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The role of energy in economic growth: A comparison between Denmark and Norway 1960-2012

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Abstract: The aim is to study the role of energy in economic growth in two Nordic countries, Denmark and Norway. Both countries are welfare states with high living standards but with different energy supply structures. The overall research question is broken down in six hypothesis and the causal relationship between energy consumption and economic growth is determined by Granger causality tests. The role of energy in economic growth seems to be different in Denmark and Norway, at least during the period 1990-2012. The development in Norway might be taken as evidence for the mainstream economic theory where energy only plays an intermediate role while the Danish development seems to be more in line with the ecological economic view where energy has a central role. The results for Denmark also support the fact that causal relationships may change over time. Possible explanations to the different development in Denmark and Norway might be differences in the energy supply structure and the different development of the structure of their economies. The relative scarcity of domestic energy endowments in Denmark compared to the more abundant access to energy, particular electricity, in Norway seems to have promoted growth of the industry sector with high energy intensity.

Key words: Energy consumption, economic growth, Granger causality, energy intensity, structural change, Denmark, Norway.

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Content

1 Introduction and background

1.1 The role of energy

Energy has always been an important factor for the society and mankind and energy use has increased over time. This is particular true since the first industrial revolution took off in the 18^{th} century in UK where coal played a key role. The use of energy has significantly increased over the past 200 years and economic growth has in parallel shown a strong and remarkable development. The fact that energy use, directly or indirectly, plays an important role as a production factor in economic growth is not disputed (Stern, 2011).

In the literature on energy and economic development the role of energy has been discussed from basically two different viewpoints (Toman and Jemelkova, 2003). The first one is that the economic development affects energy use and is manifested by the theoretical approach by Solow in the 1950s (Solow, 1956). The Solow theory does not explicitly include energy in the model but regard energy use as an exogenous variable which could substitute labor and/or capital. The second viewpoint, supported by ecological economists, is that energy use plays a central role in economic growth and therefore, as an important driver of economic growth, ought to be an endogenous variable in any theoretical model. Efforts to combine the different views in a more general theory has been made (Stern, 2011). However, the decisive question is still today if energy use causes economic growth or if it, eventually, is the other way around.

1.2 Causal relationship

The causal relationship between energy use and economic growth is of importance when it comes to policy making. An illustrative example is if energy use causes economic growth in a country and the country introduces an energy policy which restrict energy use. In this case the policy would harm the economic growth in the country and be contra-productive. In the reverse case, when economic growth causes energy use, an energy policy aiming at lower energy use would not be harmful for economic growth. The importance of the causal relationship between the use of energy and economic growth is further stressed by the current debate about climate change. Primary energy use is always connected with a certain environmental impact and in the case of fossil fuel use the outlet of carbon dioxide is crucial. Different ways to reduce the outlet of carbon dioxide are available like higher conversion efficiency, fuel substitution and even capturing of carbon dioxide. But another way to reduce the carbon dioxide outlet and thereby reduce the impact on climate change is of course to use less fossil energy. This fact implies that it is important to understand the causal relationship between energy use and economic growth. A policy to reduce carbon dioxide outlet through reduced energy use will harm the economic growth in the country if energy use causes economic growth.

An analytical investigation of the causal relationship between the energy use and economic growth by the mainstream theoretical models or the ecological models briefly mentioned is normally quite complex and therefore an empirical/statistical approach is often chosen to study causal relationship and the role of energy use in economic growth. Application of the Granger causality test to find out if energy causes economic growth or vice versa is quite common. This is a way to find out if there is a significant causal relationship between energy use and economic growth. The relationship between energy use and economic growth can be unidirectional, bidirectional or neutral. This means there is four possible outcomes of a Granger causality test (Bozoklu and Yilanci, 2013). First, energy use Granger causes economic growth. Second, economic growth causes energy use. Third, there is mutual causation between energy use and economic growth at the same time (bidirectional). Fourth, there is no causation in either direction (neutrality).

The Granger causality test can be used in different contexts. In the literature basically three different approaches can be found. The most basic approach is the bivariate VAR (Vector Auto Regression) model together with Granger causality tests. In this case only energy use and economic growth is considered. An alternative to the bivariate VAR model is the multivariate VAR model. In this case further variables are introduced to avoid misspecification biases. Here the variables from the Solow model, labor and capital can be introduced but also other variables like energy prices or human capital to mention a couple of examples (Stern, 2011). The time series for economic growth and energy consumption covers often only a few decades and are relatively short. The power of the tests can be challenged due to short time series. One way to improve the power of the causality tests is to employ VAR and Granger causality tests in a panel environment. The dimension of time is complemented by the cross sectional dimension. In practice this means that further countries are added and analyzed during a certain period of time (Ozturk, 2010).

1.3 The overall research question

The level of development and the energy supply structure are specific for a country and may play an important role for the causality between energy use and economic growth. The aim in this paper is to study the role of energy in two developed countries in the Nordic region, Denmark and Norway. Both countries are welfare states with high living standards but with different energy supply structures. The overall research question is to find the role of energy, in terms of causal relationships, in economic growth in both countries and then to compare the countries to find possible explanations to potential differences with focus on the time period 1960-2012. The main contribution of this paper is an analysis of the countries by sectors that has not been found in the literature and a direct comparison of two neighboring countries with different energy supply structures, also not found in the literature.

1.4 Outline of paper

In the next section a brief literature review will be presented with papers with focus on the general causal relationship between energy use and economic growth and a couple of OECD studies including Denmark and Norway. This section is followed by a description of the energy supply structure in Denmark and Norway to give a background to the discussion of the result. The following section describes growth theory and focus on the role of energy in economic growth and the mechanisms involved. The choice of methodology is then discussed in the next section. After that the research question is broken down in a number of hypotheses to be investigated. The following section describes the data sources and the properties of the time series (variables) to be used. The next section presents the testing procedure and is followed by two sections where the results of the investigation are presented. The paper is finalized by a section where the results are discussed and a section with conclusions. Detailed results are presented in Appendix 1 to 4.

2 Literature review in brief – focus on causal relationships

2.1 General observations

The studies of the causal relationships between energy consumption and economic growth in the literature can roughly be divided into three groups (Akinlo, 2008). In the first group the studies which indicate unidirectional causality (from energy to economic growth or the reverse) are included, the second group includes studies which indicate bidirectional (in both directions) causality and in the third group, studies are found, which indicate that there is no causal relationship in either direction (neutrality). In the case of unidirectional causality it is important if energy causes economic growth or the other way around. If energy use Granger causes economic growth it indicates that if energy use is restricted this may affect the economic growth in a country negatively, while in the reverse situation economic growth will increase energy use. In the case of bidirectional causality the energy use and economic growth affect each other at the same time (Jumbe, 2004). The absence of a Granger causal relationship implies that a change in either energy use or economic growth does not affect the other variable. In the real world causal relationship between energy use and economic growth plays an important role for i.e. policy making in the energy sector.

Several scholars have studied the causal relationship between energy use and economic growth by using Granger causality tests. There is no general consensus about the answer to the causal relationship between energy use and economic growth. The results seem to be dependent on context, methods applied, definitions and specification of variables and level of development in the studied country. In a paper by Chontanawat et al (2006) at least an indication to an answer can be found. The Granger causality between energy use and economic growth was tested in this paper by a bivariate VAR model for 30 OECD and 78 non-OECD countries. For most countries data from 1960-2000 was used but the times series in some cases were shorter (the shortest from 1976-2000). The conclusion is that energy use Granger causes economic growth more prevalent in the developed countries than in the developing countries. In numbers it can be expressed as the Granger causality in the OECD countries in 69 % of the cases goes from energy use to economic growth but in developing countries it is only about 40 %, depending on the level of development (Chontanawat et al, 2006).

In most studies the time series are relatively short, as mentioned above. This might reduce the power of the tests. In a recent study the Granger causal relationship between energy use and economic growth in Sweden has been studied using a data set from 1850 to 2000 (Stern and Enflo, 2013). In addition, the sub-periods 1900-2000 and 1950-2000 have been analyzed. Bivariate as well as multivariate VAR methodologies have been applied in this paper. One interesting conclusion is that the causal relationship may have changed over time as energy use Granger causes economic growth over the full period (1850-2000) while economic growth Granger causes energy use during the period 1950-2000. This may indicate that the causal relationship does not have to be stable over time. This means that structural breaks may occur over long time series and a new challenge is introduced as structural breaks in many cases are not so easy to detect. In addition to the problems mentioned above, like choice of methodology and definition and specification of variables, structural breaks are a further problem. The possibility that causal relationship may change over time is a challenge to scholars when long time series are used to increase the power of the tests.

2.2 Denmark and Norway – a few earlier results

There is no specific studies with focus only on Denmark and/or Norway found in the literature. However, there is studies of groups of countries where Denmark and Norway are included. A brief summary of a couple of these studies will be presented here. In the study mentioned above by Chontanawat et al (2006) Denmark and Norway are included in the OECD group. The outcome of the study is that there is evidence of causality, energy consumption to GDP, in both countries but the variables are only co-integrated in Norway. The variables are in both countries integrated of order one. The method applied is bivariate and uses Granger causality tests and the Hsiao procedure. The time series cover the period 1960 to 2000.

In a more recent paper the causal relationship between energy consumption and real economic growth in OECD countries has been examined (Bozoklu and Yilanci, 2014). The results of traditional Granger causality tests show that neutrality is valid for both Denmark and Norway. This implies no causal relationship between energy consumption and real economic growth in either direction. The time series for Denmark cover the period 1966 to 2011 and Norway 1970 to 2011. In addition, frequency causality tests are performed to capture the time varying nature of the causal relationship mentioned above. The results of the causality tests indicate that the conservation hypothesis dominates for both Denmark and Norway. This means that a reduction of energy consumption in both of the countries will only have a minor short run effect without any negative impact on economic growth.

In these two investigations the causal relationship between energy consumption and real economic growth seems to be different. In the next the energy supply structure in both countries will be briefly reviewed to find out potential differences.

3 Energy supply structure in Denmark and Norway

3.1 General

Denmark and Norway are two neighboring countries in the Nordic region and considered part of the western sphere. Both countries are small with a population around 5 million and dependent on international trade. They are both members of OECD while only Denmark is an EU member, though Norway has an association agreement. The OECD Better Life Index shows that the countries are among the most developed in the world (OECD, 2015). Norway is ranked as second in the world after Australia and Denmark is ranked in the fourth place. The score behind the ranking is based on 11 different areas (like income, education and health care). Their top positions are confirmed in the World Development Index (WDI) published by UN (World Bank Data, 2015). The development of population and economy over the period 1960 to 2012 are shown in Table 3.1.

Table 3.1 Population in millions (Pop) and real GDP in 2005 US$ per capita (GDP) in Denmark and Norway in 1960, 1990 respectively 2012. Source: World Bank Data.

Variable	Denmark	Norway
Pop 1960	4.580	3.581
Pop 1990	5.141	4.262
Pop 2012	5.592	5.019
GDP 1960	17226	17332
GDP 1990	36964	45858
GDP 2012	47640	65616

The facts show that the real GDP per capita in 1960 was about the same level for Denmark and Norway but that Norway has had a faster economic growth than Denmark during the period 1960-2012. During the same period the population in Denmark has increased roughly by a million and in Norway by almost one and a half million.

3.2 The energy supply structure in brief

The conditions and historical background for the energy supply structure in the countries are quite different. The topology in Denmark is very flat while it is the opposite in Norway. The mountains in Norway have created an opportunity for expanding hydro power production in the country while these opportunities in Denmark are very rare. Denmark has therefore relied on imported energy, particular coal in the past, to a higher extent compared to Norway. The development of total energy consumption per capita, percentage of fossil energy consumption of total and final consumption of electricity per capita during the period 1960-2012 are shown in Table 3.2.

Table 3.2 Energy use per capita in kg of oil equivalent (EUC), fossil energy consumption in percentage of total (FE) and electricity consumption per capita in kWh (ECC) in Denmark and Norway 1960 and 2012 (2011). Source: World Bank Data.

Variables	Denmark	Norway
EUC 1960	1923	1906
EUC 2012	3048	5942
FE 1960	99.87	60.50
FE 2012	70.58	57.27
ECC 1960	1089	7681
ECC 2011	6122	23174

This shows that the energy consumption per capita was at about the same level in Denmark and Norway in 1960 but in 2012 the total energy consumption has increased, though much more in Norway. In 2012 the total energy consumption per capita in Norway is almost twice as in Denmark. In 1960 Denmark was close to totally dependent of fossil energy while Norway only had about 60 % dependence. The electricity consumption per capita was in 1960 more than seven times higher in Norway which has been reduced to about 4 times in 2011. This might be explained by the favorable conditions for hydropower in Norway. Both countries have reduced their dependence of fossil energy. However, the reduction is much more substantial in Denmark.

The dependence of fossil energy has been reduced during the period considered in this paper. Denmark found natural gas in the North See and started to produce gas in the beginning of 1980s. These resources have peaked during the period and are declining today. Norway found both oil and natural gas in the waters outside the coast and started to produce during the 1980s as well. The volume of oil and natural gas reserves in Norway is much larger than in Denmark (EIA, 2015).

The oil crises in the 1970s and the emerging awareness of the risk for climate change in the beginning of the 1990s has started a debate about burning fossil fuels. The use of fossil fuels contribute to a higher concentration of carbon dioxide in the atmosphere which promotes the global warming. Denmark and Norway have both adopted energy policy measures to cut the outlet of carbon dioxide. Denmark, as most dependent of fossil fuels, started by promoting wind power and the use of renewable fuels already in the 1980s with the ambition to establish a wind power industry. The wind power generation was about 25 % of the total electricity power generation in Denmark in 2014. Norway, less dependent of fossil fuels, started later to promote wind power and other renewable technologies. Today both Norway and Denmark are supporting renewable technologies outside the sector of hydro power generation. Here it is important to stress that what said above is related to the final consumption of energy at home. Norway is a major player when it comes to export of oil and natural gas and the Norwegian economy is dependent on revenues from oil and gas to a great extent. The value of the export of natural gas from Denmark is, in comparison with Norway, much smaller (EIA, 2015).

