MASTERTHESIS

'THE INFLUENCE OF STRUCTURAL CHANGE ON ENERGY CONSUMPTION'

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Date: 14-10-2014

Study:
Master Public Administration

Specialization:
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FORWORD

A couple of years ago, during my study Environmental Sciences, I read Tim Jackson's (2011) book: 'Prosperity without Growth'. The book discusses the links between fossil fuel consumption, CO_2 emissions and climate change. When I read it I became interested in the subjects natural resource depletion and economic growth. Often-times these issues are treated independently. Milieu activists are calling for environmental protection, while economists stress the need for economic growth. As an environmental scientist I first thought that economies would do well without growth. Also I thought that economic and environmental goals could easily be reconciled by applying some sort of 'techno-fix'. However, things changed when I read Richard Heinberg's (2011) 'The End of Growth'. After I finished the reading I realised that there is a tension between economic and environmental objective. The current neo-liberal economic framework requires economies to grow and growth in turn requires additional input of materials and energy. Problematic is the fact that as soon as we run out of energy, economies stop growing, with unemployment, bankruptcies and rising governmental spending as a result. All these aspects are important for economic and environmental policy decisions.

Because value ultimately depends on the utility attributed to goods and services, I thought that in theory it should be possible to create value with just small amounts of energy. One could think of all kinds of services, which production does not require much energy. Therefore it follows that on paper replacing energy consuming goods by low energy consuming services could save lots of energy. In this research I investigated whether a trend from goods to services is taking place. Also I studied its relationship in comparison to other factors aimed at delinking energy and growth.

While looking back at this research I notice that I learned a lot writing it. Many people inspired me, gave their advices or assisted me with editing this research. Special thanks go to my supervisors Alexey Voinov and Tatiana Filatova. Alexey was always prepared to discuss the energy and economic dynamics. He helped me understanding the influence of Energy Return on Energy Invested on the total energy consumed. Tatiana taught the course called 'Economic measures for sustainability assessment'. During that course I learned about critical natural capital, substitution, downsides of growth, welfare accounting and how to conduct a cost benefit analysis. I am indebted to Thandi Soko-de Jong for her effort in checking my thesis for spelling and grammatical errors. During the master I spent a lot of time with Beau Warbroek and Frederik Röse. I owe them my thanks for the great time we had.

I want to express my thanks to my near family. Almost all of my research took place at home in the living room. My dad assisted me with advices about structuring the research and my mom often served me tea during the afternoon. Ultimately I want to thank the God in who I believe for giving me the opportunity to rationally think about energy scarcity and inspiring me in dealing with this issue.

SUMMARY

Energy is indispensable in human societies. Humans use energy to transform manmade capital and natural capital into goods and services, which represent financial value. For over two centuries cheap fossil fuel energy is used to produce financial capital and to maintain it. Nowadays the world consumes more energy than ever before in human history. About 80% of our energy comes from finite fossil fuels. The relationship between fossil fuel energy and economic growth becomes problematic when realizing that most likely the era of cheap abundant energy will soon be over. Changing the composition of goods and services produced by an economy, called structural change, is often presented as an excellent measure for delinking economic activity from energy consumption. In this research the influence of the expansion of services on energy consumption has been studied by analysing statistical data for Portugal, France, Austria and Denmark over the period from 1970 to 2009. Apart from the influence of structural change, also the influence of the overall level of economic activity, changes in energy efficiency rates and substitution between energy sources has been investigated. If the rise of the service sector would contribute to a declining energy consumption, three requirements should be met:

1. Goods should replace services in terms of absolute financial value added.
2. Services should require less energy per unit of value added than the goods they replace.
3. The energy conservation effect of replacing goods by services should not be offset by economic growth.

A strong relationship between energy consumption and price adjusted GDP is observed in three of the four countries. All countries except Denmark saw their absolute energy consumption increase. Energy consumption quadrupled in Portugal, grew by more than half in Austria and France, but slightly declined in Denmark. Price adjusted GDP tripled in Portugal, doubled in Denmark and grew by about 250% in France and Austria. Between 1970 and 2009 the services sectors in all four countries grew fast in both absolute and relative terms. Crucial is the fact that although the relative contribution financial size of agriculture and industry declined in all four countries, the absolute added value of those sectors increased. This means that services did not replace goods in absolute monetary terms. Moreover many private services like transport and Research and Development depend for their existence on the sales of goods and therefore cannot replace them. The same applies for public goods which are financed by taxes coming from the private sector. This research shows that energy intensity rates in France, Denmark and Austria decreased with respectively 29.8%, 42.2% and 27.4%. In contrast Portugal´s energy intensity increased with 48.1%. Denmark´s energy efficiency performance can largely be attributed to its domestic energy policy starting in the 70´s. Portugal´s poor performance is partly the result of its economic expansion, the rising demand for mobility and the absence of well-defined energy targets. Changes in fossil fuel mix accounted for 9.7% of the variation in energy intensity rates. It positively influenced the energy intensity rates of France and Austria, but negatively affected those of Portugal and Denmark. The energy efficiency effect accounted for 60.5% of the variation in the energy intensity rate and structural change accounted for 29.8% of the variation. The energy intensity of services is significantly lower than that of manufacturing, however services accounted for just 21.7% of all variation in energy intensity rates. So the influence of the tertiarisation on the energy consumption of Portugal, France, Austria and Denmark was very limited.

Modern economies require growth, growth requires energy, but within a short period coal and oil will probably reach their peak production rates. That is why fossil fuel alternatives, energy efficiency, and structural change should compensate for the fossil fuel declines. If these measures turn out to be insufficient, de-growth measures could be taken. Non- fossil fuels can replace considerable amounts of fossil energy, but substitutes are qualitatively inferior to fossil fuels, are expensive, highly intermittent or only available in limited amounts. Energy efficiency improvements face thermodynamic limits and could possibly be raised by 55%. Structural

change could reduce energy intensity rates with an additional 27.5%. In practice these potentials are far more limited, because of socio-economic aspects. Moreover on the long term none of the measures aimed at decoupling energy are insufficient to offset the influence of economic growth. This means that in order to adapt to a reality of limited available energy, European countries should abandon the driving mechanisms behind economic growth at some point in time.

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1 INTRODUCTION

This chapter deals with the current situation regarding to energy. It shows the role of energy in modern-day societies and describes the global energy consumption over time. Also future prospects regarding the demand and supply of fossil fuel energy are described, just as the importance of energy 'decoupling'. In the remaining part of chapter the goal of this research, research questions, relevance and the outline of this research are discussed.

1.1 A BIOPHYSICAL PERSPECTIVE ON THE ECONOMY

Energy is crucial for every human activity. People use capital in combination with labour and energy to transform natural resources into goods and services and to create capital (Cleveland, Costanza, Hall, & Kaufman, 1984). From a physical perspective, the consumption of resources can be compared with an hourglass which cannot be flipped upside down (H. E. Daly, 2005). Human beings extract high quality low entropy useful fuels and materials from the earth's crust, and after consumption these resources decay into high entropy useless waste (see: Figure 2: Entropy hourglass). The size of the material and energy flow is captured with the term: 'throughput' (Daly, 1992, 1997). The hourglass analogy is based on the second law of the thermodynamics which states that with every action taking place in a closed system the amount of useful energy and matter decreases (Ayres, 1998a). Since any process aimed at turning high entropy waste into useful resources requires energy, its availability is essential for human survival (Cohen, 1995). That is why British physicist Frederick Soddy (1933) stated:

"*If we have available energy, we maintain life and produce every material requisite necessary. That is why the flow of energy should be the primary concern of economics*" (p. 56).

As visualized in the picture below does the only energy that enters the earthly system originate from the sun.

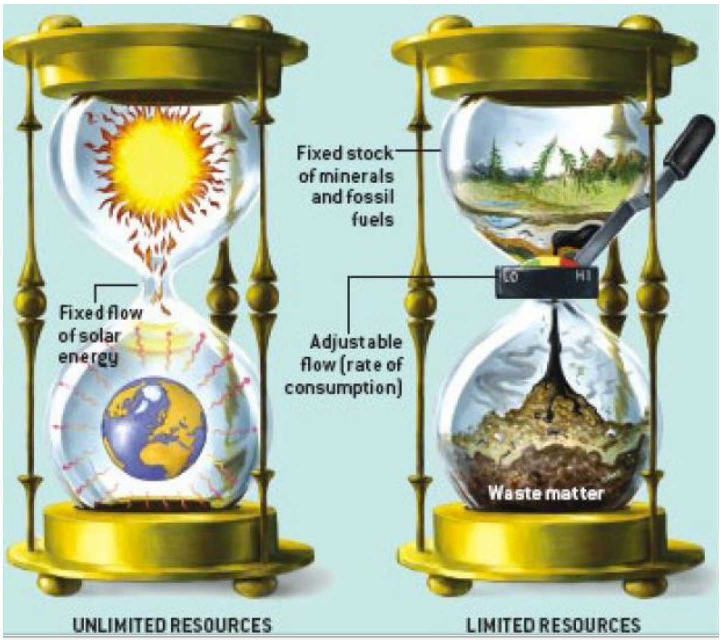


Figure 1: Entropy hourglass Source: Daly (2005).

All traditional societies used human and animal power in combination with technical artefacts to produce food and other goods and services. Prior to the industrial revolution people burned biomass to produce the thermal energy for comfort, cooking food and light (Smil, 2005). During the 18th century most economic activities were agricultural ones, aimed at producing food or feed, but since the beginning of the industrial revolution, human and animal muscles have been replaced by fossil fuel powered machines (Ayres & Warr, 2010). Fossil fuels have been applied on a large scale because of their high energy density, transportability and cheap availability (Cleveland, Kaufmann, & Stern, 2000). Between 1820 and 2010 the world consumption of fossil fuels grew almost 800 fold from approximately 12.9 million tons oil equivalent to 10.3 Gigaton oil equivalent (Maddison, 2007a; WEO, 2012). In 2010, 81.1% of the world's total primary energy supply was generated by fossil fuels (see figure 1: Energy composition by source and sector). Coal generated 3.47 gigaton oil equivalent (Gtoe), oil generated 4.11 Gtoe, which corresponds to about 83 million barrels per day, and natural gas generated 2.74 Gtoe, 0.72 Gtoe was generated by nuclear power plants, 0.3 Gtoe by hydro, bioenergy accounted for 1.28 Gtoe and the remaining 0.11 Gtoe was generated by other renewables.

