-run. However, the patents might not be widely and quickly adopted, which could limit their role in reducing CO_2 emissions to some extent.'* (Wang, Yang, and Zhang, 2012, p. 6). This explanation fits within the theory of rationalization and spread of technologies. Therefore it seems a solid explanation for this short-run interaction between the two variables. The GDP variable of the Netherlands is again having a short run positive effect on itself in relation to the first lag and in relation to the second lag it has a significant negative effect on itself (Table 5-26).

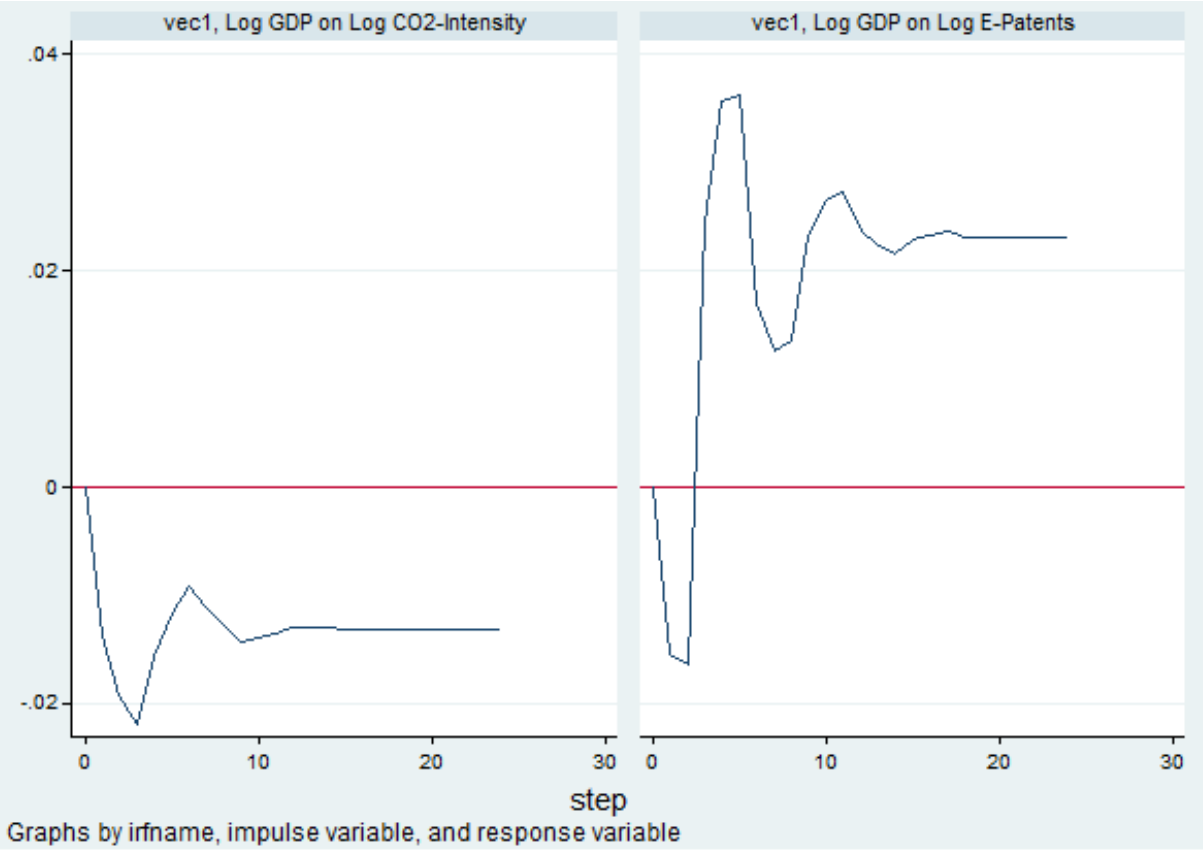
The IRF's that resulted out of the estimates of the second Dutch model shed an interesting light on the short and long-run impulse and responses of the variables. On the left side of Figure (5-7) a short-run positive effect is visible that was also represented in the VECM result table (5-26). The short-run effect does no continue but becomes after nine years significant negative indicating that as well as for Denmark in the Netherlands an increase in Log E-patents is associated with a negative long-run impact of the CO_2 intensity. The influence of E-patents on GDP are similar as to the results of model I. For model II there is again a positive long-run association between an impulse in log E-patents and log GDP (Figure 5-7).

Figure 5-7: **IRF E-Patents, CO_2 Intensity, GDP (Model II NLD)**



The final IRF's (Figure 5-8) show on the left side the impact of log GDP on log CO_2 intensity and the right side the impact of log GDP on log E-patents. The IRF measuring what the effect of an impulse in log GDP has for effect on log CO_2 intensity presents the result that, an impulse in log GDP has a significant short term and long-term effect on the CO_2 intensity. This result indicates that the Dutch economy is decoupling its economic growth from its energy consumption. Due to the change of variables, the effects of Log GDP on Log E-patents has changed considerably. In the first model, a significant short and long-run negative association was measured, within the setting of the second model this short-run significant negative impact remains but becomes a significant positive effect after approximately three years and remains positive on the long run. This indicates that on the long term the growth of the absolute size of the economy leads in the Netherlands as observed earlier in Denmark to innovations in the energy sector.