3.3 The development of energy intensity

The energy intensity is defined as the ratio between energy per output. The total final energy consumption in relation to GDP is one measure, another one is final electricity consumption to GDP. In Table 3 both measures for Denmark and Norway are shown for 1960, 1990 and 2012 in Table 3.3.

Table 3.3 Energy intensity (total) in kg oil equivalent per unit constant 2005 US$ (EIT), energy intensity (electricity) in kWh per unit constant 2005 US$ (EIE) in Denmark and Norway 1960, 1990 respectively 2012 (2011). Source: World Bank Data.

Variable	Denmark	Norway
EIT 1960	0.0244	0.0307
EIT 1990	0.0178	0.0261
EIT 2012	0.0144	0.0180
EIE 1960	0.0138	0.1237
EIE 1990	0.0313	0.1232
EIE 2011	0.0228	0.0724

The total energy intensity shows a declining trend over the period 1960 to 2012 in both Denmark and Norway after about 1970 in Figure 3.1.

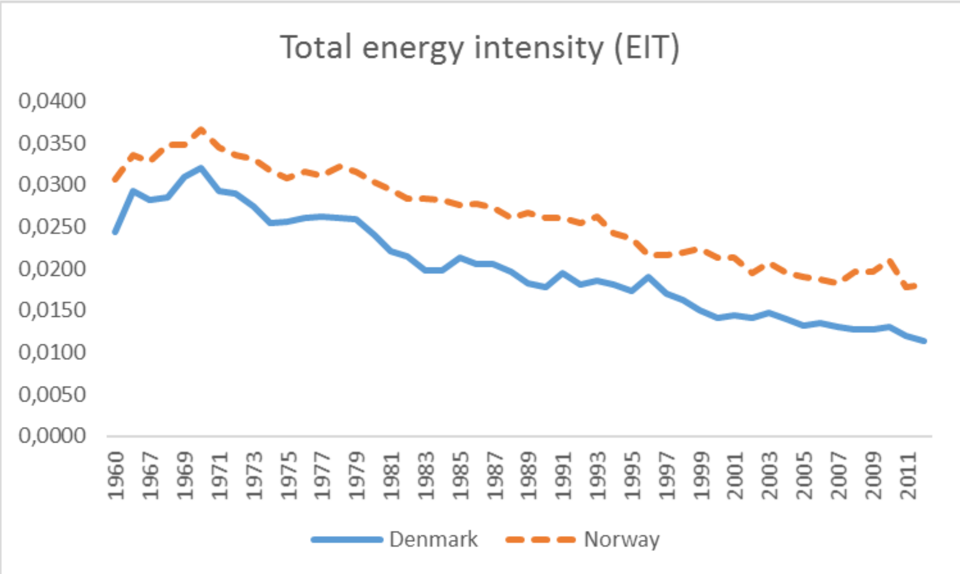

Figure 3.1 Total energy intensity in Denmark and Norway 1960-2012. Source: World Bank Database.

The downward trend is similar but Norway remains on a higher level over the whole period. However, the electricity intensity in Norway shows a different pattern compared to Denmark in Figure 3.2. The trend in Norway is clearly declining at least since the early 1970's. In Denmark the trend seems to be slightly positive up to the early 1990's when it starts to decline. The electricity intensity is significantly higher in Norway compared to Denmark. However, the gap between the countries is declining over the period 1960-2012, but is still substantial in 2012.

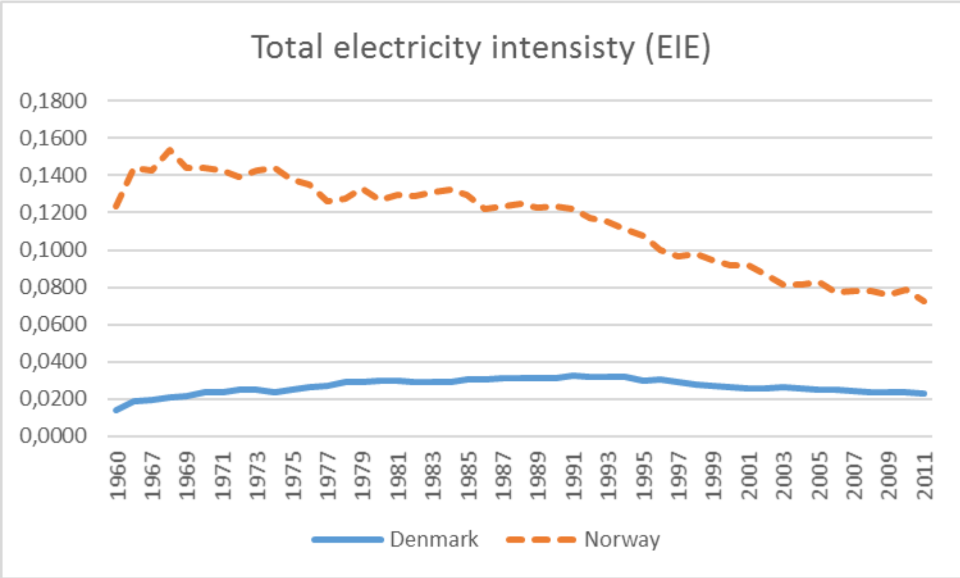

Figure 3.2 Electricity intensity in Denmark and Norway 1960-2012. Source: World Bank Database.

The energy intensity may be calculated by sector (data only available from 1990) for the period 1990 to 2012. The sectors considered are industry, transport and residential. These sectors covers the main part of the total energy consumption in both countries. See Table 3.4 below.

Table 3.4 Energy intensity industry sector (EII), energy intensity transport sector (EIT), energy intensity residential sector (EIR) in kg of oil equivalent per unit constant 2005 US$ for Denmark and Norway 1990 respectively 2012. Source: Eurostat Data Base.

Variable	Denmark	Norway
EII 1990	0.0142	0.0328
EII 2012	0.0089	0.0191
EIT1990	0.0213	0.0207
EIT 2012	0.0187	0.0163
EIR 1990	0.0212	0.0194
EIR 2012	0.0167	0-0134

The definitions of energy consumption used by Eurostat and World Bank are different (See Appendix 1). Therefore a direct comparison with data in Table 3.3 is not possible. In general energy consumption in the considered sectors declines over time. The industry sector shows the major difference between the countries. Norway had in 1990 more than two times higher energy intensity in the industry sector compared to Denmark and this relationship remains in 2012, though on a much lower level. In the transport and residential sectors the energy intensities are more equal in 1990 and the reductions are less substantial. The numbers suggest that Norway has reduced the energy intensity in these sectors a bit more compared to Denmark during this period.

3.4 Structural change in output

The energy supply structure may also be related to output in an economy. The output has changed over the time period and can be described as the change in the value added in percentage of GDP for the sectors agriculture, industry and service. The industrial revolution imposed a shift from agriculture to industry and more recently a shift from industry to service has been recognized. Agriculture is today only a few percent of GDP in Denmark and Norway. Data for the full period 1960-2012 is not available in the World Bank Data set, but the available data is presented in Table 3.5.

Table 3.5 Structural change in Denmark and Norway 1970-2012 as value added in percentage of GDP. The percentage of industry and service sectors are given and together with the agriculture sector it sums up to 100 %. Source: World Bank Data.

Variable	Denmark	Norway
Industry 1970	n. a.	30.76
Industry 1990	26.13	33.36
Industry 2012	23.11	40.02
Service 1970	n. a.	63.35
Service 1990	70.09	63.22
Service 2012	75.10	56.80

The composition of output has changed over time but interestingly in different directions. In Norway the value added of industry output has increased and the service sector has decreased, expressed as percentage of GDP, while the opposite development can be seen in Denmark. The Danish development is more in line with what might be expected.

3.5 Conclusion

In conclusion, the energy supply structure in Denmark and Norway was quite different in 1960 but the real GDP per capita and total energy consumption per capita were about the same. Denmark has changed its energy supply structure substantially since 1960, from a dependence of almost 100 % of fossil energy to about 70 % today while the dependence of fossil energy in Norway only has declined from about 60 % to 57 %. Energy intensity and electricity intensity are in general higher in Norway and both show a declining trend since the 1990's. The energy intensity by sector implies that industry in Norway is more energy intensive than in Denmark. In Norway the energy intensive industry is more prevalent than in Denmark. The structural development in the countries seems to confirm that the development goes in different directions. The increase of the industry sector, in terms of value added, might be one reason for the higher energy intensity in Norway.

The real GDP per capita during the period 1960-2012 shows a clear divergence, though both still are ranked among the wealthiest in the world. This is a part of the background to study the role of energy in the countries. The theory for the study is outlined in the next section.

4 Growth theory – the role of energy in economic growth

4.1 Theoretical considerations

The role of energy in economic growth is not easily explained as indicated in the introduction section in this paper. The mainstream of economists has their origin in the Solow theory and consider the role of energy in economic growth as indirect. However, they are challenged by ecological economists which claim that the role of energy is much more central and has a more direct impact on economic growth. In order to discuss the role of energy in economic growth the potential linkages between energy and economic growth in these different theoretical approaches first have to be briefly reviewed.

The classical economic growth theory recognizes labor and capital as the most important inputs to the process of production and energy as such is not treated as a production factor. Energy is considered as an intermediate product of labor and capital. The general approach to intermediate products, not only energy, are that those products are created during the process of production and are also entirely used up during the process. This approach make a distinction between intermediate (energy) and primary input (labor and capital) to the production process. The primary production factors exist at the start of the production process and may be degraded but are not entirely consumed. A machine is a typical example of degradation of physical capital. A primary production factor may also be expanded during the process. An example here is labor as the quality of labor may increase during the process by learning (Mallick, 2009).

The consequence of this approach with primary and intermediate production factors is that energy does not have any direct impact on economic growth. The availability of energy and the price of energy would hardly have any impact on economic growth (Mallick, 2009). As one major assumption in this theory is that there is no effects on return by scale the capital will diminish. The economic growth is instead to a great extent related to technological progress. This factor is regarded as exogenous and automatic. The effect of the oil crises in the 1970’s fuelled the debate of the role of energy in economic growth and the classical theory of growth.

The high oil prices were followed by an economic downturn and the opponents to the mainstream economists claimed that energy played an important role in this process. The defenders of the mainstream thinking argued that the cost share of energy compared to other inputs in the production process is relatively small and that the impact of high energy prices on economic growth is low (Okun, 1974). This view was supported by others and the additional argument raised that energy is only one of many components in the process of production and that it is not likely that high prices on energy may impact productivity and economic growth (Perry, 1977). These arguments do also support the belief that higher energy prices will substitute labor for capital without any impact on production and economic growth (Ebohon, 1996). The counter argument to this is that even if energy and labor may be substituted the complementarity between energy and capital increases the importance of energy for the production process more than its cost share implies (Berndt and Wood, 1975). However, there is no consensus among scholars on the relationship between energy and capital.

In the mainstream economic thinking energy plays an insignificant role in economic growth as has been illustrated by the brief discussion above. The conclusion is, energy availability or energy prices cannot explain economic recessions as a consequence of energy price spikes. As the impact of high energy prices on capital and technology progress is not obvious the remaining explanation is reduced to labor hours. The reduced number of labor hours is then rather a consequence of a recession than a cause of one. Economic recessions are a known fact of the economic life and may be caused by a number of factors. Such a factor may be energy price spikes (Ayres et al, 2013). This is one reason for ecological economist to believe in a more central role of energy in economic growth. Another reason for this belief is that there is no substitute for energy though some energy carriers may be replaced by others (Stern, 2011). Labor nor capital can function without energy inputs. Energy as food is a basic requirement for laborers and the use of production factor capital require fuels for engines, electricity generating, communication and most appliances. The dependence of fossil fuels in the economy has been and is still high.

The emerging physical restriction of fossil energy can be illustrated by the energy return on energy investment (EROEI) ratio. This ratio has be declining since the 1930’s and when it reaches unity energy ceases to exist in economic terms. The cost of extracting energy will be equal to the benefits of the energy in the economy. The energy prices will continue to raise as the EROEI decreases towards unity (King and Hall, 2011). At unity the remaining fossil energy resources will not be extracted. This discussion illustrates that the scarcity of energy is leading to higher energy prices and will support the insight that energy is more important than indicated by the cost share discussed above.

Further, the argument based on the low cost share, elaborated on above to support the classical growth theory, does not hold (Ayres et al, 2013). The cost share theorem says that the output elasticity of a production factor must be proportional to its cost share. Applying this theorem on a food production system and recognizing that the factor fresh water only account for a very small part of economy it is vital to the entire economy, even if the production of food would be a minor part of the economy. The production function labor would not function without food and as there is no substitute there would be no economy at all. The historical evidence from periods of famines is that prices on food would increase and the relative contribution of to the economy would rise. The same argument can be applied to energy (Ayres et al, 2013).

In the theoretical approach by the classical economist the Cobb-Douglas production function often plays a central role. The assumptions behind the Cobb-Douglas function are constant returns to scale and constant output elasticity. The historical evidence from the US economy with close to constant cost shares might by first sight seems to justify the rather simple Cobb-Douglas function. However, as discussed above there seems also to be good reasons to challenge the Cobb-Douglas production function.