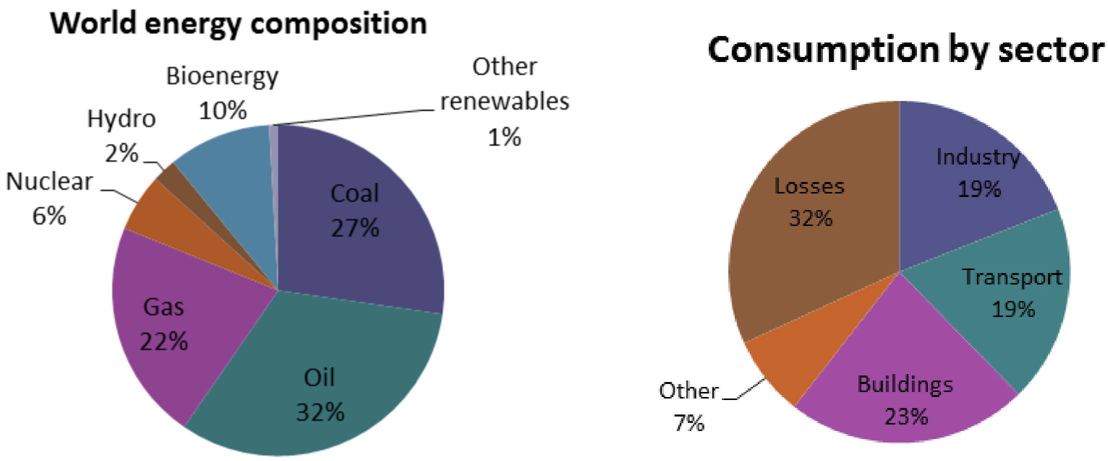


Figure 2 Energy composition by source and by sector. Based on: (WEO, 2012)

Technical innovations enabled us to extract fossil fuels at a relatively low price. Today a litre of gasoline, corresponding with about four days of hard work, only costs a few dollars (Pfeiffer, 2013). Hall and Klitgaard (2011) calculated that the energy consumption of a typical citizen of the US represents the labour capacity of 60-80 energy slaves.

1.2 ENERGY FORECAST

Various researchers point at the fact that the world economy could only continue to grow for two centuries, because of our ability to extract and deploy cheap abundant fossil fuels (Ayres & Warr, 2010; Heinberg, 2011; Smil, 2004). They indicate that economic growth will cease as humanity runs out of fossil fuels. The pattern of oil discoveries and oil supplies follows a bell shaped curve. Campbell (2005) showed that the number of discovered oil barrels already peaked in 1968. The gap oil between discoveries and oil consumption is growing (Collin Campbell, 2006). According to Day et al. (2009), humanity now consumes 4-5 barrels of oil for every barrel that is found. Per capita oil consumption already peaked in 1979 at 5.5 barrels per capita a year and declined from that time on by about 1.2% a year (Duncan, 2000). Moreover since 2000 most of the oil developed oil fields were offshore and according to the International Energy Agency 45% of the oil yet to be discovered is located off the coast (Rubin, 2009; WEO, 2012). These oil fields are depleted much faster than conventional oil.

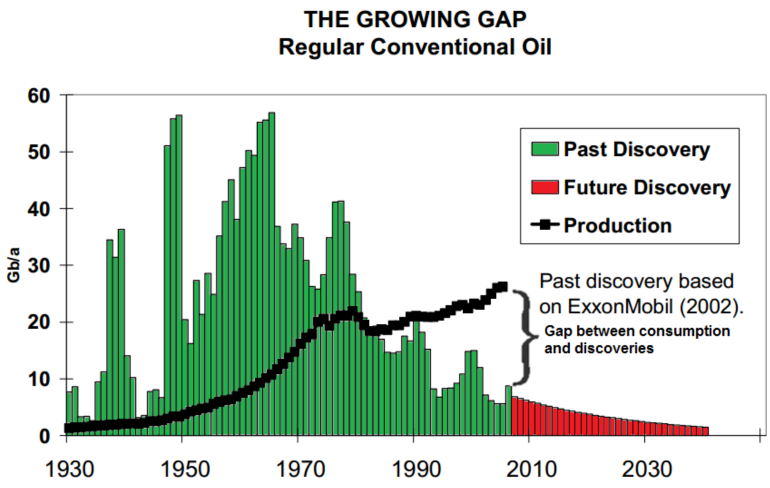


Figure 3: Oil discoveries and oil consumption in Gigabarrels per year. Source: Campbell (2006).

Till today about 1.1 trillion barrels of oil have been produced. Well known petroleum geologists estimate that only 1.2 trillion barrels are still in the ground (Hall & Klitgaard, 2011). Forecasts for peak oil production vary between 1989 and 2030 (Hall & Klitgaard, 2011). Energy analysts Richard Heinberg and David Fridley (2010) expect coal to reach its peak in 2020. Smil (2005) asserts that fossil fuel reserves cannot be accurately determined because no-one knows how much oil is left in the ground. But as the cost for oil production rise, the demand for it will decline and certain oil fields and coal mines will become too expensive to develop (Hall, Balogh, & Murphy, 2009). It is difficult to find out when the global peak of oil will take place, because the total supply is determined by political, geological and economic factors (Hall, Powers, & Schoenberg, 2008). Geological conditions pose the most absolute restriction to fossil fuel extraction, but also our willingness to invest in production capacity and technical abilities to extract fuels are important determinants. When it comes to producing energy, the concept of energy surplus is of major importance. Energy surplus is defined as the energy left over, after subtracting the costs for obtaining it (Hall et al., 2009). Human survival depends on the energy surplus of food production. The remaining energy is used for all kinds of non-subsistence activities, such as leisure time, arts, the production and the consumption of non-agricultural goods and services. Usually energy return on energy investment (EROI) rates are used to express the energy surplus for an energy source. Murphy and Hall (2010) used the following formula to calculate EROI rates:

$$EROI = \frac{Energy\ obtained}{Energy\ required\ for\ getting\ it}$$

Because stocks of fossil fuels are declining, it takes more energy to extract fuels and they come with a lower quality. That is why EROI rates are declining over time and energy production is getting more expensive. Rising oil prices are especially problematic since oil plays a crucial role in modern transport and the production of chemicals (Hirsch, Bezdek, & Wendling, 2005). In 2007 oil provided 94% of the energy used by the transport sector, gas accounted for 3.3%, electricity for 1%, biofuels for 1.5% and other sources accounted for the remaining 0.2% (WEO, 2009). EROI rates for energy sources vary from 1:1 for certain biofuels to >100:1 for hydropower (Hall, Lambert, & Balogh, 2014). Of all fossil fuels, coal has the highest EROI rates. Estimates vary from 27:1 for Chinese coal to 80:1 for US' coal. Hall et al. (2009) discovered that EROI ratios for oil decreased from 100:1 in 1930 to 18:1 in 2000. Minimum EROI rates for oil need to be at least 3:1 when consumed at the gas station in order to be able to repay the energy costs of extracting the oil, refining it, oil transport, building and maintaining vehicles and road etc. (Hall et al., 2009). Other energy resources require similar minimum EROI's. Oil EROI-rates are supposed to reach the ratio of 1:1 by the year of 2035 (Gupta & Hall, 2011). Oil fields with EROI's of 1:1 are not even worth their investment. The EIA expects that due to technical and geological constraints, conventional oil supply will probably never reach the 2006 level anymore (Birol, 2010). Declining EROI ratios cause inflation which in turn leads to declining purchasing power rates (Hall et al., 2009). From a trade perspective energy decoupling is especially important for countries who do not possess large energy stocks. Hallock et al. (2004) for instance show that from all the 200 nations of the world only 42 countries produce oil and only 38 of them export it to other countries.

1.3 THE NEED FOR ENERGY DECOUPLING

Because nowadays humanity uses more energy than ever before and most of that energy comes from exhaustible fossil fuels, the absolute energy used by the global economy needs to decline at some point in time. In addition large amounts of harmful emissions, like CO_2, NO_x and PM10 are associated with fossil fuel combustion (Lvovsky, Hughes, Maddison, Ostro, & Pearce, 2000). Therefore products and production processes should be designed in such a way that producing the same wealth as before requires less energy (Jackson, 2011). This process is called decoupling, or dematerialization. It is important to distinguish the concept of relative decoupling from that of absolute decoupling. Relative decoupling can be defined as reducing the energy required for producing a unit of gross domestic product (GDP), while absolute decoupling means reducing the absolute energy amount flowing through the economy (Behrens, Giljum, Kovanda, & Niza, 2007). Four ways can be distinguished when it comes to energy decoupling. One of them is by changes in the composition of output of the economy, which is called: 'structural change' (Stern, 2004b). Since the 1970's many researchers recognized that structural change is an important determinant regarding the energy need per unit of economic output (Liu & Ang, 2007). The evolutionary theory of industrial society describes how economies evolve from agriculture and industry, to services (Heiskanen & Jalas, 2000). Adherents of this theory expect economies to evolve in an environmentally friendly direction, from polluting heavy industrial goods to benign services. Daniel Bell (1976) for instance claims that societies slowly evolve to a post-material stage in which goods are replaced by services. According to Stonier (1983) Kahilainen (2000) and Kelly (1999) information will replace other production factors like nature, capital and labor and Danny Quah (1996) assumes future value to be expressed in bytes and bits. Goldemberg et al. (1985) expect that the rise of the service sector will lead to a lower energy demand. Intuitively this line of thought makes sense. Empirical research shows that for instance internet activities require five times less energy per unit of economic output than average economic activities (Laitner, Koomey, Worrell, & Gumerman, 2000). In line with the theory Rowthorn and Ramaswamy (1997) have shown that the share of services as percentage of GDP has grown in all industrialized countries over the period from 1960 to 1994. Also Dietrich (2009) concluded that a significant relationship exists between economic growth and the rise of the service sector. Jänicke et al., (1997) distinguished four assumptions underlying the evolutionary theory of industrial society:

- When per capita income increases, non-material services are valued higher, just as the qualitative aspects of products like durability and sustainability (Dinda, 2004);
- The material intensity of all goods and services is expected to decline as a result of technical progress;
- The share of the service sector measured as proxy of the gross domestic product will grow at the cost of the agricultural and the industrial sector;
- The demand for basic materials within processing industries will decrease, due to process optimization and flexible production schemes like just in time production.

Other assumptions are that value is only created by knowledge, globalization is inevitable and work can be localised everywhere (Huws, 1999). The implications of a potential of structural change could be far reaching. If in modern economies physical goods were replaced by non-physical services, like the scholars mentioned above assume, economies could keep growing, while reducing their material and energy consumption rates at the same time. Opponents of the evolutionary theory of industrial society, consider economic growth as being the cause of environmental deterioration instead of the solution to it (Ayres & Warr, 2010; Stern, 2004a, 2004c). Empirical research shows declining rates for certain emissions like NOx, SO_2 and CO (Bossanyi, 1979; Grossman & Krueger, 1991). However other scholars point out that global pollutions like CO_2, most natural resources and energy consumption are rising (Stern, 2004c). Moreover, because most of the world's countries are in the early stages of economic development, worldwide pollution and fossil fuel consumption are expected to increase (Ayres, 1996; Ekins, 1997; Holtz-Eakin & Selden, 1995).

1.4 ENERGY DECOUPLING OF EUROPEAN COUNTRIES

Because of the fact that energy is a precondition to all economic activities and fossil fuel supply is expected to decline over time, it is important to investigate to which degree the rise of the service sector of countries contributes to a reduction in energy consumption levels. European countries rely heavily on energy imports. 52.4% of all energy used by the EU in 2006 was imported and energy accounted for 54% of all the imports by that time (Eurostat, 2014; Weisz et al., 2006). The European (2002) estimates that if the current trend continues by 2030 even 70% of all energy consumed in the European Union should be imported. For this reason the evolutionary theory of industrial society will be tested for four European countries. In order for services to contribute to absolute energy reduction, three conditions should be met:

1. Goods should replace services in terms of absolute financial value added.
2. Services should require less energy per unit of value added than the goods they replace.
3. The energy conservation effect of replacing goods by services should not be offset by economic growth (Heiskanen, Halme, Jalas, Kärnä, & Lovio, 2001).