Figure 5-8: **IRF GDP, E-Patents, CO_2 Intensity (Model II NLD)**



6 Conclusion and discussion

This thesis examines the dynamics between CO_2 emissions/intensity, GDP, and energy patents in the Netherlands and Denmark from 1976-2007. The VECM model and the IRF figures provided new insights on the short run and long-run dynamics between innovations in the energy sector and the CO_2 consumption/intensity of a developed Western European country. The aim of this thesis was to relate the theory that an increase of innovations in the energy sector could contribute to the decoupling of CO_2 output and economic growth to quantitative analysis on developed countries.

In this chapter first, the results of the quantitative analysis will be related to the hypotheses (chapter 3). Secondly, a reflection on the results in a broader perspective will be presented.

The previous research of (Schön, 2008) contributed to the idea that innovations in the energy sector could lead to an increase in GDP over time. The first hypothesis (1) was, therefore, assuming that: energy patents have a positive association with GDP. This hypothesis is supported by the results of the IRF's for both Models I & II of both the observed countries. This finding indicates that investments within the energy sector could have a positive impact on the economic growth.

Since the economy is bigger than the energy sector alone and a large share of the emissions are exhausted by our means of transport. Bearing in mind the findings of Kander (2005) regarding the Baumol disease this thesis expected that an increase in energy patents would not have a strong enough effect to lead to a decrease or increase in the absolute amount of emissions in a developed country. The expectations of hypothesis (2) concurred with the findings of Model I for the long run in Denmark. For both the short and the long-run dynamics in the Netherlands the association appeared to be positive. These results suggest that most innovations in the energy sector are done during the period of transformation of the structural cycles when investments are made to create new markets what is less (energy) cost efficient than investments that are done during the period of rationalization. The results of the Netherlands follow a similar pattern with the previous results of China by (Wang, Yang, & Zhang, 2012). The differing of the Danish results is probably related to the overall decrease in emissions of the Danish economy where The Netherlands and China have both an overall increase in emissions over time.

The technological context of this thesis shown that rapid developments in renewable energy and nuclear power emerged during the observed period of this thesis. These inventions are represented in the energy patents variables, the theory expected through hypothesis (3) that these innovations and inventions will have a negative association on the CO_2 intensity. This negative association can be found in the results for the Netherlands and Denmark. The IRF's indicate that the negative association exists on the long- and short-run. This finding correspondent with the earlier research of Wang, Yang, and Zhang (2012). These findings support the conclusion that investments in the energy sector could force long-run changes in the use of energy per capita. Although it is not directly affecting the absolute output of emissions, it still pushes the output of developed countries towards a less polluting path of development. This thesis supports the idea that this is not only relevant for countries that are in the transition process towards becoming a developed country, and that this is also relevant for small developed countries.

The earlier findings of Stern (2000) indicated that economic growth is coupled to the energy output of an economy. Therefore had this hypothesis (4) the expectation that an increase in GDP has a positive association with the absolute amount of emissions. The dynamics plotted by the IRF indicate that for the Netherlands there was no long-run effect of GDP on emissions. For Denmark, there were fluctuations on the impact of GDP on emissions. In the short-run increase in GDP had as the effect a short run increase in the first three years and a decrease in the fourth till eight years, the effects die out on the long run. The results indicate that for Denmark and The Netherlands the hypothesis can be rejected. For both countries, there were no significant long-run associations between GDP and emissions.

Besides the findings of Stern (2000), another expectation considering GDP was that this variable has a positive association with some energy patents applied for. The idea behind this hypothesis (5) was that during periods of economic growth investments would increase and therefore the number of patents applied for in the energy sector would follow this pattern. This hypothesis is supported by the results of Model I for Denmark and Model II for the Netherlands and Denmark. The results of Model I of the Netherlands are not concurring with the other results. Model I and II indicate that within the dynamics of the Danish economy an impulse in GDP leads to a change in equilibrium with; as a result a long- and short-term increase in energy patents. For the Netherlands, a similar pattern can be observed in model II. These findings support the assumption that economic growth might over time lead to a faster decoupling of growth and energy consumption through the increase in energy innovations.

This assumption is backed by the findings related to the last hypothesis (6). This hypothesis expects that there is a negative association with GDP and the relative amount of emission output. This hypothesis was grounded in the idea that countries over time tend to become more efficient in their energy use. Even though the literature suggested that due to maturing of the third IR innovations and the diminishing character of energy saving replacements there is still the expectation that when a country develops it becomes increasingly energy efficient per unit of GDP. The final hypothesis was supported by the findings of this thesis; Model II indicates through the IRF's that in both the Netherlands and Denmark an impulse in GDP has a negative association between the CO_2 intensity variable.