Ayres et al (2013) have specified an alternative production function taking into account the technological constraints in reality. These constraints limits the substitution between the factors of production and this is particular true if energy is considered as a production factor together with labor and capital. The constraints may be “hard” and “soft”. The “hard” ones can be exemplified by the fact that a machine can only use the amount of energy corresponding to the maximum utilization. Further, the degree of automation is limited by the technological possibilities. The “soft” constraints may refer to financial, organizational, legal and even social constraints. An introduction of these constraints in a theoretical model suggests that the output elasticity and the cost share does not have to be constant. If they are removed the result will be the same as with the Cobb-Douglas production function. The conclusion is that the role of energy contributes significantly more to economic growth than the cost share of energy suggests (Ayres et al, 2013).

The theoretical approaches discussed above result in different and conflicting conclusions regarding the role of energy in economic growth. In the mainstream economic view energy is considered as an intermediate factor and has only a marginal role while in the ecologist view energy is key and the importance is central and much larger than its cost share. The role of energy, as long as energy is abundant, seems to fit with the mainstream view, but when energy get scarce it fits better with the ecological view (Stern, 2011). In the next the focus will be shifted to the linkages between energy and economic growth.

4.2 Mechanisms – linkages between energy and economic growth

The theoretical considerations indicate that energy as a factor of production plays a role in economic growth. Further, that the availability of energy could constrain economic growth when the relative abundance of energy change to a situation of scarcity. But there are also empirical studies which suggest a decoupling between energy and economic growth (Stern, 2011). The energy consumption in many countries grew much slower after the first oil crises in 1973 although a significant economic growth. The result in the developed countries can be seen as a declining trend in the energy intensity (ratio energy/GDP). But does these facts imply that there is no linkage between energy and economic growth?

Stern (2011) has in a paper discussed the relationship between energy and aggregated economic output with a production function approach (Stern, 2011). The production function in his paper can be written in a general form:

$$Q = f(A, X, E)$$

where Q represent various outputs like goods and services, X various non-energy inputs like labor and capital, E various energy inputs like oil and coal and A the state of technology like TFP (Total Factor Productivity). The outcome is that the linkages between energy and economic growth can be found in four areas. The first one, substitution between energy and other inputs. The second one, technology change. The third one, shifts in the composition of energy input. The fourth one, shifts in the composition of the output (Stern, 2011). In the following these areas will be further discussed.

4.2.1 Substitution between energy and other inputs

The linkage between energy and other inputs like capital and labor may be illustrated by the following discussion. If the price of energy increases the response in the production process is likely to be to use less energy. That could be done by putting more capital into the process and thereby substitute energy by capital or more labor to compensate with more manual work. As the latter seems less likely less energy use may be reached by more efficient machines and systems, if such are available. There is at least in the short term perspective a limitation to such a substitution of energy by capital. The limit is set by the best available technology at the time. In the long run the potential for substitution may be higher as the technological level will be improved by innovation. Another aspect besides the price aspect is that energy may be a complement to capital and augment the value of capital in the production process. There is a vast amount of literature which discuss if energy is a substitute or complement to capital (Stern, 2011). In conclusion, it seems that energy and capital are rather poor substitutes short term but long term much better as the capital stock is renewed (Stern, 2011).

The linkage between energy and labor indicated above is that manual labor work in the past has to a great extent been replaced by capital (machines) and energy. Therefore energy can be considered as an indirect substitution for labor. However, the automation is not likely to be reversed and the focus is on energy and capital.

4.2.2 Technology change – a change in TFP

As indicated above high energy prices can be a driver of technology change. But innovation as well as energy policy are other potential drivers for technology change in the energy sector. Technology changes that are not related to energy prices are called changes in the autonomous energy efficiency index (AEEI) (Kaufmann, 2004). The energy efficiency as a measure for the ratio between energy consumption and GDP has declined in most countries over time but the impact of AEEI is mixed (Jorgenson and Wilcoxen, 1993). This indicates that price of energy plays an essential role in technology change. An increase in energy prices tend to accelerate the development of energy saving technologies and vice versa. The effect of higher energy efficiency and accelerated TFP growth may result in more efficient and cheaper consumer goods but also a rebound effect. This means that even if the energy efficiency is reduced the total energy consumption may increase. The industry sector works normally with energy saving and aims for higher productivity and offers products with better energy efficiency and lower price to the consumers. The demand from the costumers will then increase and the energy consumption in the household sector may increase and offset the savings in industry (Jorgenson, 1984). In conclusion, an essential link between energy and technology change seems to be the relative price of energy.

4.2.3 Energy quality and shifts in composition of energy input

The energy mix in a country is normally related to domestic endowment of primary energy resources or the lack of them. In the case of lack of domestic resources a country has to rely on import of energy. The energy quality, defined as the economic usefulness per heat equivalent unit, plays an important role as different energy forms have different physical properties. Examples on these properties are energy and power density and the impact on environment. But the ease of distribution and storage of energy also contribute to the relative quality. Some energy forms can be used in a large number of activities while others in fewer. Electricity in particular is an energy form which have the capacity to transform a workplace and change work processes and promote productivity in the economy. Shifts in the energy input tend to change the energy mix in the course of economic development. A country is said to move up the energy ladder (Hoiser, 2004). This means substitution of energy forms of lower quality by energy forms of higher quality. Shifts in the energy mix do also impact the energy intensity. Electricity is generally believed to be of the highest quality. In descending order followed by natural gas, oil, coal, wood and biofuels (Stern, 2001).

A step up on the energy ladder would be to substitute coal by oil and thereby lower the energy intensity. An investigation of the US economy shows that a shift away from coal use in favor of in particular oil use reduced the energy intensity over the period 1929-1999 (Kaufmann, 2004). But there might be limits to substitutions of this type as availability of natural gas and oil in the long run is likely to decline.

4.2.4 Shifts in the composition of output

The composition of output in an economy changes, as the composition of energy inputs, as the economic development proceeds over time. In the past there has been a shift away from agriculture to resource extraction and heavy industry. During the past decades the shift has been towards lighter manufacturing and services. This structural change of output in the economy is often believed to lead to a reduction in energy used per unit output (Panayotou, 1993). However, the rebound effect discussed above may challenge the belief that the effect of structural change may result in energy saving and lower energy intensity in the different sectors of the economy. The energy intensity in the household and service sectors may be more energy intensive than expected (Constanza, 1980). Households uses a wide range of different appliances in their daily life for which electricity is required. The service sector, at first glance, seems to have low energy intensity. But office towers and other locations where the activity is conducted require energy for construction, operation and maintenance. The expanding use of computers and internet in all sectors require high quality energy in form of electricity. The effect of internet on energy intensity has received a lot of attention. The dispersal of population made possible by internet may reduce commuting costs and act as energy conserving (Romm, 1999). A number of evidence counter this argument and an example is that the online book retailing business uses more energy than traditional one (Matthews et al, 2002). In conclusion, shifts in the composition of output in the economy does not by necessity have to lower energy intensity in all sector of the economy. The consumer sector shows rising energy intensity while the manufacturing sector shows the opposite over time (Judson et al, 1999). An investigation of disaggregated use of energy might show different trends in energy intensity.

4.3 From theory to reality

The discussion about linkages between energy and economic growth show that energy may promote growth by substitution (by other energy forms or other inputs like capital) but also by augmenting other inputs and driving technology change. Further, higher energy quality is supporting economic growth. The role of energy in the structural change of an economy is depending on the sector studied. The discussion so far has only been about the relationship between energy and economic growth. In order to discuss the role of energy the causal relationship between energy and economic growth is also of interest. This will be empirically investigated by analyzing the time series of energy and economic growth. Next the choice of methodology will be discussed.

5 The choice of methodology

5.1 Background

One of the methods used up to the early 1990's to identify the causal relationship was often the Granger causality test in a VAR framework. A number of scholars did at this time show that the conventional asymptotic theory used earlier was not applicable to hypothesis testing in a VAR framework in levels when the time series were integrated or/and co-integrated (Park and Phillips, 1989). In the case when time series have a unit root (not stationary) and are not co-integrated the first and eventually second differences have to be used for the variables in the VAR framework to make it possible to rely on the conventional asymptotic theory in the hypothesis testing. The use of variables in a differenced form in the VAR framework results in loss of valuable information about the long term relationship and is clearly a drawback in causality testing. Further, in the case of co-integration between variables an error correction model (ECM) has to be specified to deal with the co-integration properties in the variables. In these situations a number of pretests have to be performed and as pretests do not always have a high power the risk of biases in these tests are obvious. Therefore the "standard" Granger causality test in the VAR framework with the variables in levels is not fully reliable as it suffers from a number of weaknesses.

5.2 Toda-Yamamoto methodology

Toda and Yamamoto proposed in a paper 1995 an augmented version of Granger causality for the test of causal relationship between time series to avoid the shortcomings of earlier methods. Their methodology can be applied to the variables in the VAR framework even if they are integrated up to order 2 or/and co-integrated. This means that the variables can be used in levels without any loss of information and that a co-integration relationship between the variables does not matter. The augmented version of the Granger causality includes the Wald statistics which is asymptotically chi-square distributed. The optimal lag length (k) in the VAR framework has then to be increased by the maximal order of integration (d_{max}) of the variables (Toda Yamamoto, 1995).

5.3 The choice

In the introduction of this paper three different classes of VAR models were mentioned. The panel VAR model is not convenient as the aim in this paper is to compare two countries. The choice is then between a bivariate and a multivariate approach. As the time series available are relative short the bivariate VAR model is chosen here together with the augmented Granger causality test proposed by Toda and Yamamoto to find out the causal relationship between the variables energy and economic growth (Toda and Yamamoto, 1995).

The chosen functional form of the variables is log-log and the specification of the bivariate VAR model can be written as in equation 1 and 2:

$$Y_t = a_0 + \sum_{i=1,N} b_i{*}Y_{t-i} + \sum_{i=1,N} c_i{*}E_{t-i} + u_t \qquad (1)$$

$$E_t = d_0 + \sum_{i=1,N} e_i{*}Y_{t-i} + \sum_{i=1,N} f_i{*}E_{t-i} + v_t \qquad (2)$$

where Y = log(economic growth), E = log(energy consumption), N = number of lags, a_0 and d_0 are constants, b_i, c_i , e_i and f_i are the coefficients and u and v are white noise with zero mean and constant variance.

The number of lags, N, in the VAR model is the sum number of lags (k) derived from an information criteria and the maximal order of integration (d_{max}) of the variables in the VAR. In the causality test by the augmented Granger, however, only the number of lags derived from the information criteria is used (Toda Yamamoto, 1995).

5.4 Definition of Granger causality and null hypothesis

The simple definition of Granger causality, assuming two time series variables Y and E is that Y Granger causes E if E can be better predicted by using both the time series (Y and E) than it can by using only the time series of E. In practise the test for Granger causality is performed as a non-causality test. The null hypothesis is that the coefficients c_1 to c_N are all equal zero in equation 1 above. This implies no causality as the coefficients for E are all zero and E does not help getting a better prediction of Y. However, if the null hypothesis can be rejected in this case, meaning that the coefficients for E are not all zero, E impacts the estimation of Y and it can be stated that E Granger causes Y. Then the corresponding test is performed for the coefficients e_1 to e_N in equation 2 above. If the null hypothesis cannot be rejected Y does not Granger causes E. However, if the null hypothesis can be rejected the conclusion is that Y Granger causes E and that means that using Y gives a better prediction of E.

The statistical package used in this paper is STATA13C which offers the augmented Granger causality test in a VAR framework.

5.5 Strengths and weaknesses with the chosen approach

The strength of the Toda-Yamamoto methodology is that the variables can be used in levels and the long run information in the time series can be kept. Simplicity is a further strength as the method only requires extra lags in the formulation of the VAR model. At the same time this may be a weakness as the addition of extra lags risks to over fit the model. This might result in some loss of power, especially in the case with many variables and with a true lag length of one. However, the risk of biases in pre-tests of unit root and co-integration may be more serious (Toda and Yamamoto, 1995). The strengths seems to outperform the weaknesses.

The choice of a bivariate VAR system with only two variables is easy to handle and that could be seen as a strength. However, this might be a weakness if important variables are omitted. The omitted information will then be found in the error term and the power of explanation is then reduced.

6 The research question – formulation of hypotheses

The role of energy in economic growth is often defined as the impact of final energy use in a given country during a given period of time. The overall research question in this paper is to study the role of energy in Denmark and Norway and to compare the results to identify potential differences between the countries. The research question is broken down in a number of hypotheses for both countries for a given time frame. The hypotheses are based on the ecological growth theory assuming a direct impact from energy consumption to economic growth.

The first hypothesis is that the total final energy consumption in Denmark and Norway does Granger cause economic growth 1960-2012.

The second hypothesis is that the final electricity consumption in Denmark and Norway does Granger cause economic growth 1960-2012.

In order to judge the stability of the causal relationship over the period 1960-2012 between total final energy consumption the first hypothesis is tested for the time period 1990-2012. A structural break may well be expected during the period 1960-2012 as oil prices spiked in the 1970s. Another reason for this choice is that both Denmark and Norway found oil and natural gas in their territorial waters and started to produce oil/natural gas in the 1980s. The next hypothesis may then be formulated.

The third hypothesis is that the total final energy consumption in Denmark and Norway does Granger cause economic growth 1990-2012.

The first hypothesis has been addressed in a few studies where a larger group of countries, like the OECD countries, have been investigated in order to clarify if there is a causal relationship between energy use and economic growth. This paper contributes to a deeper comparison of the two Nordic countries not found in the literature. This fact makes it also interesting not only to study the impact of total final energy consumption but also the impact of energy consumption by sector in Denmark and Norway.

The fourth hypothesis is that final energy consumption in the industrial sector in Denmark and Norway does Granger cause economic growth during 1990-2012.

The fifth hypothesis is that energy consumption in the transport sector does Granger cause economic growth in Denmark and Norway during 1990-2012.