In order to investigate how structural change affects energy consumption, theories of structural change and dematerialization will be discussed. Subsequently the relationship between structural change and energy consumption will be discussed for four European countries: Denmark, Austria, Portugal and France over the period from 1970-2009. If it turns out that significant decoupling results can be achieved by structural change, current levels of economic activity could be maintained some time. If structural change is not sufficient for bringing down the energy consumption levels, other measures oriented at decoupling should be taken.

1.5 OBJECTIVE

The aim of this research is to gain insight into how the rise of the service sector relates to the consumption of energy. This is done by using statistical data for structural change and energy consumption for Austria, Denmark, France and Portugal over the period from 1970 to 2009.

1.6 MAIN QUESTION AND SUBQUESTIONS

The main question of this research is: '*To what extent and how does the rise of the service sector influence energy consumption?*'.

In order to answer this question, four questions listed below will be answered:

1. What is the relationship between economic growth and the sectorial shift to the service sector?
2. What is the relationship between economic growth and energy consumption?
3. To which degree does outsourcing the energy intensive industries affect the reduction of consumed energy?
4. What are the implications of our abilities to decouple energy from economic activity for economic policies?

1.6.1 DEFINITIONS

Structural change: A change in the sectorial composition of the economy, measured in 2005 dollar value output. This research especially focusses on the potential effect of the shift from the agricultural and industrial sectors to the service sector, because of its alleged low energy intensity.

Energy dematerialization/ decoupling: The absolute reduction of energy consumed in a national economy. In this study the energy embodied in imported goods and services is taken into account.

1.7 SOCIETAL AND SCIENTIFIC RELEVANCE

In the past century, economic growth has become one of the main policy goals of politicians and policy makers. Growth of per capita GDP increases overall purchasing power and leads to a higher quality of life under certain circumstances (Jackson, 2011). Economic growth is a necessary element in capitalistic economies. Without growth companies are unable to repay their debts and will get bankrupted, unemployment rates will rise, governmental expenditure increases and tax incomes decrease at the same time (Spangenberg, 2010). Eventually long-lasting economic stagnation may even lead to severe social disruptions (Brown et al., 2011). Growth, however required huge amounts of fossil fuel energy in the past. Therefore it is highly questionable whether this process can continue in the future. Moreover growth has many downsides as we will show in chapter two. Scholars have tested the relationship between the rise of the service sector and the use of particular natural resources in the past. Sousa and Ometto, (2011) give an overview of case studies which are conducted for various resources. However a coherent overview of the causes for fossil fuel dematerialization and the theoretical potential for absolute energy decoupling by means of structural change is omitted. It is of crucial importance to respond to future energy scarcity in the right way.

1.8 THESIS OUTLINE

In the second chapter of this thesis the theoretical framework will be presented. The relationship between energy and economic growth will be discussed in that chapter as well as the conditions for energy decoupling. Chapter three presents the methods used in this research. To which degree structural change contributed to an absolute energy decoupling in France, Austria, Portugal and Denmark is discussed in chapter four. The policy implications of the dematerialization effect caused by the rise of the service sector will be discussed in chapter five and in chapter six the conclusions of this research will be presented.

2 THEORETICAL FRAMEWORK

In this chapter theories about economic growth and structural change will be described. First the drivers of energy supply and demand are explained, secondly the main causes for economic growth will be discussed. Subsequently we will go into the four explanations of energy decoupling. Special attention is devoted to the principle of structural change. It is important to get a grasp of the drivers for structural change in order to discover the likelihood that structural change meets the criteria that lead to energy decoupling.

2.1 EXPLAINING ENERGY SUPPLY AND DEMAND

During the past centuries technical innovation improved our ability to extract and deploy large amounts of fossil fuels (Ayres, 1998b). The costs of energy declined over time as our methods to extract energy improved. Synchronously to the introduction of fossil fuels, all kind of appliances were invented. During the early 18th century Newcomen introduced his steam engine in England and almost a century later James Watt introduced his more efficient engine (Smil, 2004). It took a long time before coal was widely applied. After a certain time more and more appliances were introduced to use the energy source. Coal was first used in the cotton industry and subsequently by trains, ships and metallurgy (Foster, 2005). Oil was commercialised in 1859 by colonel Edwin Drake in Titusville Pennsylvenia (Bank, 2010). At first he produced just 15 barrels of oil a day, but within a year he raised the production to a 500.000 barrels per day. Two years later production reached three million barrels per day. Oil was first cracked to produce kerosene for lighting. It took until 1882 for the first electricity generation plants to be built (Smil, 2004). During that period a whole range of inventions constituted the basis for the fossil fuel era like the electric transformer, the electric motor and the carburettor. The rising energy demand fostered upscaling the fossil fuel production, and the introduction of new extraction methods, which in turn resulted into lower energy prices and a higher energy demand (Ayres, 1996). Nowadays energy only accounts for 4-6% of the production costs in industrialized countries (Baron, 1997; Warr & Ayres, 2010). In the past two centuries the supply for energy was largely constrained by the demand for it. Technical progress allowed humanity to lower the production costs of fossil fuels. The United States for instance managed to raise its oil production between 1930 and 1960, while the oil price was falling (Cleveland & Kaufmann, 2003). In the past few decades political and economic factors as well as the physical availability of oil have become more important (Hall et al., 2008). In the next paragraph, when the relationship between energy and economic growth is discussed, more details about the physical availability of fossil fuels will be revealed.

2.2 EXPLAINING ECONOMIC GROWTH

Economic growth is nowadays measured in terms of gross domestic product (GDP). It measures the monetary value of all the goods and services produced by a country in one year (Cobb, 1995). More specifically it captures the final sales of products, investments, businesses inventory, and the value of exports to other countries minus the monetary value of imports over the period of one year (Burda & Wyplosz, 2012). Real GDP can be calculated by correcting GDP for inflation. Joseph Schumpeter thought that economic growth was primarily caused by technical breakthroughs which changed the structure of existing markets or created entirely new ones (Schumpeter, 1939). Neoclassic economists endorse this view by assuming that technical progress is the only cause of continuous economic growth (Grossman & Helpman, 1991; Lucas Jr, 1988; Romer, 1990; Solow, 1956). Other production factors like nature, capital and labor, and energy are deemed less important. Yet the question is whether they are right.

2.2.1 ENERGY THE ENGINE OF ECONOMIC GROWTH

During the past two centuries technical breakthroughs enabled us to release huge amounts of fossil fuels energy, raise productivity rates and lower production costs (Ayres, 1998b; Wrigley, 1990). Without the technical abilities to utilize energy, this kind of extraordinary growth would not even be possible. Since without energy no single economic activity can take place technical progress and other production factors like capital and labour are actually by-products of the primary production factor solar energy (H. E. Daly, 2005; Kümmel, 1989). Energy declines can only to a limited extent be offset by technical progress. Fossil fuel extraction follows the low hanging fruit principle. High quality easy accessible fuels are extracted first, but the quality of the remaining fuel will decline and the effort to extract energy will grow with every additional energy unit extracted out of the ground (Heinberg, 2011). Energy also explains much of the variation in economic growth. Reiner Kummel (1989) investigated the production of goods and services of Germany, Japan and the United States. He discovered that energy and technological progress taken together explain economic growth to a large extent. Cleveland et al. (2000) showed that after adjusting for the quality of energy sources, energy consumption caused GDP for the United States. Smil (2005) found that the relationship between energy and the GDP of 63 countries was 0.96 and the variation in consumed energy explained 92% of the variance in GDP (constant 1990 $). He discovered that both indicators rose 16-fold during the past century. Chontanawat, Hunt and Pierse (2006) investigated the one sided relationship running from energy to growth for 30 OECD countries and 78 non-OECD countries and found Granger causality for 87% of the OECD countries and 65% of non-OECD countries. Most studies point at an unidirectional relationship running from energy to economic growth, indicating that energy causes economic growth and is the limiting factor to it (Ozturk, 2010).

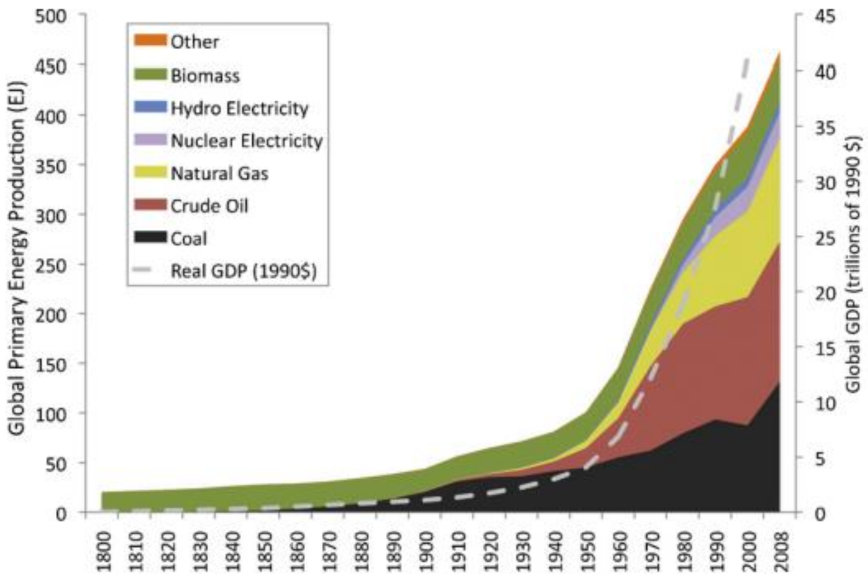


Figure 4: Correlation energy consumption growth. Source: (Murphy & Hall, 2011)

2.2.2 ENERGY GDP AND STRUCTURAL CHANGE

Energy does not just explain GDP, but also indirectly also explains the change in the sectorial composition of economies. Investigating the relationship between growth and structural change for 65 countries, Echevarria (1997) found a negative relationship between GNP growth and the share of primary goods and a positive relationship between GNP growth and service sector growth. Klodt (1997) and Dietrich (2009) came up with similar results. The cause for this shift is interpreted in three different ways. Adherents of the supply side theory attribute the shift from the primary to the tertiary sector to productivity increases, which enabled humanity to liberate a part of the population from subsistence activities (Clark, 1967; Fisher, 1939; Wrigley, 1990). Demand side theorists associate this development with changing consumer preferences, while outsourcing theorists relate the rise of the service sector to outsourcing business activities from the industrial sector to the service sector (Baumol, 1967; Schettkat & Salverda, 2004; Schettkat & Yocarini, 2006). In Appendix 1 all three theories are explained more elaborately. Important regarding these theories is that if changing preferences would turn out to be the best explanation for the rising service sectors, the shift from goods to services could be part of the solution to our current energy challenge. On the other hand if the expansion of the tertiary sector would turn out to be the product of energy driven productivity increases, the shift from goods to services would be part of the problem.