The empirical results of this thesis provide the insight that the earlier found dynamics between energy-patents, emissions, CO_2 intensity, and GDP, in a developing country, appeared to be existing in developed Western-European countries as well. The implication of this research is that pro-energy innovations policies are recommended. The relative decoupling of the Danish and Dutch economy through an increase in energy innovation indicates that it is possible to decrease the output of luxurious energy consumption without harming the economic growth of a developed country. To put a hold on natural disasters and to put a hold on the inequality considering the North-South situation it is important to realize that there are still dynamics to discover and that backing up theoretical assumptions (how obvious they might look like) with quantitative results is needed to enable opportunities towards sustainable growth.

For further research I would recommend to do a similar approach for a set of large developed countries with a similar historical background and diverse energy policies. Another method that could have interesting outcomes is relating patents out of other sectors than the energy sector with energy intensity.

References

Akaike, H. (1973). Information theory and an extension of the maximum likelihood principal, in B.N. Petrov, & F. Csaki (eds), *2nd International symposium on Information Theory*. Budapest: Akademini Kiado, pp.267-281

Albino, V., Ardito, L., Dangelico, R.M., & Petruzzelli, A.M. (2014). Understanding the development trends of low-carbon energy technologies: A patent analysis, *Applied Energy,* vol. 135, no. 15, pp.836-854

Ang, B.W. (2004). Decomposition analysis for policymaking in energy: which is the preferred method?, *Energy Policy,* vol.32, pp.1131-1139

Arellano, M. (2004). Lagrange Multiplier Test, in J. Segura and C. Rodríguez Braun (eds), *An Eponymous Dictionary of Economics*

Bernstein, P.M, Montgomery, W.D & Sugandha, D.T. (2006). Potential for reducing carbon emissions from non Annex B countries through changes in technology, *Energy Economics,* vol. 28, pp.742-762

Borràs, S. (2016). Innovations of economics, Guest Lecture, Lund University School of Economics and Management, Sweden, 25 November 2016

Bulkeley, H. & Newell, P (2014). Governing Climate Change, New York: Routledge

Centraal Bureau voor de Statistiek, (2012). Hernieuwbare energie in Nederland 2012, Den Haag: Graftmedia, Available online: https://www.cbs.nl/nl-nl/publicatie/2013/35/hernieuwbare-energie-in-nederland-2012 [Accessed 5 May 2017]

Dahmén, E. (1988). 'Development blocks' in Industrial Economics, *Scandinavian Economic History Review,* vol. 36, no.1, pp.3-14.

DEA (2015). Biomass for Energy, *Danish Energy Agency,* Copenhagen, Denmark

EurObserver (2013). Baromètre Photovoltaïque, *Le journal de Photovoltaïque,* vol. April 2013, no. 9

Freeman, C. (1996). The Greening of technology and models of innovation, *Technological forecasting and social change,* vol.53, pp.27-39

Gupta, S. (2015). Decoupling: a step toward sustainable development reference to OECD countries, *International Journal of Sustainable Development & World Ecology,* vol.22, no.6, pp510-519

Hellema, D, Wiebes, C, Witte, T. (2004), The Netherlands and the Oil Crisis, Amsterdam: *Amsterdam University press.*

Henriquez, S.T. (2017). Energy Intensity Decomposition, EKHM83 lecture 7, Lund University School of Economics and Management, Sweden, 10 February 2017, Available online: https://liveatlund.lu.se/departments/EconomicHistory/EKHM83/EKHM83_2017VT__-

99___/CourseDocuments/EKHM83_Lecture7Decomposition10Feb2017.pdf [Accessed 27 April 2017]

Henriquez, S.T & Kander, A. (2010). The Modest Environmental Relief Resulting from the Transition to a Service Economy, *Ecological Economics,* vol..70, no.2, pp.271-282

Hjalmarsson, E. & Österholm, P. (2007). Testing for Cointegration Using the Johansen Methdology when Variables are Near-Integrated, *IMF working papers,* vol.7, no.141, pp.1-21

Johansen, S. & Juselius, K. (1990). Maximum Likelihood Estimation and Inference on Cointegration – with Applications to the Demand for Money, *Oxford Bulletin of Economics and Statistics,* vol.52, no. 2, pp.169-210

Johnstone, N., Haščič, I., & Popp, D. (2009). Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts, *Environmental and Resource Economics,* vol. 45, no.1, pp.133-155

Kander, A., Malanima, P., & Warde, P. (2014). Power to the People. Princeton: Princeton University press

Klimaatonderzoek Nederland, Hulscher, M. (2017) Windenergie uitwisseling Nederland met Denemarken, Available online: https://klimaatonderzoeknederland.nl/windenergie-uitwisseling-nederland-met-denemarken/ [Accessed 8 May 2017]

Mackay, D.J.C. (2009). Sustainable Energy –without the hot air, Cambridge: UIT Cambridge

Mann, M.E, Rahmstorf, S, Kornhuber, K, Steinman, B.A, Miller, S.K & Coumou, D. (2017). Influence of Antropogenic Climate Change on Planetary Wave Resonance and Extreme Weather events, *Scientific reports,* vol. 7, no.45242