The sixth hypothesis is that energy consumption in the residential sector in Denmark and Norway does Granger causes economic growth during 1990-2012.

These hypotheses will be tested in a bivariate framework. The variables will be grouped pairwise in the form economic growth and energy in different forms and by sector. In the next section the data sources and the data required for the hypotheses testing are presented and briefly discussed.

7 Data

7.1 General information

The dataset for Denmark and Norway, including total energy consumption, electricity use and economic growth, for the period 1960-2012 is collected from the World Bank Database (www.worldbank.org). The disaggregated final energy consumption by sector for both countries is collected from the Eurostat Data Base (Eurostat, 2015). The sources are based on national information and it seems difficult to challenge them.

For total energy consumption the variable “energy use” in kg of oil equivalent per capita is used, for electricity consumption the variable “electricity use” in kWh per capita is used and for economic growth the variable “GDP” in constant 2005 US$ per capita is used to avoid the impact of inflation. The definitions of these variables are presented in Appendix 1.

The data for the disaggregated energy consumption in industry, transport and residential sectors are only available for the period 1990-2012 in kt oil equivalent in the Eurostat Data Base. (Eurostat, 2015) The definition of the final energy consumption in Eurostat is different compared to the World Bank definition. Appendix 1 presents the Eurostat definition. The Eurostat energy consumption data is given in absolute numbers and has been recalculated to kg of oil equivalent per capita by using the population numbers from the World Bank Data base.

7.2 Variables – graphical inspection

The GDP growth in Denmark and Norway is shown in Appendix 1, Figure A1.1. The graph indicates that the economic growth during the period 1960-2012 has been growing fairly linear up to the last recession in 2008 in both countries, though faster in Norway. The total energy consumption in Denmark has been almost stable while Norway shows a growing trend as shown in Appendix 1, Figure A1.2, The total electricity consumption is also shown in Appendix 1, Figure A1.3, for both countries and shows a linear growing trend up to the end of the 1990’s and then a flat development until the recession when it seems to decline slightly. The overall picture is similar in both countries, in particular when it comes to economic growth. The total energy and electricity consumption differ a bit.

The total final energy consumption per capita in Denmark and Norway for the period 1990-2012 with the Eurostat definition is shown in Appendix 1, Figure A1.4. The graphs suggest a rather stable total energy consumption over the period for both countries. This development seems to fit with the World Bank data for Denmark but not for Norway. The Eurostat data indicate a slight positive trend for Norway, probably due to the different definitions of the energy consumption. The disaggregated final energy consumption by sector for Denmark and Norway 1990-2012 is shown in Appendix 1, Figure A1.5 to A1.7. The industry sector in both countries shows a rather stable development until around 2005 and then a downward trend can be seen, though the energy consumption in industry is much higher in Norway. The final energy consumption in the transport sector slightly increases up to a round 2005 and then starts to decline. The residential sector indicate more variations over the period. In both countries the transport sector shows a positive trend in energy consumption until the mid of 1990's. Then the energy consumption in the residential sector shows a downward trend with a short hick up just after the recession in 2008. The sectorial development of final energy consumption in Denmark and Norway is similar but not identical. For the statistical investigation the variables have been transformed to logarithms. The statistical properties of the variables in logarithms are presented in the next.

7.3 Variables - mean value, deviation and autocorrelation

The mean value, standard deviation, maximum/minimum values and lags with autocorrelation is presented for the variables, economic growth (YS), total final energy consumption (ES1) and total final electricity consumption (ES2) for the period 1960-2012 for Denmark and Norway. See Table 7.1 and 7.2.

7.3.1 Period 1960-2012

Table 7.1 Denmark 1960-2012. Description of time series.

Variable	Mean	Std. Dev	Min	Max	Lags	Obs.
YS	10.42	0.31	9.75	10.83	5	54
ES1	8.14	0.17	7.56	8.34	2	53
ES2	8.36	0.52	6.99	8.83	4	52

Table 7.2 Norway 1960-2012. Description of time series.

Variable	Mean	Std. Dev	Min	Max	Lags	Obs.
YS	10.59	0.43	9.76	11.12	5	54
ES1	8.37	0.33	7.55	8.80	4	53
ES2	8.83	0.33	8.95	10.15	4	52

The number of lags refers to the autocorrelation test of the variables. The variables show similarity in levels and standard deviation, only the total final energy consumption in Denmark seems to be bit out of the frame with the lowest standard deviation and only two lags of autocorrelation. The result of the autocorrelation test is graphically presented in the Appendix 1, Figure A1.8 to A1.13

7.3.2 Period 1990-2012

For the time period 1990-2012 the information about the variables: total final energy consumption (ES1), final energy consumption in the sectors industry (ES2), transport (ES3) and residential (ES4) is presented together with the economic growth (YS) for Denmark and Norway in Table 7.3 and 7.4.

Table 7.3 Denmark 1990-2012. Description of time series.

Variable	Mean	Std. Dev	Min	Max	Lags	Obs.
YS	10.71	0.10	10.52	10.83	2	24
ES1	7.95	0.04	7.85	8.00	1	24
ES2	6.26	0.11	6.01	6.37	2	24
ES3	6.82	0.07	6.67	6.95	2	24
ES4	6.73	0.04	6.66	6.83	0	24

Table 7.4 Norway 1990-2012. Description of time series

Variable	Mean	Std. Dev	Min	Max	Lags	Obs.
YS	10.98	0.13	10.71	11.12	2	24
ES1	8.31	0.03	8.23	8.36	1	24
ES2	7.25	0.07	7.09	7.37	1	24
ES3	6.95	0.06	6.83	7.05	1	24
ES4	6.78	0.04	6.72	6.86	0	24

The autocorrelation test of the variables are shown in Appendix 1, Figure A1.14 to A1.23 and only the number of lags indicating autocorrelations are presented above. The test shows autocorrelation in maximum two lags for all variables in both Denmark and Norway. This indicates that the problem with autocorrelation is less than in the time period 1960-2012. The standard deviation in the later period is also low (and lower than for the full period). This indicates fairly stable development of the variables.

7.4 Correlation matrix

The correlation between the variables economic growth (YS), total final energy consumption (ES1) and total final electricity consumption (ES2) is presented in a correlation matrix for Denmark and Norway for the time period 1960-2012 in Table 7.5.

7.4.1 Period 1960-2012

Table 7.5 Denmark and Norway 1990-2012. Correlati*on* matrix.

Country	Denmark			Norway		
Variable	YS	ES1	ES2	YS	ES1	ES2
YS	1.00			1.00		
ES1	0.58	1.00		0.97	1.00	
ES2	0.95	0.77	1.00	0.95	0.99	1.00

The correlation matrix shows a very high and positive correlation between economic growth and final electricity consumption in both countries. In Denmark the correlation between economic growth and total final energy consumption is less strong than in Norway and the same goes for the

correlation between final energy and electricity consumption. However, the level of correlation is high between all variables.
The corresponding matrix is presented for the variables economic growth (YS), total final energy consumption (ES1), final energy consumption in industry (ES2), final energy consumption in the transport sector (ES3) and residential energy consumption (ES4) during 1990-2012 for Denmark and Norway in Table 7.6 and 7.7.

7.4.2 Period 1990-2012

Table 7.6 Denmark 1990-2012. Correlation matrix.

Variable	YS	ES1	ES2	ES3	ES4
YS	1.00				
ES1	0.20	1.00			
ES2	-0.43	0.65	1.00		
ES3	0.90	0.52	-0.16	1.00	
ES4	-0.25	0.68	0.40	0.00	1.00

In Denmark the total energy consumption (ES1) is still positively correlated with economic growth but weaker than for the full period 1960-2012. The matrix shows a negative correlation between final energy consumption in industry and residential sectors and economic growth. A further negative correlation is found between final energy consumption in the sectors of industry and transport, though not strong.

Table 7.7 Norway 1990-2012. Correlation matrix.

Variable	YS	ES1	ES2	ES3	ES4
YS	1.00				
ES1	0.68	1.00			
ES2	0.03	0.55	1.00		
ES3	0.87	0.68	-0.09	1.00	
ES4	-0.26	0.29	-0.07	-0.08	1.00

In Norway all variables are positively correlated with economic growth except final residential energy consumption. The energy consumption in the industry sector is close to uncorrelated with economic growth. The final energy consumption in industry is slightly negatively correlated to the energy consumption in the transport and residential sectors. The same goes for the correlation between the transport and residential sectors.

The correlation matrix does not give any information about the causal relationship between the variables. Therefore the Granger causality tests have to be conducted to identify potential causal relationships, but first a description of the testing procedure.

8 The procedure of testing

8.1 General

The methodology employed in this paper is based on the bivariate VAR model together with Granger causality tests and the procedure can be divided in three steps.

8.2 Step 1 of testing procedure

The first step is to investigate the order of integration of the variables. If a variable is stationary in levels the order of integration is zero. However, if the variable in levels has a unit root it is non-stationary. In this case the first difference has to be tested. If the differenced variable still has a unit root the second difference has to be tested and so on. The Augmented Dickey Fuller (ADF) and the Phillips-Perron (PP) tests are applied to tests of unit root. The null hypothesis, H0, is that the variable has a unit root and is then non-stationary. The ADF test starts with a constant and a trend and an assumed number of lags. In the test procedure the trend is removed if not significant. A replication of the ADF test is used to detect autocorrelation in lags. The number of lags is reduced one by one if not significant in the test down procedure until the last lag is significant. The number of lags is reduced until the absolute test statistic is greater than the absolute critical value, then the H0 can be rejected. In the PP test it is not necessary to assume number of lags.

8.3 Step 2 of testing procedure

In the second step it is tested for co-integration. The Engle-Granger test of co-integration can only handle two variables but the dependent variable has to be defined. This means that the test has to be performed with both variables as dependent which require more work. The Johansen test can handle a system with more than two variables and it is not necessary to define the dependent variable. In the case of only two variables the Johansen and Engle-Granger give the same result. As a bivariate approach is chosen in this paper the Johansen co-integration test is applied.

If the variables are co-integrated or not does not matter in the causality test by Toda-Yamamoto, but the information about co-integration gives valuable cross-check. By definition, if two variables are co-integrated there must be Granger causality in at least in one direction. However, if Granger causality is found, the variables are not by necessity co-integrated.

8.4 Step 3 of testing procedure

The third step is the Granger causality test as described in the methodology section. In the bivariate VAR model with two variables X and Y the number of lags is decided by an Information Criteria. The null, H0, hypothesis is that there is no Granger causality meaning that the coefficients for the lags are zero for Y in the X equation and vice versa. The rejection of the null hypothesis implies that there are coefficients for the lags in Y which are not zero. This confirms that past values of for example variable Y significantly contribute to the prediction of variable X and then Y is said to Granger cause X. This might be true in the other direction as well if the null hypothesis for the Y equation can be rejected. In this case variable X is said to Granger cause the variable Y. In the case X and Y are co-integrated there should be Granger causality at least in one of the directions (unidirectional), eventually in both (bidirectional).

9 Results – time period 1960-2012

9.1 Introduction

In this section the economic growth and the total final energy and the electricity consumption, respectively, have been analyzed for the period 1960-2012. The results can be found below and in Appendix 3, Table 2.1 to Table 2.8.

9.2 Results step 1

In the first step of the analysis the chosen variables are tested to find out if they are stationary or not. The Augmented Dickey Fuller (ADF) and the Phillips-Perron (PP) tests are both performed in levels for all variables. If one or both of tests suggest that a variable is non stationary the first differences are created and the tests are repeated. If one or both tests still suggest that a variable is non stationary the second difference is created tested again by both methods.

9.2.1 Denmark

This approach is applied first for Denmark and then for Norway during the time period 1960-2012 and the result is summarized in Appendix 2 (Tables A2.1 to A2.4) for Denmark. The variables are YS, ES1 and ES2 representing the logarithms of economic growth, total final energy consumption and total final electricity consumption respectively. The H0 hypothesis is that the variable has a unit root. The critical value corresponds to the 5 % level of significance in both the ADF and the PP tests. If the absolute value of the test statistic is lower than the absolute value of the critical value then the H0 hypothesis (unit root) cannot be rejected and the variable is non stationary.

The ADF tests (Table A2.1) suggest that the total final energy consumption is stationary in levels while the economic growth and the total final electricity consumption are not. The PP tests (Table A2.2) suggest that the variable economic growth is stationary in contrast to the ADF test. The conclusion is that the total final energy consumption is stationary and that the other two variables have to be tested in first differences.

The variables are now denoted as dYS and dES2 and representing the first difference of economic growth respectively electricity consumption. The ADF tests (Table A2.3) suggest that the economic growth and total final electricity consumption are stationary in their first differences which is confirmed by the PP tests (Table A2.4).

The conclusion for Denmark is that the variables economic growth and total final electricity consumption are stationary in first differences while total energy consumption is stationary in levels.

9.2.2 Norway

The above procedure is repeated for Norway and the corresponding results are shown in Appendix 2. The ADF tests (Table A2.5) suggest that the total final energy consumption is stationary in levels while the economic growth and the total final electricity consumption are not. The PP tests (Table A2.6) suggest that the variable economic growth is stationary in contrast to the ADF test. The conclusion is that the total final energy consumption is stationary and that the other two variables have to be tested in first differences. The variables are again denoted as dYS and dES2. The ADF tests (Table A2.7) suggest that the economic growth and total final electricity consumption are stationary in their first differences. The PP tests (Table A2.8) confirm that the variables economic growth and total final electricity consumption are stationary in first differences.

The conclusion for Norway is that the variables economic growth and total final electricity consumption are stationary in first differences while total energy consumption is stationary in levels.

9.2.3 Summary of results in step 1

The order of integration based on the stationary tests of the variables are summarized in Table 9.1 for the variables economic growth (YS), total final energy consumption (ES1) and total final electricity consumption (ES2).