2.2.3 CAPITAL AND INCOME

In most of today's countries economic growth is an important policy goal. It is often assumed that when the economy grows people's ability to purchase goods and services increases and therefore they will be happier, but empirical evidence shows that oftentimes this is not the case (Daly & Farley, 2010; Layard, 2011). Other points of critique are that GDP ignores the division of income, and that it adds the value of goods like education and cultural expenditure to that of so-called 'bads', like the production of weapons, the prevention of disasters etc. (Costanza, Hart, Talberth, & Posner, 2009; Easterlin, 1974; Ekins, Simon, Deutsch, Folke, & De Groot, 2003; Lawn, 2003). Regarding this research, GDP's inadequacy in discerning capital from income is especially important. GDP ignores the value of non-monetary social and environmental capital that is consumed to create monetary value. In his book 'Wealth and Income' Hicks (1946) emphasized the importance of distinguishing capital from income:

"The purpose of income calculations in practical affairs is to give people an indication of the amount which they can consume without impoverishing themselves. Following out this idea, it would seem that we ought to define a man's income as the maximum value which he can consume during a week, and still expect to be as well off at the end of the week as he was at the beginning" (p. 172).

In order to calculate income in a more reliable way, scholars have insisted that natural capital and built capital depreciation should be subtracted from the GDP (Talberth, Cobb, & Slattery, 2007). For its role in the economy it is of special importance to subtract fossil fuel revenues. Uneconomic growth takes place when the value of the social and environmental capital used to produce monetary value exceeds the monetary value produced by the economy (H. Daly, 2005). That is why in order to avoid impoverishment the link between fossil fuel consumption and economic growth should be disconnected.

2.3 ABSOLUTE AND RELATIVE DECOUPLING

Important regarding the relationship between energy consumption and economic growth is the concept of 'decoupling'. Relative decoupling can be defined as reducing the energy required for producing a unit of gross domestic product (GDP), while absolute decoupling implies reducing the absolute energy amount in the economy (Behrens et al., 2007). Countries and sectors differ in their energy requirement per unit of value added. The energy required for the production of a unit of GDP is captured by the concept 'Energy intensity' (Mulder & de Groot, 2012). It is calculated with the following formula:

$$EI = \frac{Consumed\ energy}{GDP} \qquad (1)$$

It is often asserted that energy intensity declines contribute to lower energy prices and indirectly result into higher energy consumption levels (Herring, 1999, 2006). Khazzoom as cited by Maddler and Alcott (2009) showed that the price reductions of a good or service induced by declining energy intensity rates cause the supply curve to shift rightward, thereby ceteris paribus contributing to a larger energy demand. In such a situation relative decoupling between energy and GDP takes place, while the absolute amount of energy consumed increases.

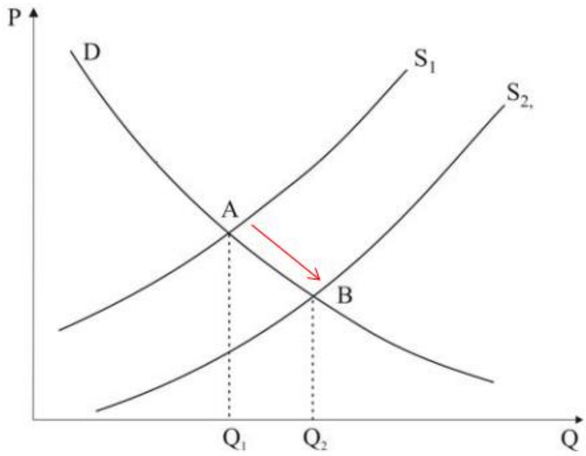


Figure 5: Shift of the supply curve. Source: (Madlener & Alcott, 2009).

Declining energy intensity rates are thus neither necessary nor sufficient for reducing energy consumption levels. For both absolute and relative decoupling to occur at the same time, energy intensity rates must decline faster than the economic growth rate (Spangenberg, 2010).

2.3.1 EXPLAINING ENERGY DECOUPLING

In the previous paragraphs we saw that the economic growth that took place during the past centuries was enabled by the supply of massive amounts of cheap energy. Because the era of cheap fossil energy will soon be over and about 80% of today's energy comes from fossil fuels, the growth and energy consumption should be delinked (WEO, 2012). Decoupling may result from intrinsic motivations of economic actors, or is enforced by external factors like governments, oil exporting countries or physical limits (Mol, 1997). Variables that explain the energy GDP relationship have been classified in different categories by various scholars (Ang, 2004; Cleveland & Ruth, 1998; Ziolkowska & Ziolkowski, 2011). In this research just four categories are distinguished following Stern (2004b):

1. *The change in the overall activity level of a country.* The most important explanatory variable belonging to this category is the GDP level, but also non-market activities influence the activity level. Energy is an important explanatory variable for economic growth, but economic activity does also explain the demand for energy. Other factors kept constant, economic decline will result into energy savings and economic growth leads to higher energy consumption levels (Chertow, 2000). The existence of black markets leads to overestimating a country's Energy Intensity (Smil, 2005). Schneider (2005) estimated that shadow economies capture on average 16.4% of the GDP in OECD countries.

The following three factors determine the energy intensity (1) of an economy:

2. *Substituting one energy source for another.* Energy sources differ in their capacity to do useful work, their power density, flexibility of use, Energy Return on Energy Invested (EROI), etcetera. Cleveland et al. (2000) found that the marginal product of oil is 2.64 times higher than that of coal and 1.21 times higher than that of gas. Furthermore, compared to coal gas produces 2.1 times more value per unit of energy. The marginal

product of electricity is even considerable higher than those of gas and oil. Based on these factors they can be ordered from high to low quality, starting with electricity and followed by gas, oil, coal and wood (Stern, 2004a). If high quality fuels get exhausted countries need to shift back to lower quality ones, which in turn contributes to energy increases, so replacing one fossil fuel by another is no final solution to energy scarcity (Stern, 2004a). Apart from theoretical limits, the potential for energy sources is constraint by economic, geographical, technical and social factors (De Vries, van Vuuren, & Hoogwijk, 2007).

3. *Energy efficiency developments*, meaning that producing the same good or service requires less or more energy than before. On a country level, energy efficiency developments are measured by monitoring the energy intensity of sectors over time (Ang, 2004). Thermodynamic laws limit the maximum achievable energy efficiency levels. Energy can never be generated nor used at a 100% efficiency. Photovoltaic cells for instance can at maximum convert 66% of all sunlight (Blankenship et al., 2011) Furthermore energy efficiency improvements follow the low-hanging fruit principle. In practice this means that the economic returns on energy efficiency investments will decline over time (Heinberg, 2011). A picture capturing this principle is displayed below:

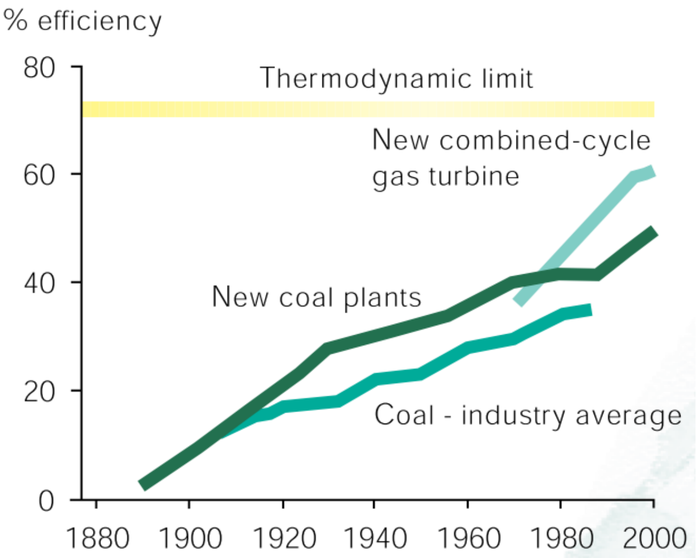


Figure 6: Efficiency development electricity production. Source: Davis (1997)

4. *Changes in the composition of goods and services produced and consumed by an economy, called structural change* (Stern, 2004a). In this research special emphasis is paid to this category of energy decoupling. On a country level the structure effect is measured by looking at the shifts in the financial contribution of separate sectors over time, which is done in this research (Ang, 2004). Shifts in the composition of output may be enforced by the government, result from scarcity, or may result from autonomous free producer- and consumer choices. Factors as the introduction of new products, market saturation and the introduction of leasing constructions cause structural change (Cleveland & Ruth, 1998; Tukker, 2004). Displacing energy intensive activities to developing countries is also part of structural change. Many expanding economies tend to displace polluting economic activities to developing countries (De Bruyn, 2000; Dinda, 2004; Rubin, 2009; Smil, 2013b; Stern, Common, & Barbier, 1996). According to Grossman (1995) does displacement of dirty industries to developing nations not significantly contribute to reductions in energy consumption of modern economies.

2.3.2 CONCEPTUAL MODEL

The four factors contributing to energy decoupling are included in the diagram presented below. The model departs by recognizing that currently huge amounts of finite fossil fuel energy is used to drive economies. As described in the first chapter of this research, energy cannot be replaced by other resources. In the context substitution means replacing fossil fuels by other energy sources. Outsourcing energy is possible on a country scale but not possible on a global scale.