Ministry of Foreign Affairs of Denmark, A World-Leader in Wind Energy, Available online: http://denmark.dk/en/green-living/wind-energy/ [Accessed 9 May 2017]

Murray, R.L. (2001). Nuclear Energy (fifth edition), an Introduction to the Concepts, Systems and Applications of Nuclear Processes, Amsterdam: Elsevier

Nagaoka, S., Motohashi, K., & Goto, A. (2010). Patent statistics as an innovation indicator, in B. Hall & N. Rosenberg (Eds.), *Handbook of the economics of innovation,* Amsterdam: North-Holland, pp.1083—1127

Nederlandse Aardgas Maatschappij (2017), Historie van aardgas en aardolie: http://www.nam.nl/gas-en-oliewinning/het-winnen-van-aardgas/historie-van-aardgas-en-olie.html [Accessed 23 May 2017]

OECD (2009). Basic Criteria for Compiling Patent-Based Indicators, in *OECD Patent Statistics manual,* OECD Publishing.

OECD (2017). http://www.oecd.org/science/inno/msti.htm [Accessed 3 April 2017]

OECD (2013). Patent database, *http://stats.oecd.org/Index.aspx?DataSetCode=PATS_IPC* [Accessed 3 April 2017]

Panne (van der), G. (2007), Issues in measuring innovation, *Scientometrics,* vol.71, pp.495-507

Pantula, S. G. (1989). Testing for unit roots in time series data. Econometric Theory, vol.5, no. 02, pp.256–271

Ptasinski, K.J. (2016). Efficiency of Biomass Energy: An Exergy Approach to Biofuels, Power and Biorefineries, Hoboken: Wiley and Sons

Rotmans, J., Duursma, M., & Postma, R. (2017). Afbraak van de Fossiele Haven gaat Razendsnel, *Nieuw Rotterdams Courant Handelsblad,* 27 April, pp.4-5

Schön, L. (2009). Technological Waves and Economic Growth - Sweden in an International Perspective 1850-2005, *Circle Electronic Working Paper Series,* vol.6

Ship-Technology (2017). Information about the biggest ports in the world: http://www.ship-technology.com/features/feature-the-worlds-10-biggest-ports/ (accessed on 28 April 2017)

Stenkjaer, N. (2009). Tidevandsenergi: http://www.folkecenter.dk/dk/rd/boelgekraft/boelgekraft/tidevandsenergi/ [Accessed 5 May 2017]

Stern, D.I (2000). A Multivariate Cointegration Analysis of the role of Energy in the US Macroeconomy, *Energy Economics,* vol. 22, pp.267-283

Stern, D.I. (1993). Energy use and Economic Growth in the USA, a Multivariate Approach, *Energy Economics,* vol 15, pp.137-150

Taalbi, J. (2014). Innovation as Creative Response, Determinants of Innovation in the Swedish Manufacturing Industry, 1970-2007, Lund Studies in Economic History, vol. 67

Taalbi, J. (2016). Innovations of economics, Lecture 2, Lund University School of Economics and Management, Sweden, 11 November 2016, Available online: https://liveatlund.lu.se/departments/EconomicHistory/EKHM71/EKHM71_2016HT__-99___/CourseDocuments/EKHM71%20Impact%20of%20innovation%20on%20growth%20and%20employment.pdf [Accessed 7 May 2017]

United Nations, (2012). Denmark's renewable energy policies, in Emmons, K. (eds), *Low Carbon Green Growth Roadmap for Asia and the Pacific. 'Turning resource constraints and the climate crisis intro economic growth opportunities',* Bangkok: United Nations publications

United Nations, (2015). Paris climate conference information site: *http://unfccc.int/meetings/paris_nov_2015/meeting/8926.php* [Accessed 10 April 2017]

Whang, Z, Yang, Z & Zhang, Y, (2012). Relationships between energy technology patents and CO_2 emissions in China: An empirical study, *Journal of Renewable and Sustainable Energy,* vol. 4 no.031807, pp.1-10

World Bank (2016). World Development indicators, Available online: http://data.worldbank.org/data-catalog/world-development-indicators, [Accessed 28 March 2017]