Table 9.1 Order of integration. Time series for Denmark and Norway 1960-2012.

Variable	Denmark	Norway
YS	1	1
ES1	0	0
ES2	1	1

In conclusion the variables are integrated of order 1 or lower. In the case of total energy consumption the ADF and PP tests give the same result in levels but that is not the case for economic growth and total electricity consumption. This indicates that the efficiency of the tests may differ.

9.3 Results step 2

In the second step of the analysis the co-integration of the variable economic growth (YS) and total final energy consumption (ES1) respectively economic growth (YS) and total final electricity consumption (ES2) is performed for first Denmark and then Norway.

9.3.1 Denmark

In order to determine the number of lags for the VAR model the information criteria of Akaike (AIC), Hannan-Quinnon (HQIC) respectively Schwarz-Bayes (SBIC) are used and then the maximum rank is derived two conclude if co-integration is suggested. The results are summarized in Table 9.2.

Table 9.2 Denmark. Number of lags for Johansen co-integration test.

Variables	AIC	HQIC	SBIC	Chosen	Obs.
YS ES1	1	1	1	1	49
YS ES2	1	1	1	1	48

The maximum rank with the chosen number of lags is now determined with the Johansen co-integration test and presented in Table 9.2. The trace statistic is shown together with the critical value at 5 % significance level. The maximum rank is the first time the trace statistic is lower than the critical value.

Table 9.3 Denmark. Maximum rank for co-integration.

Variables	Lag	Trace statistic	Critical value	Max. rank
YS ES1	1	23.23	15.41	
		3.58	3.76	1
YS ES2	1	54.44	15.41	
		0.90	3.76	1

The Johansen co-integration test suggest maximum rank 1 for both pair of variables which suggest a possible co-integration between the variables.

9.3.2 Norway

The results for Norway is now derived in the same way as for Denmark and is summarized in Table 9.4 and 9.5.

Table 9.4 Norway. Number of lags for Johansen co-integration test.

Variables	AIC	HQIC	SBIC	Chosen	Obs.
YS ES1	2	2	2	2	49
YS ES2	3	2	1	3	48

Table 9.5 Norway. Maximum rank for co-integration.

Variables	Lag	Trace statistic	Critical value	Max. rank
YS ES1	2	22.76	15.41	
		5.89	3.76	0
YS ES2	3	30.99	15.41	
		4.09	3.76	0

The Johansen co-integration test suggest maximum rank 0 for both pair of variables, as the trace statistic is larger than the critical value in both cases, and does therefore not suggest any co-integration between the variables.

9.3.3 Summary of results in step 2

The outcome of the co-integration test is that in Denmark, the economic growth seems to be co-integrated with total final energy consumption and total final electricity consumption respectively while this is not the case in Norway.

9.4 Results step 3

In the third step of the analysis the Granger causality is derived for the considered variables in first Denmark and then in Norway. The variables are all integrated by maximum order 1 and in the case of Denmark co-integrated. The Toda Yamamoto method allows for an order of integration of maximum 2 and co-integration between variables. Then it is possible to apply VAR in levels and test the Granger causality Wald test. The lags for the VAR model are derived by using the same information criteria as above. The outcome of the causality tests for Denmark is presented in Table 9.6 and for Norway in Table 9.7.

9.4.1 Denmark

Table 9.6 Denmark. Probability for Granger causality 1960-2012 and direction.

Equation	Excluded	p value	Granger causality	Direction
YS	ES1	0.61	no	Neutral
ES1	YS	0.28	no	Neutral
YS	ES2	0.66	no	Neutral
ES2	YS	0.05	no (0.052)	YS=>ES2 (10 %)

9.4.2 Norway

Table 9.7 Norway. Probability for Granger causality 1960-2012 and direction.

Equation	Excluded	p value	Granger causality	Direction
YS	ES1	0.30	no	Neutral
ES1	YS	0.12	no	Neutral
YS	ES2	0.46	no	Neutral
ES2	YS	0.06	no	YS=>ES2 (10 %)

9.4.3 Summary of results in step 3

In conclusion, the result does not suggest any Granger causality in either direction between total final energy consumption and economic growth in Denmark and the result is the same for Norway during the period 1960-2012 at the level of 5 % significance. The results indicate neutrality between economic growth and total final energy consumption. At this level of significance the same goes for economic growth and total final electricity consumption. However, the results suggest that economic growth Granger causes final electricity consumption in both Denmark and Norway at the 10 % level of significance.

9.5 Tests for normality and autocorrelation

The results from the normality and autocorrelation tests of the equations are presented for Denmark and Norway in Appendix 4, Table A4.1 and A4.2 respectively. The results indicate that the equations for Denmark and Norway does not suffer from any severe problems with either normality or autocorrelation. This conclusion is based on the fact that skewness, which is considered to be the most serious problem, has a rather low score (Prob>chi2) both for Denmark and Norway. The kurtosis tests show high scores for one equation in each country but is normally considered less severe than skewness. The Granger causality tests can therefore be regarded as reliable from this perspective.

10 Results – time period 1990-2012

10.1 Introduction

For the period 1960-2012 the economic growth and the total or aggregated final energy and the electricity consumption, respectively, have been analyzed. The result suggests neutrality between total final energy consumption and economic growth and therefore it seems of interest to investigate the total final energy consumption by sector. Data for the disaggregated final energy consumption by sector has not been found for the whole period. But Eurostat offers final energy consumption by sector in Denmark and Norway from 1990. In the following the sectors industry, transport and residential are analyzed in order to find out if any of these sectors may Granger cause economic growth during 1990-2012. In addition the total final energy consumption during the period is also studied to be able to compare with the whole period 1960-2012.

The same procedure of testing in three steps as has been applied in the previous section is used to determine the order of integration, possible co-integration and Granger causality between variables. The variables in this section are economic growth (YS), total final energy consumption (ES1), final energy consumption in industry (ES2), final energy consumption in transport (ES3) and final residential energy consumption (ES4).

10.2 Results step 1

In the first step the order of integration of variables are determined. The results for Denmark and Norway are presented in Appendix 3, Table A3.1 to Table A3.10.

10.2.1 Denmark

The ADF tests (Table A3.1) suggest that economic growth is stationary in levels while the rest of the energy consumption variables are not. The PP tests (Table A3.2) suggest that the variable final residential energy consumption is stationary in contrast to the ADF test. The conclusion is that none of the variables are stationary in levels in both the ADF and PP tests. Therefore all variables have to be tested in first differences. The variables are now denoted as dYS, dES1, dES2, dES3 and dES4, the first differences of economic growth, total final energy consumption, final consumption the industry, transport and residential sectors respectively.

The ADF tests (Table A3.3) suggest that economic growth, final energy consumption in industry and final residential energy consumption are stationary in their first differences. The PP tests (Table A3.4) confirms that the variables economic growth and final energy consumption in industry and residential sectors are stationary in first differences. These variables are integrated of order 1.

The conclusion is that the second difference for ES1 and ES3 have to be investigated as well. The variables are now denoted as ddES1 and ddES3. The ADF tests (Table A3.5) suggest that economic growth, total final energy consumption and final energy consumption in transport sector are stationary in their second differences. The PP tests (Table A3.6) confirm that the variables total final energy consumption and final energy consumption in transport sector are stationary in second differences. The variables are integrated of order 2.

10.2.2 Norway

The same procedure is now applied to the corresponding variables for Norway. The ADF tests (Table A3.7) suggest that economic growth is stationary in levels while the rest of the energy consumption variables are not. The PP test (Table A3.8) suggest that the variable economic growth is stationary as in the ADF test. The rest of the variables are not stationary in the ADF test nor in the PP test. Therefore these variables have to be tested in first differences. The variables are now denoted as dES1, dES2, dES3 and dES4. The ADF tests (Table A3.9) suggest that total final energy consumption, final energy consumption in the sectors industry, transport and residential are stationary in first differences. The PP tests (Table A3.10) confirm that the variables total final energy consumption as well as the final energy consumptions in the sectors industry, transport and residential are stationary in first differences. These variables are integrated of order 1.

10.2.3 Results step 1 – in summary

Table 10.1 Order of integration. Time series for Denmark and Norway 1990-2012.

Variable	Denmark	Norway
YS	1	0
ES1	2	1
ES2	1	1
ES3	2	1
ES4	1	1

In conclusion, the ADF and PP tests suggest that all variables are integrated of order 2 or less. This means that the Toda Yamamoto procedure can be applied.

10.3 Results step 2

In the second step of the analysis the co-integration between variable economic growth (YS) and total final energy consumption (ES1), energy consumption in industry (ES2), final energy consumption in the transport sector (E3) and the final residential energy consumption respectively is performed for first Denmark and then Norway.

In order to determine the number of lags for the VAR model the information criteria of Akaike (AIC), Hannan-Quinnon (HQIC) respectively Schwarz-Bayes (SBIC) are used and then the maximum rank is derived two conclude if co-integration is suggested. Results for Denmark in Table 10.2.

10.3.1 Denmark

Table 10.2 Number of lags for Johansen co-integration test. Denmark.

Variables	AIC	HQIC	SBIC	Chosen	Obs.
YS ES1	1	1	1	1	20
YS ES2	2	2	1	2	20
YS ES3	4	4	4	4	20
YS ES4	1	1	1	1	20

The maximum rank with the chosen number of lags is now determined with the Johansen co-integration test and presented in Table 10.3. The trace statistics are shown together with the critical value at 5 % significance level. The maximum rank is the first time the trace statistic is lower than the critical value.

Table 10.3 Denmark. Maximum rank for co-integration.

Variables	Lag	Trace statistic	Critical value	Max. rank
YS ES1	1	15.48	15.41	
		6.18	3.76	0
YS ES2	2	30.99	15.41	
		4.11	3.76	0
YS ES3	4	29.08	15.41	
		6.51	3.76	0
YS ES4	1	25.25	15.41	
		7.16	3.76	0

The Johansen co-integration test suggest maximum rank 0 for all pair of variables which does not suggest any co-integration between the variables.

10.3.2 Norway

The results for Norway is derived in the same way as for Denmark and are summarized in Table 10.4 and 10.5.

Table 10.4 Norway. Number of lags for Johansen co-integration test.

Variables	AIC	HQIC	SBIC	Chosen	Obs.
YS ES1	1	1	1	1	20
YS ES2	1	1	1	1	20
YS ES3	1	1	1	1	20
YS ES4	2	1	1	2	20

Table 10.5 Norway. Maximum rank for co-integration.

Variables	Lag	Trace statistic	Critical value	Max. rank
YS ES1	1	22.40	15.41	
		5.33	3.76	0
YS ES2	1	23.68	15.41	
		3.08	3.76	1
YS ES3	1	20.71	15.41	
		5.89	3.76	0
YS ES4	2	16..99	15.41	
		6.23	3.76	0

The Johansen co-integration tests suggest maximum rank 1 for economic growth and final energy in the industry sector, as the trace statistic is lower than the critical value in this cases, and does therefore suggest a possible co-integration between the variables. For the rest of the pairs the result does not suggest any co-integration.

10.3.3 Summary of results in step 2

The outcome of the co-integration test is that in Denmark, the economic growth does not seem to be co-integrated with total final energy consumption nor final energy consumption in any of the sectors studied. However, in Norway the economic growth and final energy consumption in the industry sector seems to be co-integrated.

10.4 Results step 3

In the third step of the analysis the Granger causality is derived for the considered variables in first Denmark and then in Norway. The variables are all integrated by maximum order 1. The Toda Yamamoto method allows for an order of integration of maximum 2 and co-integration between variables. Then it is possible to apply VAR in levels and test the Granger causality Wald test. The lags for the VAR model are derived by using the same information criteria as above. The outcome of the causality tests for Denmark is presented in Table 10.6 and for Norway in Table 10.7.

10.4.1 Denmark

Table 10.6 Denmark. Probability for Granger causality 1990-2012 and direction.

Equation	Excluded	p value	Granger causality	Direction
YS	ES1	0.04	Yes	ES1=>YS
ES1	YS	0.09	No	Neutral
YS	ES2	0.72	No	Neutral
ES2	YS	0.00	Yes	YS=>ES2
YS	ES3	0.00	Yes	ES3=>YS
ES3	YS	0.00	Yes	YS=>ES3
YS	ES4	0.03	Yes	ES4=>YS
ES4	YS	0.02	Yes	YS=>ES4

10.4.2 Norway

Table 10.7 Norway. Probability for Granger causality 1990-2012 and direction.

Equation	Excluded	p value	Granger causality	Direction
YS	ES1	0.21	No	Neutral
ES1	YS	0.30	No	Neutral
YS	ES2	0.11	No	Neutral
ES2	YS	0.83	No	Neutral
YS	ES3	0.12	No	Neutral
ES3	YS	0.25	No	Neutral
YS	ES4	0.61	No	Neutral
ES4	YS	0.05	Yes	YS=>ES4

10.4.3 Summary of the results

In conclusion, the results suggest that total final energy consumption in Denmark Granger causes economic growth during the period 1990-2012 at the 5 % significance level. At 10 % significance level economic growth Granger causes total final energy consumption as well in Denmark. This implies a bidirectional relationship at this level of significance. In Norway there is neutrality between economic growth and total final energy consumption in both directions. The only relationship in terms of Granger causality found in Norway during the period 1990-2012 is between economic growth and final energy consumption in the residential sector. Here economic growth Granger causes energy consumption. In Denmark there is a causal relationships between economic growth and final energy consumption in all sectors. In the industry sector the relationship is unidirectional, economic growth Granger causes final energy consumption in industry, while in the transport and residential sectors the relationship is bidirectional between economic growth and energy consumption in the sectors.