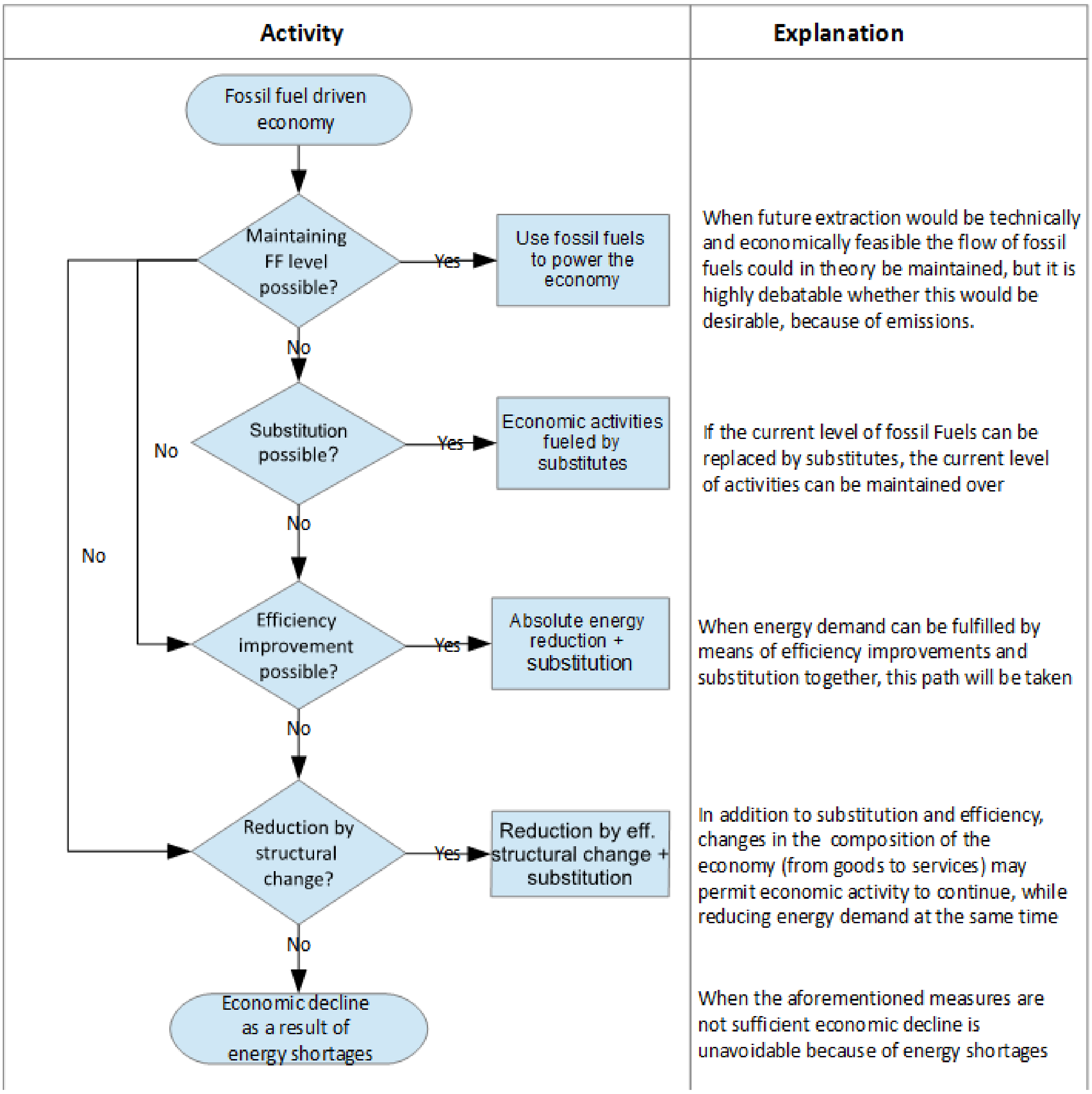


Figure 7: energy decoupling model

Structural change has the potential to contribute to significant energy savings (Romm, Rosenfeld, & Herrmann, 1999). That is why this research will specifically focus on energy reduction by changing the composition of an economy and more specifically the shift from goods to services. As we see in the model presented above, if all measures turn out to be insufficient in reducing our fossil fuel dependency, economic decline will take place anyway. In that case these measures would only stimulate a certain degree of resilience (Dhawan & Jeske, 2006). Two options would be left. Governments would accept uncontrolled economic decline, or they would try to direct economies in the direction of de-growth. The latter option implies trying to improve human wellbeing and the ecological situation while downscaling production and consumption levels at the same time (François Schneider, Kallis, & Martinez-Alier, 2010).

2.4 CONDITIONS FOR ENERGY REDUCTION BY STRUCTURAL CHANGE

So far we noticed that the exploitation of large amounts of fossil energy allowed the global economy to grow for two centuries. Economic growth in turn caused structural change from agriculture via industry to services. This kind of structural change only contributes to energy cuts if three conditions are met:

1. Goods should replace services in terms of absolute financial value added.
2. Services should require less energy per unit of value added than the goods they replace.
3. The energy conservation effect of replacing goods by services should not be offset by economic growth (Heiskanen et al., 2001).

In chapter four the influence of structural change on energy consumption will be investigated for France, Portugal, Austria and Denmark. We investigate whether energy consumption levels have grown, or declined over the 1970-2009 period and to which extent measures aimed at energy decoupling influenced energy consumption levels.

3 METHODOLOGY AND DATA

This chapter describes the methodological framework used in this research. First the choices regarding the design will be justified. Which data is used is described next and finally the case selection will be discussed.

3.1 DESIGN

This research aims to explain the relationship between structural change and energy consumption. Contemporary biophysical economics assumes a strong link between economic growth and energy consumption (Cleveland et al., 1984). From an ecological view on the economy, the relationship between energy consumption, economic growth and structural change will be studied. The focus of this research is theory verification, which means in this case that the evolutionary theory of industrial change will be tested (Punch, 2000). In addition to qualitative literature, quantitative methods are used to answer research questions. Based upon numerical data, inferences will be drawn about causes and effects of energy intensity changes (Creswell, 2013). A longitudinal retrospective design is used. In order to draw reliable inferences about changes in the composition of economic output and their effect on energy intensity, the influence structural change will be measured over a period of 40 years (Gerring, 2011). The observations will contribute to the development of theory on energy consumption. As a first step of the research, the energy consumption over time is mapped and explained combining a biophysical and economic perspective.

3.1.1 ENERGY DECOUPLING

WorldBank (2014) data on total energy consumption will be used to investigate whether relative or absolute decoupling took place and to draw a simple correlation between energy consumption and economic growth. This method allows us to measure the direction and the strength of the relationship between the two variables (Zou, Tuncali, & Silverman, 2003). Fossil fuel revenues will be subtracted from the GDP of the four European countries in order to get a more reliable overview of the countries income. The WorldBank (2014) indicator ‘adjustment savings: energy depletion’ captures the dollar value of supplied fossil fuels. Based upon data on absolute and relative value added will be determined whether or not services have replaced goods. People’s actual willingness to pay goods or services will not be measured. Furthermore based upon existing literature on sectorial connections the feasibility of replacing goods by services will be determined (Heiskanen et al., 2001). When looking at the energy data, especially the influence of energy exports will be taken into account. The influence of Both the quality of energy and the influence of renewables will be dealt with. Currently no studies for European countries on the influence of fuel composition do exist. However Cleveland et al. (2000) investigated the marginal product of coal, oil and gas. This indicator is used to determine the influence of changes in the fossil fuel composition on the energy intensity (1) of Portugal, France, Denmark and Austria. The influence of energy efficiency improvements and structural change on energy decoupling will be investigated using data on index composition analysis conducted by Mulder and de Groot (2012). Index decomposition analysis allows for decomposing energy trends into three components: the influence of the activity level of an economy, the influence of energy efficiency changes within sectors and the effect of changes in the composition of the economy, called the structure effect (Ang, 2004; IEA, 2008). Time series allow us to keep the aggregate structure and activity levels constant in order to calculate the relative contribution of each of them to the energy intensity over time. Because countries can reduce their energy intensity by importing energy intensive goods and services, the effect of outsourcing is accounted for.

3.1.2 POLICY IMPLICATIONS

In chapter five of this research the implications of existing energy paths will be discussed. Because the availability of sufficient energy is of major importance for modern societies, the potential and limitations of energy decoupling will be investigated. This research will be finished by presenting the measures required for adapting to the future energy reality. Based on existing literature on de- growth and steady state economics, measures are selected. These measures account for the socio-economic and the bio-physical dimensions of the energy challenge, as well as people's willingness to take these measures. When it comes to energy policy, often times only one of these two dimensions is dealt with, but policy should deal with both dimensions in order to be effective (Kallis, Kerschner, & Martinez-Alier, 2012; Smith, 2010).

3.2 DATA COLLECTION

Different datasets are used for this research. Most of the data used originates from the World Bank (2014) and covers the period from 1970 till 2009. WorldBank (2014) data are used to draw graphs on the correlation between absolute energy supply in Megaton oil equivalent (Mtoe) and economic growth in constant 2005 dollars. The indicator ton oil equivalent (toe) captures the energy content of one ton oil, which is about 41.87 Giga Joule (Hall & Klitgaard, 2011). One Megaton oil equivalent is equal to 1,000,000 million ton oil and has an energy content of approximately 41.87 Peta Joule. The relative and absolute size of the agricultural sector, industry and services is described using WorldBank (2014) data. Changes in employment levels in each of the three sectors is described using OECD (2014) data. Energy intensity developments in all four countries are described based upon International Energy Agency data (IEA, 2006b, 2009a, 2009b, 2009c, 2011). Data retrieved from BP (2011) is used to describe the energy mix for Portugal, France, Denmark and Austria over time. The outcomes of an index decomposition analysis are used to investigate the separate influence of structural change and energy efficiency on the energy intensity of the four European countries. As inputs for this analysis, the authors used EU- KLEMS growth and productivity data and energy data from the International Energy Agency (Mulder & de Groot, 2012). These separate databases were enriched with energy inputs in (Ktoe) and adjusted to US $ PPP's in order to be comparable. This means that the GDP of countries has been adjusted for its ability to buy a specific basket with goods and services (Rogoff, 1996). Data on value added and energy consumption were used for 50 separate sectors. For Austria, Denmark and France data is available for the period from 1980 to 2005. For Portugal data over the period from 1995 till 2005 are used, because the dataset for the period before is incomplete. The energy required for the production of export products will be subtracted from the energy account of the producer- country and added to the energy account of the consumer- country in order to calculate the final energy consumption in the most reliable way (Hong, Pei Dong, Chunyu, & Gang, 2007).

3.3 CASE SELECTION AND SAMPLING

EU citizens, representing 7.3% of the world population consumed 1713 million tons of oil equivalent energy (Mtoe) in 2008, which corresponds to 13.46% of the global energy demand. The EU is highly dependent on countries outside the EU for its energy supply. Nowadays it relies on non-European countries for 54% of its energy needs (Eurostat, 2013). For this reason the relationship between structural change and energy consumption is investigated for four European countries (N=4). For the northern part of Europe one country with a large service sector (Denmark) and one country with a small service sector (Austria) are selected. The same is done for the southern part of Europe for which France and Portugal are selected. The investigated countries represent European countries in general.

4 RESULTS

In this chapter I will show the relationship between structural change and energy consumption for Portugal, France, Denmark and Austria. First the correlation between economic growth and energy consumption will be presented for the period from 1970-2009. Subsequently the rise of the service sector will be explained using data on relative and absolute sectorial contribution. Finally the results of a decomposition analysis will be used to explain the influence of energy efficiency and structural change on variation in energy intensity.

4.1 ENERGY POLICY

Many European countries started their energy policies in response to the oil shocks in the 1970's. Since that time a wide range of policies were introduced by European countries aimed at lowering the dependence on fossil fuels. EU-member states agreed on the goal of producing 20% renewable energy by 2020 (Commission, 2009). Examples are voluntary agreements, financial motivations, research and development programs and efficiency standards. General policy applied by countries are measures oriented at improving heat pumps utilizing remnant heat and insulation. On a EU level minimum standards were introduced for boilers and for instance cold appliances. Also labels were introduced for household appliances and voluntary agreements were made on dishwashers, TV's and the fuel economy of cars (Geller, Harrington, Rosenfeld, Tanishima, & Unander, 2006). The European Union aimed to reduce its energy intensity by 1% annually (EC, 2002). In the table presented below, the particular energy policies of Portugal, France, Denmark and Austria are presented.

Portugal	*Renewable energy.* Portugal's aim is to generate 31% renewable energy by 2020 (EC, 2013). It uses Feed In Tariffs for investments in wind, biomass and photovoltaic cells. As a result wind-energy is on the rise since the year of 2001 (Haas et al., 2004). In addition Portugal reserved €35 million for an investment fund that stimulates innovation in renewable technology (IEA, 2006a). *Efficiency and structural change.* The Portuguese government obligated car manufacturers to label all passenger cars and it choose to liberalise energy markets (IEA, 2006a, 2009c).
France	*Renewable energy.* The France government committed itself to produce 23% of renewable energy by 2020 (EC, 2013). Just as in Portugal, Feed In Tariffs are used in France to guarantee producers a minimum price for their energy. Producers receive 5.5-6.1 c€ per kWh energy from hydrologic dams, 3.1-8.4 c€ per kWh wind-energy over a period of 15 years, c€ 15-30/ kWh for electricity from solar cells (Haas et al., 2004). France is especially famous for its nuclear energy policy. Since 1970 the country built 58 pressurized water reactors which generated 30% of its total energy supply in 2010 (Grubler, 2010). *Efficiency and structural change* The past 30 years, efficiency standards for buildings have been introduced, cars have been labelled and a stimulation package for low- carbon vehicles has been launched (Geller et al., 2006; IEA, 2006a).
Denmark	*Renewable energy.* Denmark uses a whole range of measures to achieve the goal of 30% renewable energy by 2020 (EC, 2013). Feed In Tariffs (FIT) are used, tax benefits, etcetera. By 2000 FIT's were drastically reduced (Haas et al., 2004). The Danish government aims to reduce fossil fuels by 15% and to produce 30% renewable energy by 2025. One of the measures to reach that target is doubling its current wind capacity. The tight electricity grid enables Denmark to transport an amount of electricity, equalling three times its domestic demand on a daily basis (Sovacool, Lindboe, & Odgaard, 2008). *Efficiency and structural change.* Denmark's government aims to lower its energy intensity with 1,7% per year while Denmark's energy intensity is already 35% lower than that of average International Energy Analysis countries (IEA, 2006a). Over the past 30 years, efficiency standards for buildings have been introduced. Also CO_2 taxes exist for fossil fuels (Geller et al., 2006).