A) Appendix I

Figure A-1: **DNK: Energy Patents (1976-2007)**

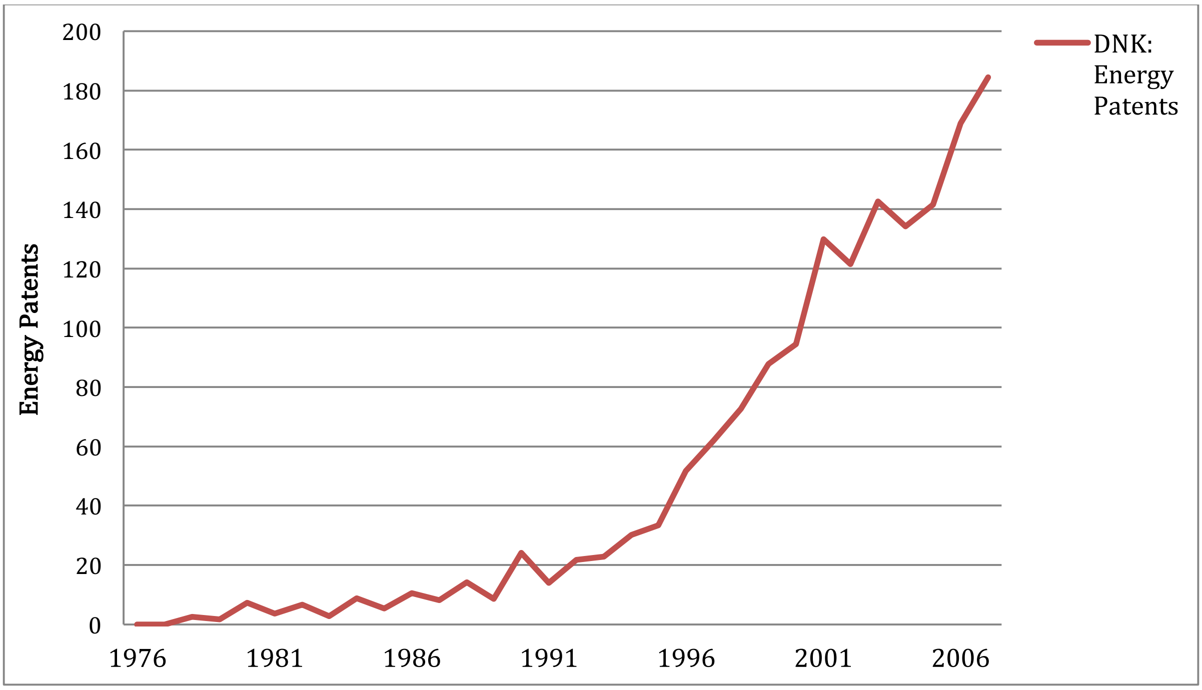


Figure A-2**: DNK: CO_2 Emissions in Kilo Tons (1976-2007)**

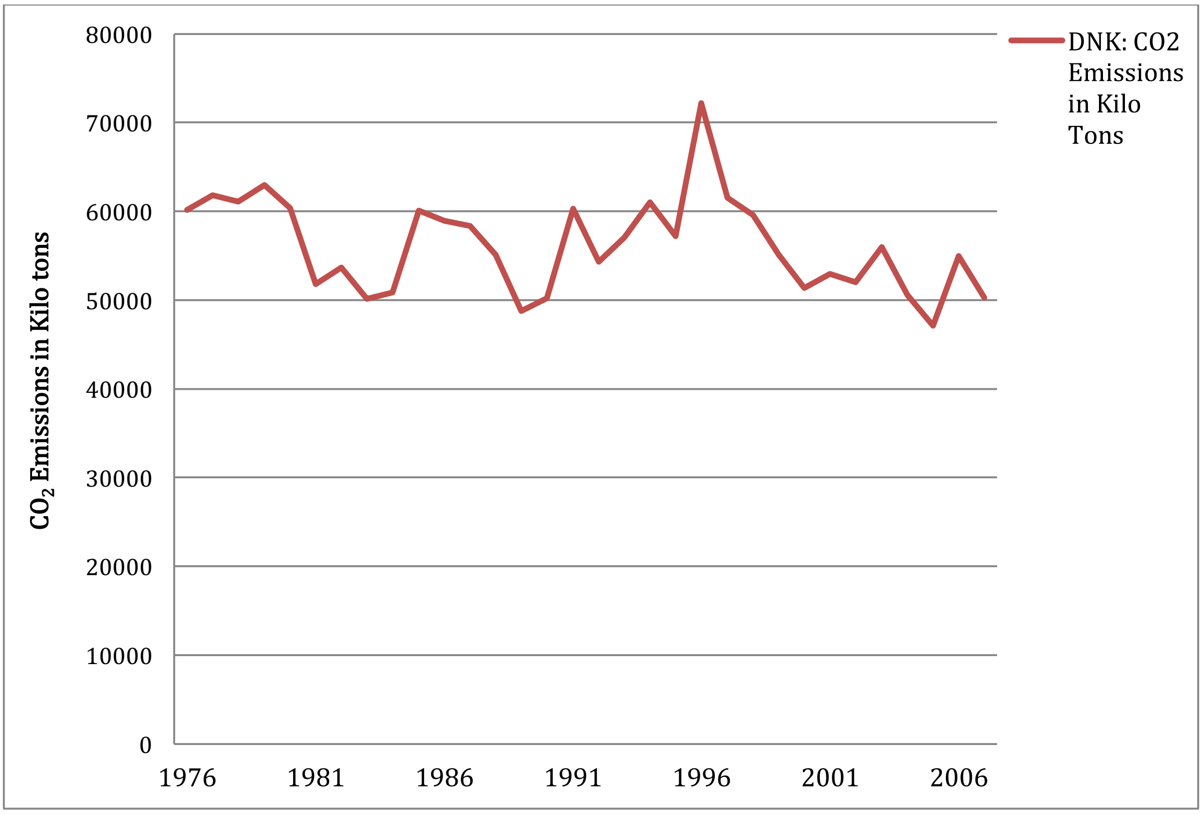


Figure A-3: **DNK: GDP at Market Prices (constant 2010 US$ in Billions) (1976-2007)**