10.5 Tests for normality and autocorrelation

The results from the normality and autocorrelation tests of the equations are presented for Denmark and Norway in Appendix 4, Table A4.3 and A4.4 respectively. The results indicate now a clear difference between Denmark and Norway, in particular the normality tests show different results. The overall impression is that the equations for Denmark indicate less problems with normality than the equations for Norway. In the case of Denmark it is only the equation with economic growth and final energy consumption in the transport sector which indicate some problems with normality, while in Norway all equations indicate normality problems. However, autocorrelation does not seem to be a problem either in Denmark nor Norway.

The time series are shorter compared to the previous Granger causality tests and may be a cause of the problems with normality. A lower reliability of the Granger causality tests is not unexpected but it seems that Denmark suffers less from problems with normality than Norway. The Granger causality tests for Denmark may therefore be regarded as more reliable than for Norway during the period 1990-2012.

11 Discussion

11.1 Does energy cause economic growth?

The first hypothesis that the total final energy consumption in Denmark and Norway does Granger cause economic growth during the period 1960-2012 does not seem to hold. The results in this paper suggest neutrality in both countries. This is in line with the outcome in one of the earlier studies by Bozoklu and Yilanci (2014) but in conflict with Chontanawat et al (2006). The results could be taken as evidence for the traditional view that energy consumption does not have a direct role in economic growth and as an indication of decoupling of energy and economic growth. However, this may be a too simple conclusion even if the empirical evidence in terms of Granger causality is missing.

The change in energy input has been substantial during the period, especially in Denmark, where the percentage of fossil energy has been reduced from almost 100 % to about 70 %. The reduction in Norway is more modest in percentage but energy consumption in absolute numbers has increased and the trend in the shift from fossil energy is similar. The energy intensity has declined in both countries which may support the theory that a shift to more efficient technologies and a shift to higher quality energy has taken place.

11.2 Does electricity cause economic growth?

The second hypothesis that the final electricity consumption in Denmark and Norway does Granger cause economic growth during the period 1960-2012 does not seem to hold. At first glance the Granger causality tests imply neutrality between the energy form electricity and economic growth at a 5 % significance level. However, at the 10 % significance level, the causality tests suggest that economic growth Granger causes electricity consumption in both countries. This could indicate that, when the countries are climbing the energy ladder and technology improves at the same time, the increase in quality of energy displays a further demand for electricity. The manufacturing process in industry gets more efficient and the supply of goods increases at lower prices, demand from the residential and service sectors increases. This rebound effect, where electricity is saved and used more efficient in some sectors of the economy may stimulate other sectors to use more appliances and the total electricity use may increase even if the electricity intensity declines. This is a plausible explanation following theory.

11.3 Stable causality over time?

The third hypothesis that the total final energy consumption in Denmark and Norway does Granger cause economic growth during the period 1990-2012 does not seem to hold for Norway but for Denmark. In Denmark total final energy consumption does seem to Granger causes economic growth while this is not the case in Norway (neutrality) in this direction. In the other direction the results suggest neutrality for both countries at the significance level at 5 %. However, at 10 % significance level economic growth in Denmark Granger causes total final energy consumption.

The first remark is that these results are in line with the results for time period 1960-2012 for Norway. However, for Denmark the results do conflict with results from the period 1960-2012 which indicate neutrality between economic growth and energy consumption but this is not the case for the period 1990-2012. The causal relationship between energy and economic growth in Denmark has changed and seems to vary over time. This fact is not a surprise as structural breaks may occur which also has been investigated by several scholars. The oil crises in the 1970's could be such a reason for the change in causal relationship in Denmark. The second remark is that the change in causal relationship in Denmark did not happen in Norway. In Denmark the neutrality between economic growth and energy consumption changes to energy driving economic growth. This implies that restrictions in energy consumption may harm the economic growth in Denmark while this is not the case In Norway where neutrality remains in the period 1990-2012. In Norway economic growth will not be restricted by restrictions in energy consumption. This fact may mirror the structural difference in energy supply between Denmark and Norway. The endowment of domestic energy resources in Norway is much greater than in Denmark. Another plausible part of the explanation may be the structural change of the economies. The economy in Norway has shifted to greater dependence, in terms of value added, on the industry sector (less on service) while Denmark has followed the mainstream development, the shift to greater dependence on the service sector. The energy intensity has followed the downward trend in both countries and may not be the main reason for the development. The electricity intensity in Norway shows on the other hand a different pattern compared to Denmark and might be a part of the explanation to the difference between the countries.

11.4 Does energy in industry cause economic growth?

The fourth hypothesis that final energy consumption in the industrial sector in Denmark and Norway does Granger cause economic growth during the period 1990-2012 does not seem to hold. However, in Norway the causal relationship indicates neutrality but not in Denmark where economic growth Granger causes final energy consumption in the industrial sector.

In both countries the energy intensity has been reduced over the period and there has been a structural change as well. However, the structural change in Denmark has resulted in a greater part of value added from service compared to industry, while in Norway it has been the other way around. The results could mean a decoupling between energy consumption in industry and economic growth in Norway but in Denmark it seems that economic growth drives energy consumption in the industrial sector. The technological change and improved energy efficiency may be part of it. Such a development would stimulate energy saving in the industry as a part of reducing the costs for their products and thereby promote business and economic growth. This might be a possible explanation to economic growth driving energy consumption in the industrial sector.

11.5 Does energy in transport cause economic growth?

The fifth hypothesis that energy consumption in the transport sector does Granger cause economic growth in Denmark and Norway during the time period 1990-2012 holds only for Denmark. This implies that the economic growth in Denmark may be harmed if energy consumption in the transport sector is restricted. Further, for Denmark there seems to be a bidirectional causal relationship between economic growth and energy consumption in the transport sector as economic growth Granger causes consumption of energy in the transport sector. For Norway the result is different and suggests neutrality between energy consumption and economic growth.

The energy intensity has declined by 10-15 % in both countries over the period so this is not likely to be a reason to the difference in the Granger causality. The structural change in their economies goes in the opposite directions and might be one reason. In Denmark the structural change has been towards a larger part of services. Could this be a reason for Granger causality in both directions between energy consumption in transport and economic growth? In a service economy the transport sector is important for the economic development, even more important than in economies dominated by the industry sector. The service sector is often located in a large amount of remote locations while electricity intensive industries, as in Norway, are more likely to be located in large facilities in a limited number of locations. This could be possible explanation to the difference in Granger causality. Further explanations? The more distinct shift away from fossil energy in Denmark, compared to Norway, has also increased the energy quality in relative terms.

11.6 Does energy in residential cause economic growth?

The sixth hypothesis that energy consumption in the residential sector in Denmark and Norway does Granger causes economic growth during 1990-2012 seems to hold only for Denmark. However, the result for Denmark also indicates that economic growth drives energy consumption in the residential sector. This latter fact also goes for Norway and supports the theoretical considerations that economic growth supports the demand for new products, especially when goods can be supplied at lower prices. This seems as a possible explanation for both countries.

In Denmark for the causal relationship is bidirectional which implies that if energy consumption is restricted that may harm economic growth. This suggest, as in the transport sector, a mutual interaction between energy consumption and economic growth. Energy consumption in the residential sector is vital for the economy and contributes to technology change and higher efficiency in the economy which lower prices on goods on the supply side which in turn supports the demand side.

12 Conclusion

The overall research question is to analyze the role of energy in economic growth in two Nordic countries, Denmark and Norway, during the period 1960-2012 and to compare the outcome. Therefore the research question is broken down in six hypotheses. The study is based on theoretical considerations, historical information (energy consumption and GDP) and empirical causality tests (Granger). Given the assumptions made in the paper and the choice of methodology a few conclusion can be made.

The relationship between total energy consumption and economic growth in Denmark and Norway suggests neutrality and no causal relationship in either direction during the period 1960-2012. The replacement of energy consumption by electricity consumption shows the same result at 5 % level of significance. However, at significance level of 10 % economic growth Granger causes electricity consumption in both countries. There is no indication of causal relationship in the other direction (energy to growth). This may be taken as evidence for the theoretical considerations by mainstream economists that energy consumption does not restrict economic growth. The role of energy consumption during the period 1960-2012, in terms of causal relationships, does not seem to differ in Denmark and Norway. However, there is differences in energy supply structure, energy intensity levels and the structure of the economies.

The role of energy consumption in economic growth seems to differ when the time period 1990-2012 is investigated by sector. In Denmark total final energy consumption Granger causes economic growth which is not the cause for the full period 1960-2012. At the 10 % significance level there is even a bidirectional causal relationship. However, in Norway the relationship between energy consumption and economic growth still suggests neutrality.

The result for Denmark does challenge the mainstream economist view and support the ecologist economist theory as energy consumption causes economic growth. Further, the empirical results suggest that the causal relationship changed over the time period 1960-2012 in Denmark but not in Norway. In addition to the total final energy consumption the sectors industry, transport and residential are analyzed. The results suggest a different role of energy consumption in Denmark compared to Norway. In the sectors transport and residential the empirical results from the Granger tests suggest a bidirectional relationship between energy and economic growth in Denmark while in Norway the only relationship in the sectors is found between economic growth and final residential energy consumption.

In conclusion, the role of energy in economic growth seems to be different in Denmark and Norway, at least during the period 1990-2012. The development in Norway might be taken as evidence for the mainstream theoretical considerations while the Danish development is more in favor of the ecological economist view and also supports the fact that causal relationships may change over time. Possible explanations to the different development in Denmark and Norway might be differences in the energy supply structure and the development of the structure of their economies. This may be related to relative scarcity of domestic energy endowments in Denmark compared to Norway. The more abundant access to electricity in Norway seems to have promoted growth in the industrial sector with high energy intensity.

The scarcity argument is used by Stern (2011) in the discussion of theories behind the views of the mainstream and ecological economist. In situations of energy scarcity the ecological theory seems to give a better explanation of the role of energy in economic growth, while in situations with abundant energy supply the mainstream economic view seems to fit better. The outcome of this paper seems to support this view.

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<u>Appendix 1:</u> Data

Definitions:

Energy use (World Bank)

Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

Electricity consumption (World Bank)

Electric power consumption measures the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants.

GDP per capita (World Bank)

GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2005 U.S. dollars.

Final energy consumption by sector (Eurostat)

This indicator expresses the sum of the energy supplied to the final consumer's door for all energy uses. It is the sum of final energy consumption in industry, transport, households, services, agriculture, etc. Final energy consumption in industry covers the consumption in all industrial sectors with the exception of the 'Energy sector'. *The fuel quantities transformed in the electrical power stations of industrial autoproducers and the quantities of coke transformed into blast-furnace gas are not part of the overall industrial consumption but of the transformation sector.* Final energy consumption in transport covers the consumption in all types of transportation, i.e., rail, road, air transport and inland navigation. Final energy consumption in households, services, etc. covers quantities consumed by private households, commerce, public administration, services, agriculture and fisheries.

Time series:

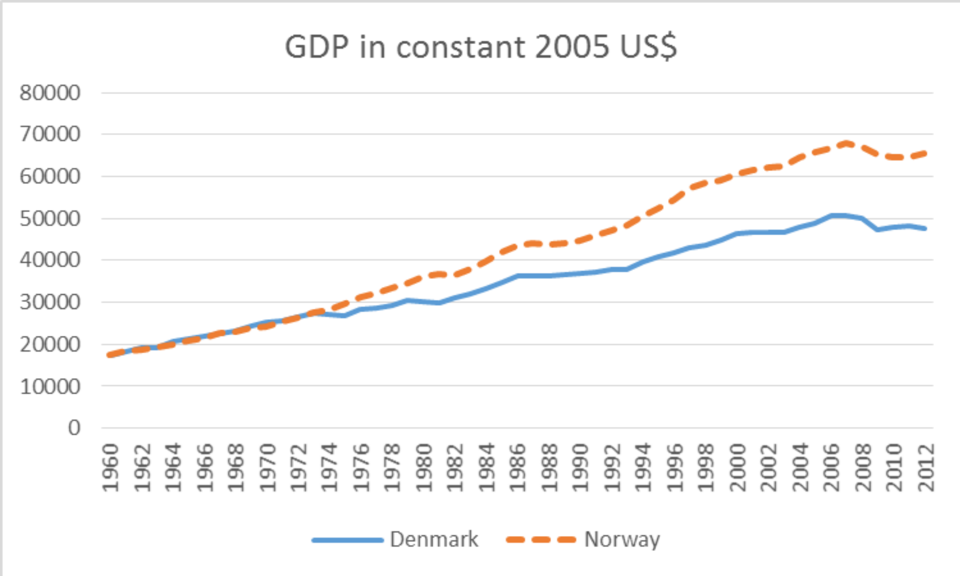

Figure A1.1. GDP per capita in constant 2005 US$ in Denmark and Norway 1960-2012. Source: World Bank Data.