Austria	*Renewable energy.* By 2020 Austria wants to retrieve 34% of its domestic energy demand out of renewables. With its 30% renewable energy, Austria is the fourth largest producer of renewable energy in Europe (EC, 2013). Quota of 8% for energy originating from hydrologic dams and 4% for other renewables, should be achieved in 2008 (Haas et al., 2004). *Efficiency and structural change:* Austria introduced subsidies for the renovation and insulation and the country is a frontrunner in efficient building (Togeby, 2009). Denmark's government supports all kinds research to energy efficiency but does not enforce those measures (IEA, 2009a).

Table 1: Energy policy in Portugal, France, Austria and Denmark

4.2 ECONOMIC GROWTH AND ENERGY CONSUMPTION

One of the four variables explaining energy consumption is the overall level of economic activity. In chapter two we saw that energy consumption contributes to economic growth which in turn leads to structural change. Structural change is assumed to contribute to energy decoupling. The graphs pictured below are drawn based upon WorldBank (2014) data and show the dynamics between energy consumption, measured in Megaton oil equivalent and GDP, measured in constant 2005 US dollars.

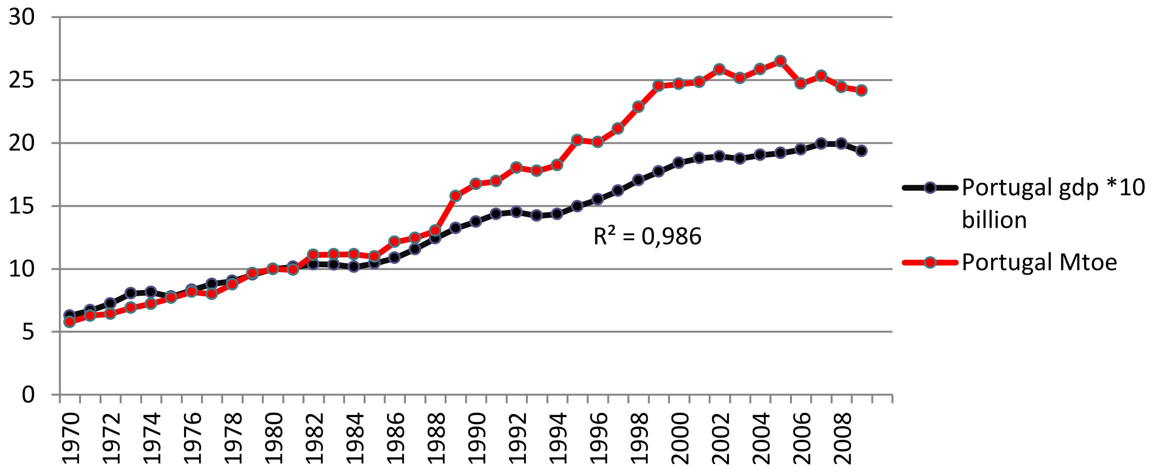


Figure 8: Dynamics between energy (Mtoe) and GDP (constant 2005 US$) in Portugal (WorldBank, 2014)

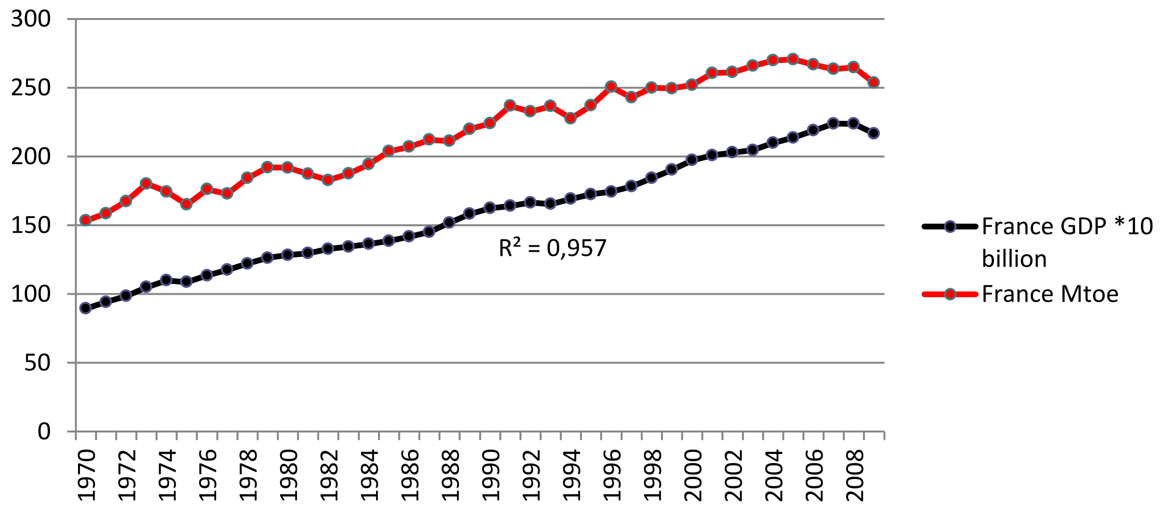


Figure 9: Dynamics between energy (Mtoe) and GDP (constant 2005 US$) in France (WorldBank, 2014)

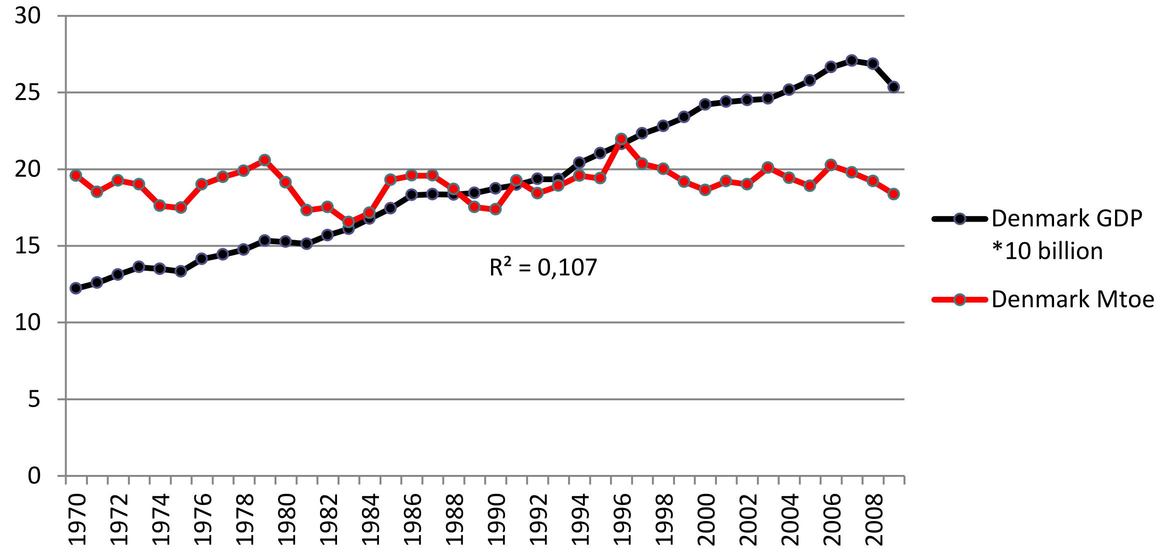


Figure 10: Dynamics between energy (Mtoe) and GDP (constant 2005 US$) in Denmark (WorldBank, 2014)

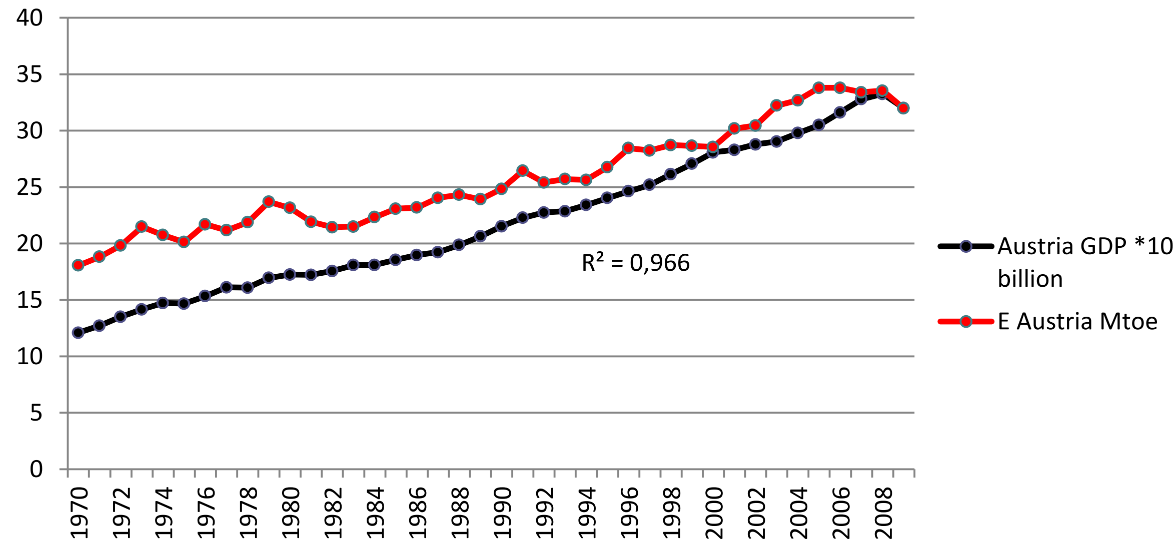


Figure 11: Dynamics between energy (Mtoe) and GDP (constant 2005 US$) in Austria (WorldBank, 2014)

The relationship between energy and growth is strong for Portugal, France and Austria, but is rather weak for Denmark. Subtracting fossil fuel revenues does not significantly change the energy-GDP relationship (See appendix 2: energy adjusted savings relationship), probably because energy usually accounts for just 5-6% of the GDP of a country (Baron, 1997; Warr & Ayres, 2010). Over the 1970-2009 period, Portugal's energy consumption increased from 5.76 Mtoe to 24.15 Mtoe, France's energy consumption grew from 228.53 Mtoe to 369.95 Mtoe, and Austria's energy demand rose from 18.06 Mtoe in 1970 to 31.96 Mtoe in 2009. Denmark managed to reduce its consumption from 19.57 Mtoe in 1970 to 18.36 Mtoe in 2009 (WorldBank, 2014). The diverging lines for Portugal indicate that from 1987 onwards the country began to use more energy per unit of economic output. This fact can be attributed to the industrial expansion and the growing demand for mobility in that period (IEA, 2009c). From 1990 to 2007 the energy consumption in the transport sector grew by more than 80%, the number of passenger cars increased by a factor 1.7 and the total number of trams and metro's doubled (IEA, 2004, 2009c). The energy consumption graphs of France, Austria and Denmark show drops in energy consumption rates in 1973, 1978, 1990 and 2008. Logical explanation for the abrupt declines are the Middle East war, the Iranian revolution and the Gulf war (Hamilton, 1996, 2011; Rubin, 2008). Energy analysts attribute the 2008 decline to the high oil price of $147 per barrel (Heinberg, 2011). Table 2 presents the price adjusted GDP of Austria, Denmark, France and Portugal.