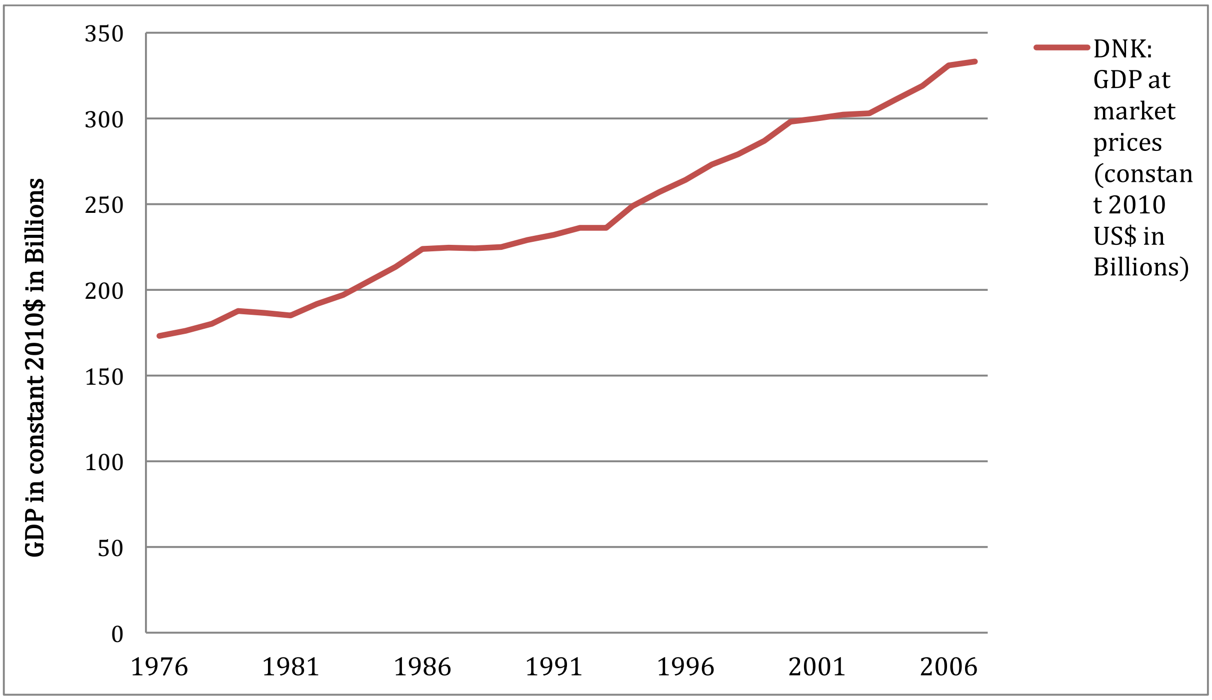


Figure A-4: **DNK: CO2 Intensity (1976-2007)**

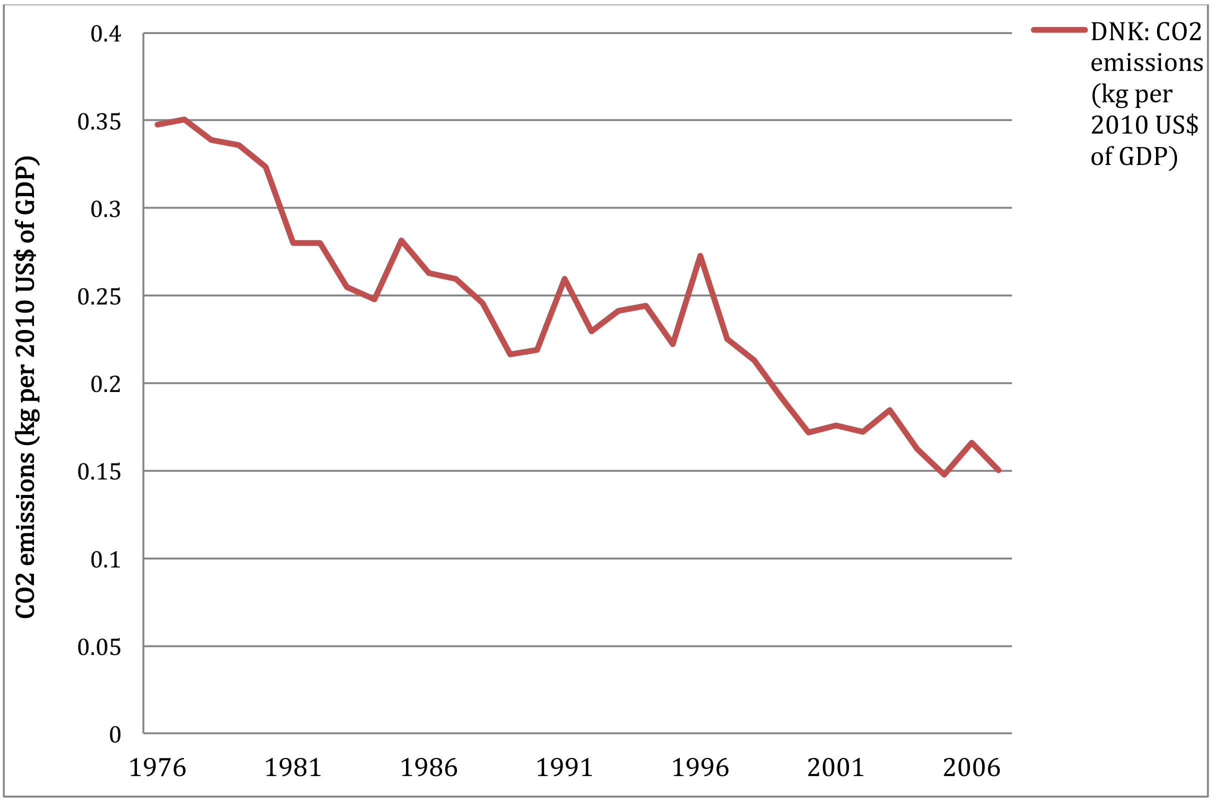


Figure A-5: **NLD: Energy Patents (1976-2007)**