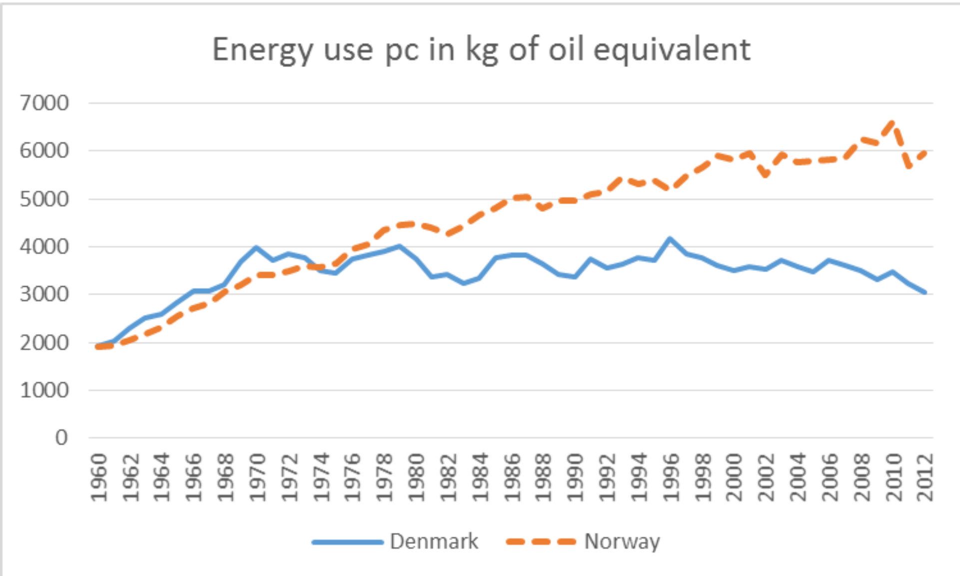

Figure A1.2. Energy use per capita in kg of oil equivalent in Denmark and Norway 1960-2012. Source: World Bank Data.

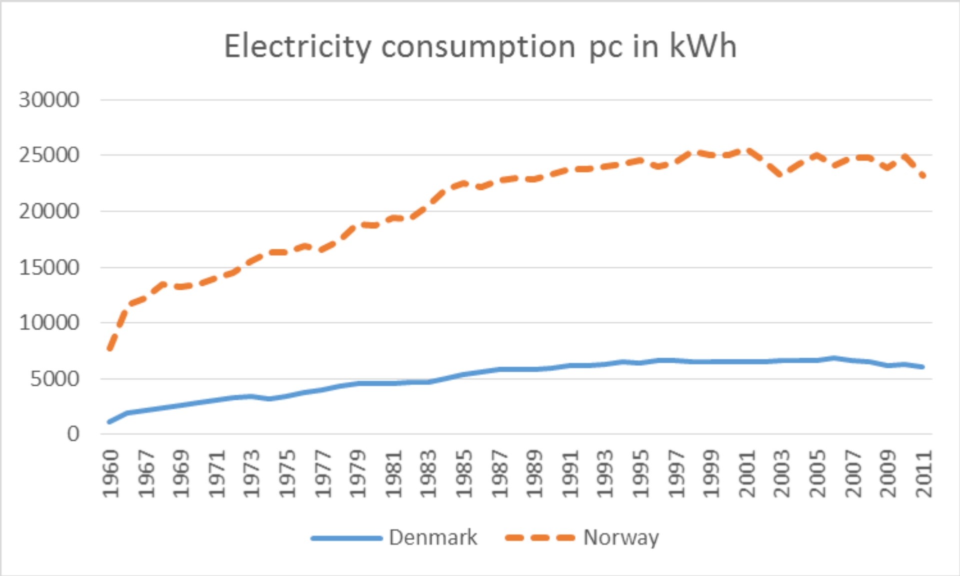

Figure A1.3. Electricity consumption per capita in kWh in Denmark and Norway 1960-2012. Source: World Bank Data.

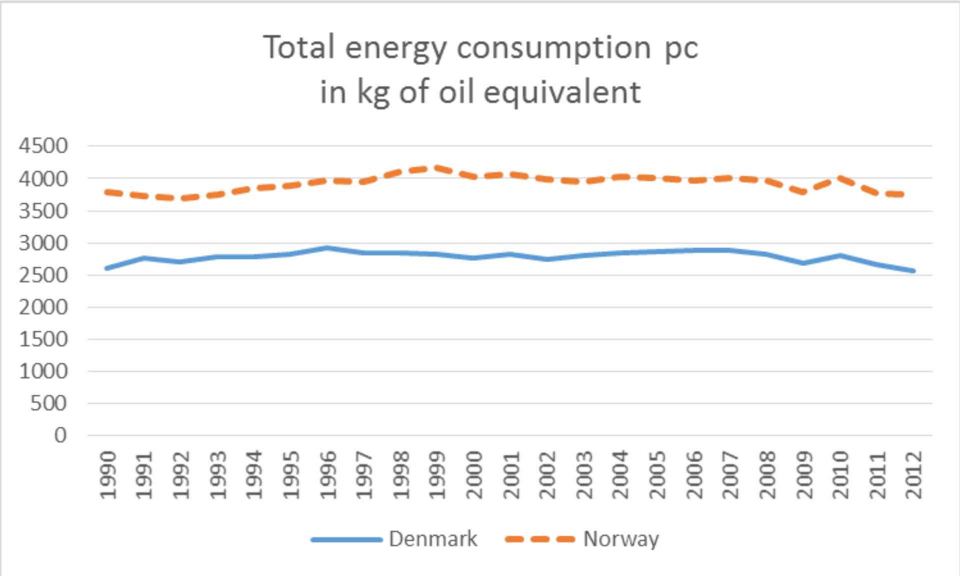

Figure A1.4 Total energy consumption in kg of oil equivalent in Denmark and Norway 1990-2012. Source Eurostat Data Base.

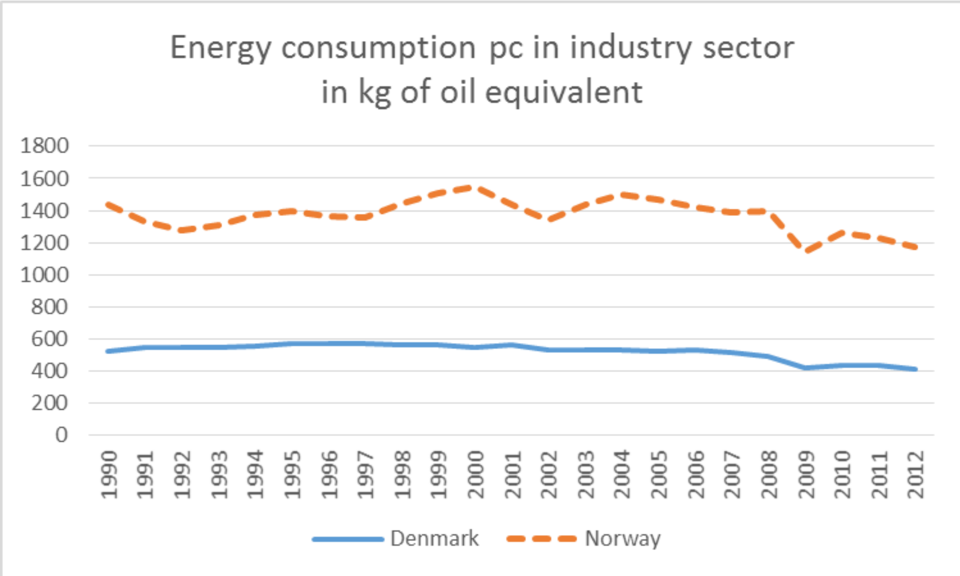

Figure A1.5 Energy consumption in industry sector in kg of oil equivalent in Denmark and Norway 1990-2012. Source Eurostat Data Base.

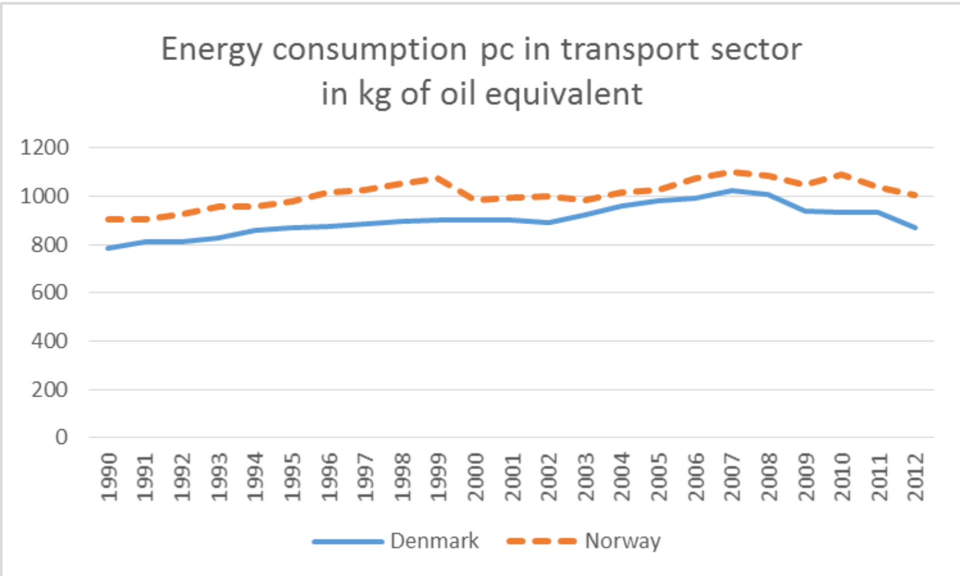

Figure A1.6 Energy consumption in transport sector in kg of oil equivalent in Denmark and Norway 1990-2012. Source Eurostat Data Base.

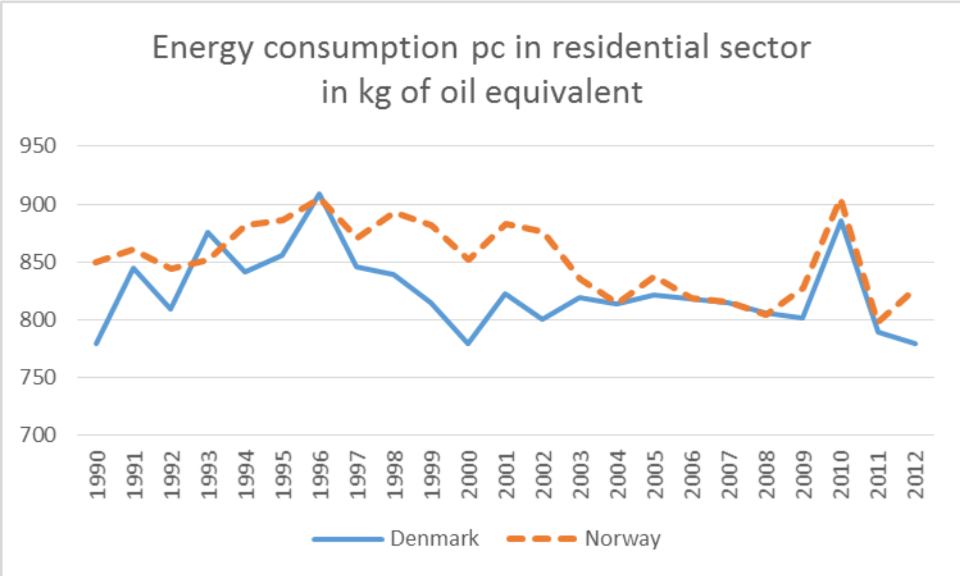

Figure A1.7 Energy consumption in transport sector in kg of oil equivalent in Denmark and Norway 1990-2012. Source Eurostat Data Base.

Tests for autocorrelation in variables:

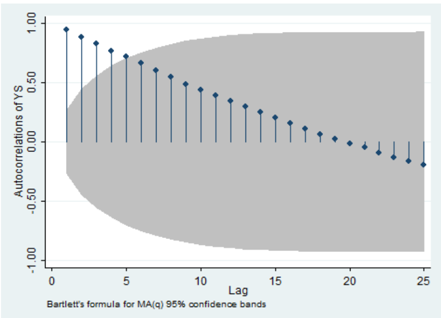

Figure A1.8 Denmark 1960-2012. Autocorrelation in GDP (YS).

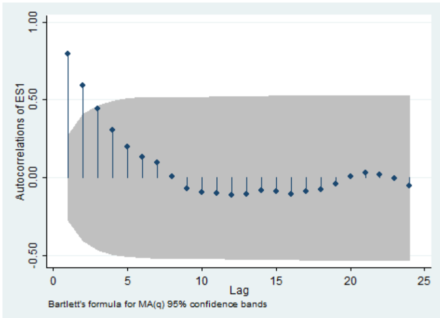

Figure 1.9 Denmark 1960-2012. Autocorrelation in energy consumption (ES1).

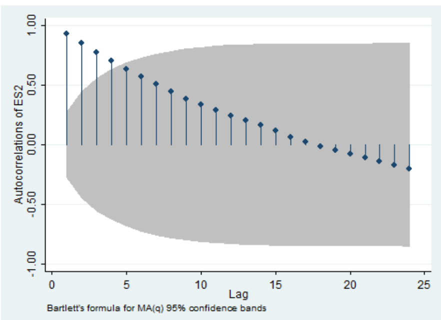

Figure A1.10 Denmark 1960-2012. Autocorrelation in electricity consumption (ES2).

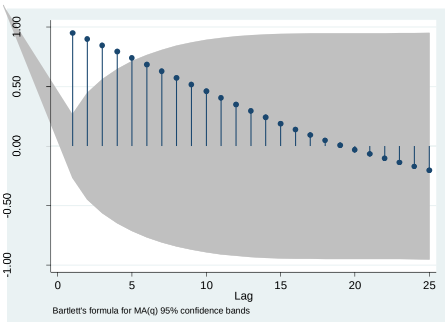

Figure A1.11 Norway 1960-2012. Autocorrelation in GDP (YS).

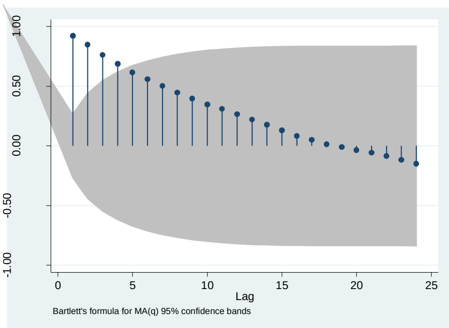

Figure A1.12 Norway 1960-2012. Autocorrelation in energy consumption (ES1).