	Portugal		France		Denmark		Austria	
	GDP		GDP		GDP		GDP	
Year	1970	2009	1970	2009	1970	2009	1970	2009
2005 billion $	62.8	193.4	894.5	2167.1	122.2	253.3	120.9	319.9
% growth	100	307.9	100	242.3	100	207.3	100	264.5

Table 2: Price adjusted GDP growth and in percentage growth. Based on WorldBank (2014).

Shadow markets are left out of the table and captured 17.5% of the Danish economy, 14.8% of the French one, 10.8% of Austria's economy and 22.3% of Portugal's economy (Friedrich Schneider, 2005). No special attention will be devoted to the shadow markets, but it is important to notice that energy intensity rates would be lower if those black markets would be added to the economies. All four countries showed considerable growth over the 1970-2009 period. Austria's economy grew by more than 250%, Denmark's economy doubled, France' economy doubled and Portugal's economy tripled (WorldBank, 2014).

4.3 CAN SERVICES REPLACE GOODS?

In this section will be determined whether or not services have replaced goods. We do this by looking at the relative and absolute contribution of sectors to the price adjusted GDP of the four European countries. The WorldBank (2014) supplies data on agricultural activities, industrial ones and services. When looking at data on relative value added generated by separate sectors, we see that in all four countries the service sector grew at the expense of agriculture and industry.

	Portugal		France		Denmark		Austria	
	% GDP		% GDP		% GDP		% GDP	
Year	1970	2009	1970	2009	1970	2009	1970	2009
Services	39.8	74.8	56.8	79.2	62.9	76.7	53.4	69.5
Industry	30.3	22.8	35.1	19.6	31.5	22.4	38.7	29
Agriculture	29.8	2.4	8.1	1.8	5.7	0.9	7.9	1.5

Table 3: Relative contribution of sectors to GDP in Denmark, Austria, Portugal and France. Based on WorldBank (2014).

Table 3 contains data on absolute value added produced by the three separate sectors. It shows that while the relative contribution of the industrial and agricultural sector declined, the absolute monetary value of all sectors in all four countries increased over the 1970-2009 period (WorldBank, 2014).

	Portugal		France		Denmark		Austria	
	Billion $ GDP		Billion $ GDP		Billion $ GDP		Billion $ GDP	
Year	1970	2009	1970	2009	1970	2009	1970	2009
Services	33.1	126.6	548	1540	66.3	162.8	69.7	201.6
Industry	15.1	38.7	229	370	33.3	50.2	33.8	82.5
Agriculture	3.9	4.7	25.2	46	1.1	3.3	4.1	4.9

Table 4: Absolute value added contributions (constant 2005 $). Based on: WorldBank (2014).

Data on relative sectorial contribution, may suggest that services replaced goods in European countries. In fact this is just an illusion. Table 5 shows that the financial contribution of the agricultural and industrial sector did not declined in absolute terms. The service sector showed the fastest absolute increase in Austria, Portugal and France (See also figure 14: Absolute sectorial growth).

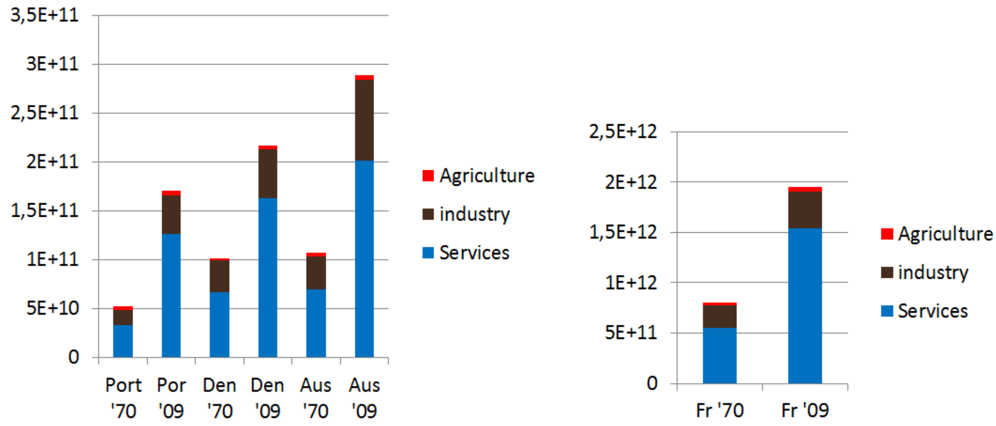


Figure 12: Absolute sectorial growth (2005 billion $) Based on: WorldBank (2014).

OECD (2014) labor force statistics show that in all countries between 1970 and 2009, employment levels in agriculture and industry declined with more than 10%, while the employment in the service sector rose by more than 20% during that period. In Denmark for instance the employment in agricultural and industry declined respectively by 9 and 18 percent over the 1970-2009 period, but the employment in services grew by more than 25%. To a certain extent the expanding service sector compensated for the declining employment in agriculture and industry. This fact has nothing to do with changing consumer preferences, economic shrinkage of goods producing sectors, or absolute energy decoupling. Moreover researchers indicate that in practice activities belonging to separate sectors cannot be treated independent of one another (Heiskanen et al., 2001; Jespersen, 1999). This is the case for many private services such as advertising, transport, Research and Development and office machinery (Fuentes, 1999). In Denmark 92% of the private services producing 50% of the value added in the service sector are connected to the production of goods (Jespersen, 1999). Furthermore since public services like education and health care are financed by tax receipts coming from the private sector, the former one cannot replace them (Norgard, 1995).

4.4 ENERGY INTENSITY OVER TIME

In the first paragraph we already saw that in all four countries the energy intensity energy, or the energy used to produce price adjusted GDP (1), changed over time. Basically this means that changes in energy composition, structural change and efficiency influenced the relationship between energy and economic growth. If energy intensity of none of the four countries would have changed the energy consumption of countries would have grown with about the same pace as the economy. The graph below shows the energy intensity over time for the four investigated countries and the EU average. Notice that the energy intensity of Portugal, France, Austria and Denmark would be down by respectively 22.3%, 14.8%, 17.5% and 10.8% if shadow economies were added to the economies (Friedrich Schneider, 2005).

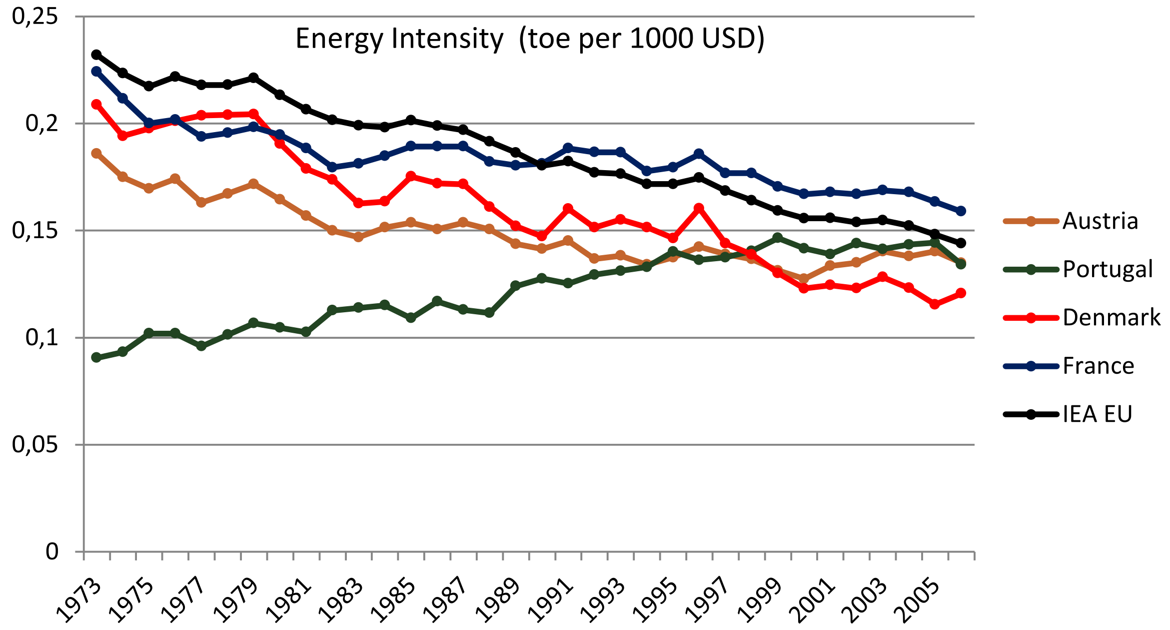


Figure 13: Energy intensity in ton oil equivalent per 1000 USD in 2000 prices and purchasing power parities, based upon: (IEA, 2006b, 2009a, 2009b, 2009c, 2011).

Over the period from 1973 till 2006, three out of four countries reduced their energy intensity rates. Portugal's energy intensity increased 48.1%, France's energy intensity declined by 29.8%, Austria's energy intensity declined by 27.4% and Denmark's energy intensity even declined by 42.2% (IEA, 2006b, 2009a, 2009b, 2009c, 2011). Energy intensity declines in Austria and France were offset by further economic growth. Figure 13 clearly shows that Portugal's energy intensity was considerable lower than that of the other three countries. It's rising energy intensity can partly be attributed to rising living standards, but is mainly the result from the weak energy efficiency policy and the absence measurable targets (IEA, 2004). Denmark´s energy intensity declined relatively fast compared to the other three countries. Lipp (2007) attributes the Denmark's extraordinary energy performances to its energy efficiency policy starting in the 1970's. Over the past 35 years, energy efficiency has been an important policy goal of Denmark. Since 1976 national energy plans were developed (IEA, 2006a). Feed In Tariffs raised the price for fossil fuels. As a result of the high energy taxes the Danish energy demand is at least 10% lower than it would be otherwise. Moreover each year Denmark spends €84 million on energy efficiency measures (Sovacool et al., 2008; Togeby, 2009). In the following sections the influence of changes in the energy composition, efficiency improvements and structural change on the energy intensity of countries will be discussed.

4.5 ENERGY COMPOSITION

This section touches upon the influence of the energy composition on the overall energy intensity. One of the possibilities to realise decoupling between economic growth and energy consumption is by substituting low quality energy sources like wood and coal for high quality energy sources like gas (Cleveland et al., 2000; Kaufmann, 2004). Since fossil fuels are finite, substitution between them is no solution to the energy scarcity problem (Stern, 2004b). The table presented below shows that the share of gas rose in all four countries, but also the share of lower quality fuels like coal and biomass has grown in some countries.