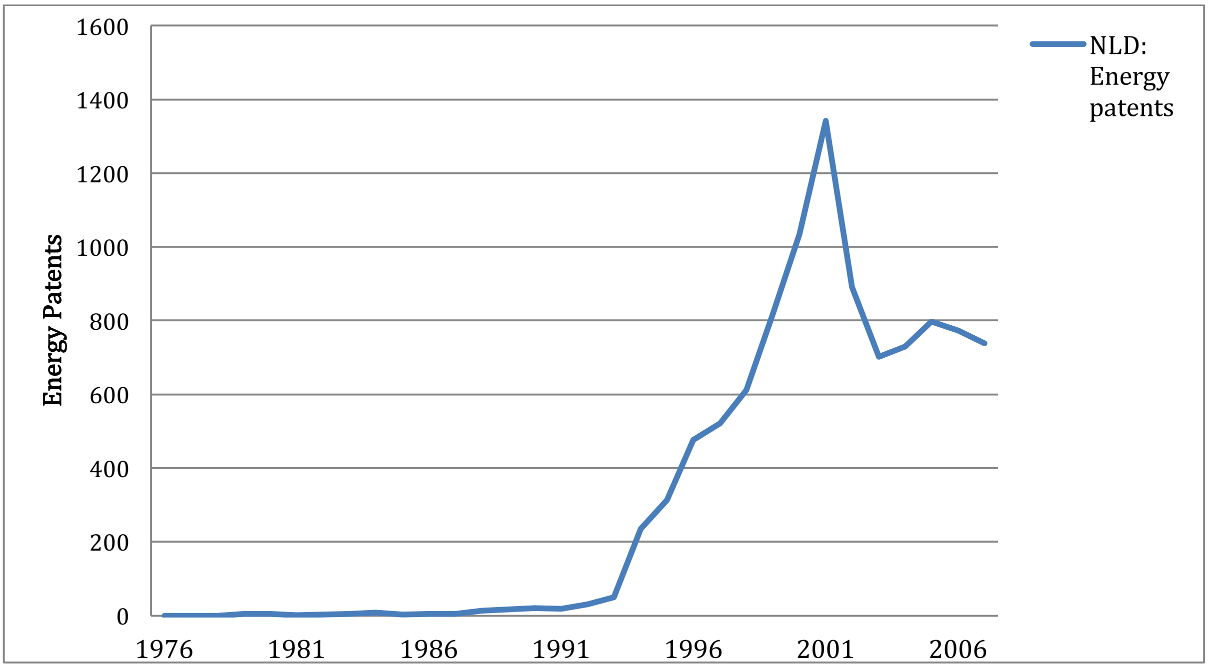


Figure A-6: **NLD: CO_2 Emissions in Kilo Tons (1976-2007)**

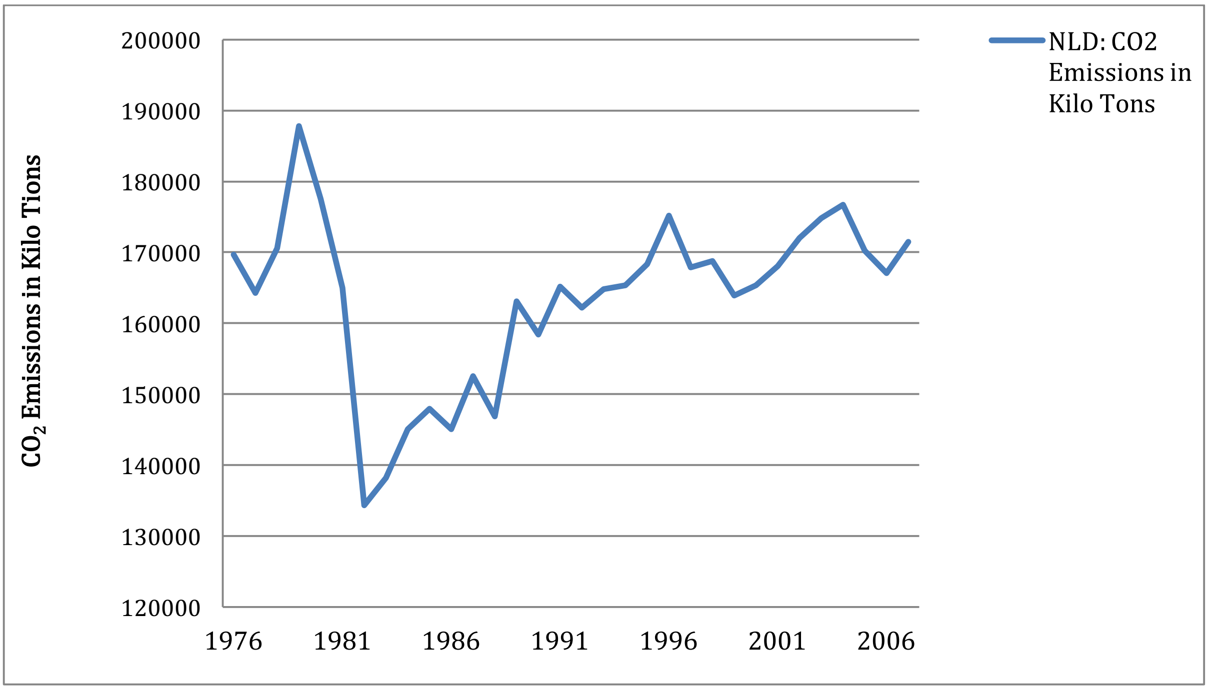