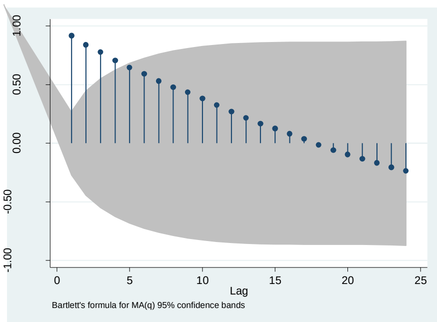

Figure 1.A13 Norway 1960-2012. Autocorrelation in electricity consumption (ES2).

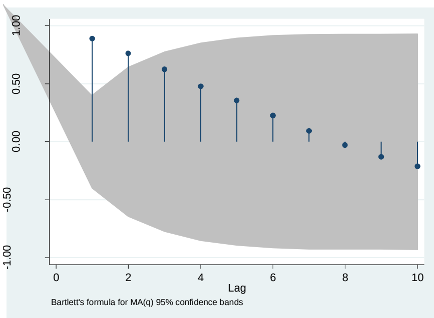

Figure A1.14 Denmark 1990-2012. Autocorrelation in variable GDP (YS).

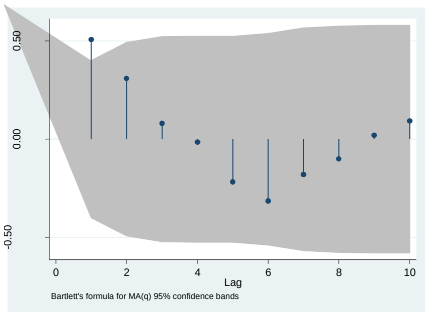

Figure A1.15 Denmark 1990-2012. Autocorrelation in final energy consumption (ES1).

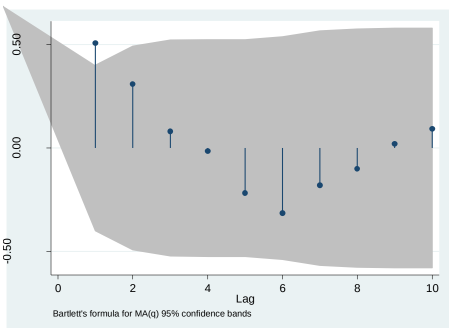

Figure A1.16 Denmark 1990-2012. Autocorrelation in final energy consumption in industry sector (ES2).

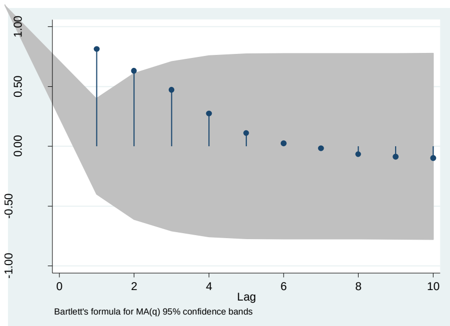

Figure A1.17 Denmark 1990-2012. Autocorrelation in final energy consumption in sector transport (ES3).

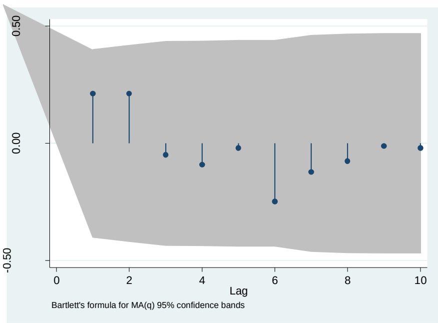

Figure A1.18 Denmark 1990-2012. Autocorrelation in final energy consumption in residential sector (ES4)

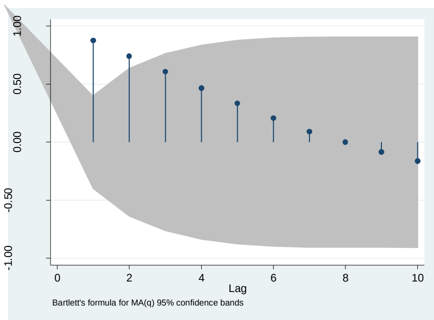

Figure A1.19 Norway 1990-2012. Autocorrelation in variable GDP (YS).

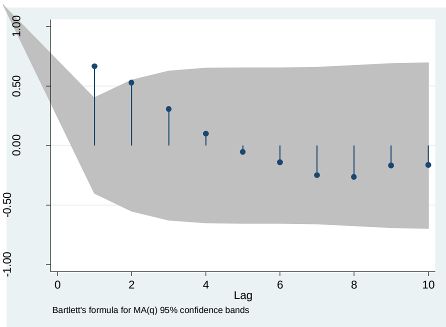

Figure A1.20 Norway 1990-2012. Autocorrelation in final energy consumption (ES1).

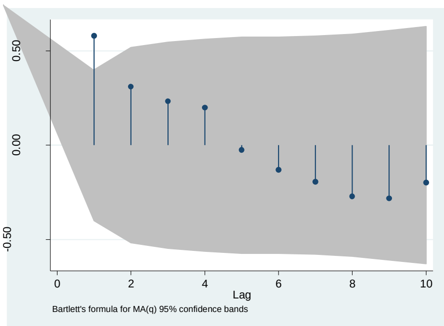

Figure 1.21 Norway 1990-2012. Autocorrelation in final energy consumption in industry sector (ES2).

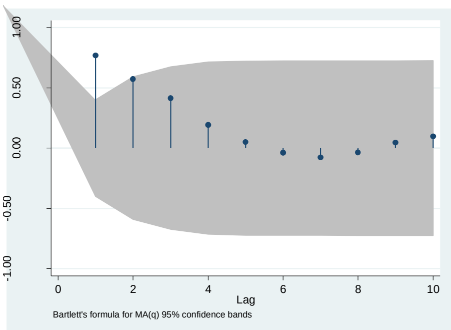

Figure A1.22 Norway 1990-2012. Autocorrelation in final energy consumption in sector transport (ES3).

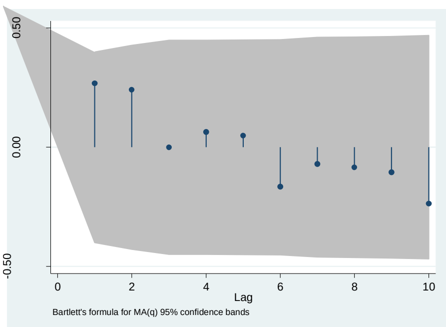

Figure A1.23 Norway 1990-2012. Autocorrelation in final energy consumption in residential sector (ES4).

Appendix 2: Results 1960-2012

Stationary tests:

Table A2.1 Result of ADF tests for Denmark 1960-2012.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	4	const	-2.294	-2.933	No	49
ES1	4	const	-3.857	-2.928	Yes	49
ES2	5	const&trend	-3.397	-3.516	No	46

Table 2.2 Results of PP tests for Denmark 1960-2012. Lags here refer to Newey-West lags.

	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	3	const	-3.837	-2.933	Yes	53
ES1	3	const	-4.286	-2.928	Yes	52
ES2	3	const&trend	-2.278	-3.499	No	51

Table 2.3 Result of ADF tests for Denmark 1960-2012. First differences.

	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dYS	3	const&trend	-3.857	-3.504	Yes	49
dES2	3	const&trend	-4.595	-3.512	Yes	47

Table 2.4 Results of PP tests for Denmark 1960-2012. Lags here refer to Newey-West lags.

	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dYS	3	const&trend	-6.612	-3.498	Yes	52
dES2	3	const&trend	-5.544	-3.500	Yes	50

Table 2.5 Result of ADF tests for Norway 1960-2012.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	1	const	-2.416	-2.928	No	52
ES1	4	const	-5.262	-2.936	Yes	48
ES2	4	const&trend	-1.274	-3.512	No	47

Table 2.6 Results of PP tests for Norway 1960-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	3	const	-3.542	-2.933	Yes	53
ES1	3	const	-4.603	-2.928	Yes	52
ES2	3	const&trend	-2.065	-3.499	No	51

Table 2.7 Result of ADF tests for Norway 1960-2012. First differences.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dYS	1	const&trend	-4.225	-3.499	Yes	51
dES2	3	const&trend	-5.154	-3.512	Yes	47

Table 2.8 Results of PP tests for Norway 1960-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dYS	3	const&trend	-4.606	-3.498	Yes	52
dES2	3	const&trend	-9.131	-3.500	Yes	50

<u>Appendix 3:</u> Results 1990-2012

Stationary tests:

Table 3.1 Result of ADF tests for Denmark 1990-2012.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	3	const	-3.164	-3.000	Yes	20
ES1	1	const	-0.514	-3.000	No	22
ES2	4	const	0.386	-3.000	No	19
ES3	5	const	-1.936	-3.000	No	18
ES4	1	const	-1.826	-3.000	No	22

Table 3.2 Results of PP tests for Denmark 1960-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	2	const	-2.150	-3.000	No	23
ES1	2	const	-1.987	-3.000	No	23
ES2	2	const	0.951	-3.000	No	23
ES3	2	const	-2,125	-3.000	No	23
ES4	2	const	-3.739	-3.000	Yes	23

Table 3.3 Result of ADF tests for Denmark 1990-2012. First differences.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dYS	2	const&trend	-4.358	-3.600	Yes	20
dES1	1	const	-2.709	-3.000	No	21
dES2	1	const&trend	-4.053	-3.600	Yes	21
dES3	2	const	-0.792	-3.000	No	20
dES4	1	const	-3.990	-3.000	Yes	21

Table 3.4 Results of PP tests for Denmark 1990-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dYS	2	const&trend	-4.018	-3.600	Yes	22
dES1	2	const	-6.009	-3.000	Yes	22
dES2	2	const&trend	-6.019	-3.600	Yes	22
dES3	2	const	-3.261	-3.000	Yes	22
dES4	2	const	-8.366	-3.000	Yes	22

Table 3.5 Result of ADF tests for Denmark 1990-2012. Second differences

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
ddES1	2	const	-3.476	-3.000	Yes	19
ddES3	1	const	-7.997	-3.000	Yes	20

Table 3.6 Results of PP tests for Denmark 1990-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
ddES1	2	const	-16.230	-3.000	Yes	21
ddES3	2	const	-7.402	-3.000	Yes	21

Table 3.7 Result of ADF tests for Norway 1990-2012.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	3	const	-3.318	-3.000	Yes	20
ES1	1	const	-1.890	-3.000	No	22
ES2	1	const	-1.427	-3.000	No	22
ES3	5	const&trend	-3.520	-3.600	No	18
ES4	1	const	-1.924	-3.000	No	22

Table 3.8 Results of PP tests for Norway 1960-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
YS	2	const	-3.389	-3.000	Yes	23
ES1	2	const	-1.942	-3.000	No	23
ES2	2	const	-1.820	-3.000	No	23
ES3	2	const&trend	-2.308	-3.600	No	23
ES4	2	const	-3.156	-3.000	Yes	23

Table 3.9 Result of ADF tests for Norway 1990-2012. First differences.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dES1	1	const	-3.733	-3.000	Yes	21
dES2	1	const	-4.439	-3.000	Yes	21
dES3	1	const	-3.730	-3.000	Yes	21
dES4	1	const	-3.952	-3.000	Yes	21

Table 3.10 Results of PP tests for Norway 1990-2012. Lags here refer to Newey-West lags.

Variable	Lags	Specification	Test st.	Crit. value	Stationary	Obs
dES1	2	const	-6.732	-3.000	Yes	22
dES2	2	const	-5.740	-3.000	Yes	22
dES3	2	const	-4.869	-3.000	Yes	22
dES4	2	const	-7.325	-3.000	Yes	22

Appendix 4: ***Results – normality and autocorrelation tests***

Table A4.1 Denmark 1960-2012. Normality tests showing Prob>chi2 and autocorrelation.

Equation	JB test	Skewness	Kurtosis	Autocorrelation
YS	0.12	0.07	0.34	
ES1	0.46	0.28	0.54	
ALL	0.21	0.10	0.53	No
YS	0.17	0.08	0.48	
ES1	0.00	0.00	0.04	
ES2	0.00	0.00	0.09	No

Table A4.2 Norway 1960-2012. Normality tests showing Prob>chi2 and autocorrelation

Equation	JB test	Skewness	Kurtosis	Autocorrelation
YS	0.39	0.22	0.53	
ES1	0.10	0.12	0.13	
ALL	0.16	0.14	0.26	Lag 4
YS	0.32	0.15	0.67	
ES1	0.16	0.06	0.59	
ES2	0.20	0.06	0.79	No

Table A4.3 Denmark 1990-2012. Normality tests showing Prob>chi2 and autocorrelation

Equation	JB test	Skewness	Kurtosis	Autocorrelation
YS	0.00	0.01	0.00	
ES1	0.50	0.69	0.27	
ALL	0.00	0.03	0.00	No
YS	0.32	0.15	0.67	
ES2	0.16	0.06	0.59	
ALL	0.20	0.06	0.79	No
YS	0.60	0.31	0.90	
ES3	0.59	0.64	0.36	
ALL	0.72	0.54	0.65	No
YS	0.01	0.05	0.02	
ES4	0.14	0.09	0.18	
ALL	0.01	0.04	0.04	No

Table A4.4 Norway 1990-2012. Normality tests showing Prob>chi2 and autocorrelation

Equation	JB test	Skewness	Kurtosis	Autocorrelation
YS	0.90	0.74	0.74	
ES1	0.18	0.07	0.64	
ALL	0.45	0.19	0.85	No
YS	0.69	0.42	0.75	
ES2	0.78	0.83	0.50	
ALL	0.87	0.71	0.76	Lag 5
YS	0.81	0.71	0.59	
ES3	0.75	0.45	0.91	
ALL	0.91	0.70	0.86	No
YS	0.81	0.71	0.59	
ES4	0.75	0.45	0.91	
ALL	0.91	0.70	0.86	No