Figure A-7: **NLD: GDP at Market Prices (constant 2010 US$ in Billions) (1976-2007)**

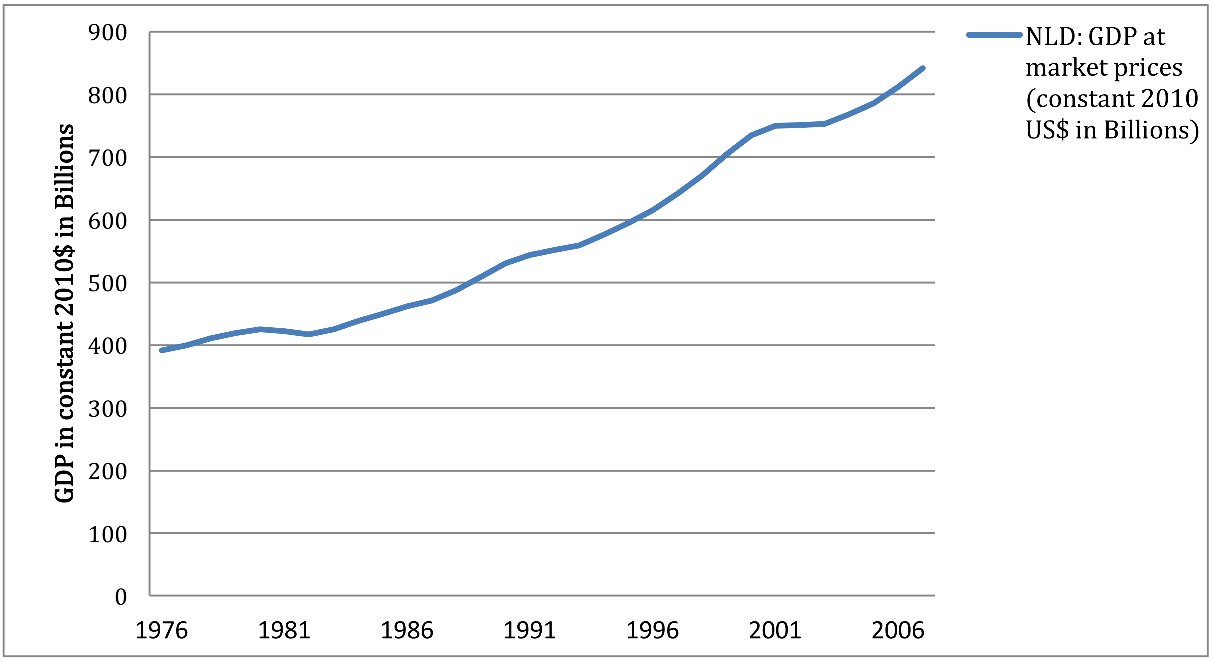


Figure A-8: **NLD: CO_2 Intensity (1976-2007)**