	Portugal		France		Denmark		Austria	
Relative contribution (%)	1970	2009	1970	2009	1970	2009	1970	2009
Oil	71.0	48.3	60.9	35.3	90.0	40.5	44.3	36.1
Gas	0.0	16.0	6.0	15.5	0.0	18.8	12.8	23.5
Coal	7.2	10.8	24.4	4.3	10.0	18.9	19.3	6.4
Fossil fuels	**78.2**	**75.1**	**91.3**	**55.0**	**100.0**	**78.3**	**76.4**	**66.0**
Nuclear	**0.0**	**0.0**	**9.6**	**37.4**	**0.0**	**0.0**	**0.0**	**0.0**
Hydro stations	20.5	7.7	8.3	5.2	0.0	0.0	23.4	26.0
Other (wind, bio, waste, geo)	0.6	8.6	0.2	1.1	0.0	10.9	0.1	4.0
Solar	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Wind	0.0	6.4	0.0	0.7	0.0	7.3	0.0	1.3
Biomass	0.6	2.1	0.2	0.4	0.0	3.6	0.1	2.7
Total renewables	**21.8**	**24.9**	**8.7**	**7.5**	**0.0**	**21.7**	**23.6**	**34.0**
Total consumption	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 5: Energy consumption by source. Based on: BP (2011).

From all four investigated countries, especially France generates much non-fossil energy. It is possible to adjust for the quality of energy sources by accounting for their marginal product. Since the marginal product of alternative energy sources are unknown we can only adjust for the quality of fossil fuels. When we do this for fossil fuels following Cleveland et al. (2000), we discover that changes in the fossil fuel composition lowered the energy intensity of Austria by 6.8% and that of France with 9.1%. In contrast the changing composition negatively affected the energy intensity of Portugal and Denmark. Portugal would have saved 8.1% by keeping the fossil fuel composition the same and Denmark would have saved 14.8%. On average changes in fuel mix accounted for 9.7% of the variation in the overall energy intensity. However since the marginal product of renewables are unknown, the exact influence of the energy composition on the energy intensity remains unknown.

4.6 STRUCTURAL CHANGE AND EFFICIENCY IMPROVEMENT

Data coming from an Index decomposition analysis performed by Mulder and de Groot (2012) is used to account for the influence of efficiency improvements and structural change on the energy intensity of Portugal, France, Austria and Denmark. The influence of the fuel mix is not accounted for, since the authors only used aggregate intermediate energy. The table presented below shows the relative effect of energy efficiency (EFF) improvements and structural change (STR) on the energy intensity levels of the four countries given in percentages. Positive values represent energy intensity increases, while negative numbers indicate declining energy intensity. Of the four countries, only Denmark and France managed to reduce their energy intensity rates over the 1980-2005 period (Mulder & de Groot, 2012). For Austria and France only data is available for the 1980-2005 period and for Portugal is only data available for the 1995-2005 period.

Year	**1995-2005**			**1980-2005**			**1970-2005**		
	EFF	STR	TOT	EFF	STR	TOT	EFF	STR	TOT
Portugal	0.6	-0.2	0.4						
France	-1.5	-0.5	-2.0	-3.1	1	-2.1			
Denmark	-1.9	-1.2	-3.2	-2.3	-0.8	-3.1	-2	-0.7	-2.7
Austria	-0.2	0.4	0.3	0.2	0.2	0.4			

Table 6: Changes in energy efficiency (EFF), structural change (STR) and energy intensity (TOT). Based on: Mulder and de Groot (2012).

Table 6 reveals that three out of four countries managed to reduce their energy intensity over the 1995-2005 period. Only Portugal's energy intensity increased over the 1995-2005 period. Furthermore France and Denmark managed to reduce their energy intensity between 1980 and 2005, but Austria's energy intensity grew by 0.4% annually during that period. Over the entire 1995-2005 period Portugal's energy intensity grew by 6%. Austria's energy intensity grew by 4% between 1980 and 2005 and France's energy intensity declined with 28% over that period. Denmark's energy intensity declined by 61.6% between 1970 and 2005 (Mulder & de Groot, 2012). Structural change contributed to energy intensity increases of Portugal and Austria and it raised France's energy intensity over the 1980-2005 period. It caused Denmark's energy intensity to decline by 22% over the 1970-2005 period. When calculating the overall effect of both efficiency and structure for the available time periods for each of the four countries, we discover that changes in energy efficiency accounted for about 60.5% of the variation in energy intensity, while structural change accounted for about 29.8% of the variation.

4.6.1 THE SECTORIAL CONTRIBUTION TO ENERGY INTENSITY RATES

When looking more specifically at the contribution of separate sectors to the energy intensity, especially the impact of the transport sector stands out (see: Table 7). In three of the four European countries, the largest contribution to the energy intensity came from transport.

	Portugal 1995-2005			**France 1980-2005**			**Denmark 1980-2005**			**Austria 1980-2005**		
	EFF	STR	TOT	EFF	STR	TOT	EFF	STR	TOT	EFF	STR	TOT
Manufacturing	104.7	-40.4	64.3	-9.4	-24.8	-34.2	-18.5	-20	-38.5	-6.5	10.6	4
Services	-27.1	12.8	-14.3	-12.2	5	-7.2	-37.3	5.1	-32.2	33.9	0.9	34.8
Transport	172.9	-127.5	45.4	-122.5	68.9	-53.6	-9.5	-0.1	-9.6	116.7	-36.1	80.6
Agriculture	19.4	-19.1	0.3	-2.4	-0,2	-2.5	-11.8	3.2	-8.6	-8.1	-5.8	-13.9
Construction	8.4	-4.1	4.2	-1.8	-0.7	-2.4	-8.8	-2.2	-11.1	-2.5	-3	-5.5
Total rise/ decrease	278.3	-178.3	100	-148.3	48.3	-100	-86	-14	-100	133.4	-33.4	100

Table 7: In percentage contribution of the efficiency and structure effect to energy intensity. Based on Mulder & de Groot (2011)

France and Denmark both managed to reduce their energy requirement per unit of output in the transport sector, while the exact opposite happened in Portugal and Austria. Manufacturing activities also exercised much influence on the overall energy intensity. Austria is the only country that used more energy in the service sector over time, indicating that the service sector did actually contribute to energy savings in three of the four countries (Mulder & Groot, 2011). Jespersen (1999) studied the energy intensity of goods and services in Denmark for the year 1990. Back then he discovered that compared to manufacturing activities, private services used 17.9% less energy for producing a certain amount of economic output. Producing the same economic output by public services required just 36.6% of the energy used for manufacturing. Although the potential influence of 'Services' in reducing the energy intensity could be large, the actual influence on the energy intensity was just 21.6% (Mulder & Groot, 2011).

4.6.2 OUTSOURCED ENERGY

Since it is possible for a country to reduce its domestic energy consumption by outsourcing energy intensive activities, it is important to investigate the influence of energy embodied in importing goods and services (Rothman, 1998). Displacing energy intensive activities to other countries is part of the decoupling category structural change. It is difficult to estimate the actual energy embodied in goods and services for the fact that energy intensity rates differ between countries and sectors. Suri and Chapman (1998) estimated that on average a 10% increase in manufacturing imports as percentage of domestic manufacturing production in industrialised countries only leads to a 1.9-2.3% energy reduction. The only country with a negative trade balance over the 1970-2009 period was Portugal. The country had a trade balance of -8.4%. France exported on average 0.1% more than it imported, Denmark 1.7% and Austria 0.4% (WorldBank, 2014). Jespersen (1999) showed that in 1992 Denmark had a negative energy balance, after adjusting for energy embodied in goods and services. Even if all of them concerned manufacturing goods, Portugal would have saved just 2% of all its energy by importing those goods. Therefore it is not reasonable to assume that outsourcing significantly influenced the energy consumption in any of the four countries.

4.7 ENERGY CONSUMPTION AND DECOUPLING

In this chapter the relationship between energy demand and economic growth has been studied for Portugal, France, Denmark and Austria. We saw that Portugal's energy consumption almost quadrupled, France's energy demand grew by 60%, Austria's energy demand rose by almost 80% and Denmark's energy decreased by about 6% (WorldBank, 2014). The relationship between energy and growth was strong for three of the four investigated countries. The expansion of the services sector resulted from productivity improvements taking place in the agricultural and industrial sectors. However services did not replace goods in absolute terms. Changes in the composition of fossil fuels contributed to higher energy intensity rates of Portugal and Denmark, but contributed to lower energy intensity rates in France and Austria. Structural change contributed to energy intensity declines in Denmark and Portugal, but the overall effect of energy efficiency improvements was larger than that of structural change. Since many private services are connected to goods and public services are financed by the private sector, clear limits exist to structural change. Similarly energy efficiency cannot grow infinitely since it is constrained by thermodynamic laws. In the next chapter the potentials for alternative energy sources, efficiency improvement and structural change in offsetting future fossil fuel shortages, will be explored.

5 IMPLICATIONS FOR ENERGY POLICY

The previous chapter showed that the rise of the service sector did not lead to absolute energy reduction in three of the four investigated countries. This chapter describes the implications of the results regarding energy decoupling. Also potential contributions of fossil fuel substitutes to future energy supply will be outlined. The same will be done for structural change and efficiency improvements. This chapter is closed by describing the need for alternative economic frameworks to the prevailing growth oriented economic framework.

5.1 GROWING ENERGY DEMAND AND DWINDLING SUPPLY

Over the past century, global energy consumption and GDP (in constant 1990 $) both grew 16 fold (Maddison, 2007a; Smil, 2005). We saw that the economies investigated in the previous chapter doubled, or tripled in 40 years. Moreover Portugal's energy demand quadrupled, while the energy demand of France and Austria grew by more than half. Hall (2008), Heinberg and Fridley (2010) expect oil and coal to peak before 2020. That is why economic growth can only be continued in the future if alternative energy sources, efficiency improvements and structural change can compensate for the declining fossil fuel supply (Stern, 2004b). Growth is a necessary element in growth oriented neo-liberal economies. Zero economic growth leads to unemployment, unpaid debts, bankruptcies, reduced governmental income and growing governmental expenditure (Spangenberg, 2010). Energy shortages in the past were devastating from a financial perspective. Hamilton (Hamilton, 1996, 2011) and Rubin (2008) have shown, that four of the five previous energy crises were followed by economic crises. Robert Hirsch (2008) estimated that a one percent reduction in oil supply causes the Gross World Product to decline by one percent. In the following sections the potential for substitution, efficiency and structural change in offsetting the fossil fuel decline will be explored for Portugal, France, Denmark and Austria. If it turns out that fossil fuel substitutes, efficiency improvements and structural change are insufficient in compensating the decline of fossil fuels, the current growth oriented economic framework should be replaced by a de-growth economic framework. In the last section this option is discussed.

5.2 SUBSTITUTION

Stern (2004b) pointed out that switching from a low quality fuel like coal to oil or gas, reduces the energy intensity of a country, but since fossil fuels are finite by nature, sooner or later they should be replaced by alternatives. Hence it is important to estimate the potential contribution of alternative energy sources to the energy mix of Portugal, France, Austria and Denmark. Problematic when it comes to alternatives are aspects such as their production costs, energy density, intermittency and lack of user flexibility (Cleveland et al., 2000; Smil, 2005). Bio-energy and hydro dams can provide constant energy flows, but are only available in limited amounts. Europe can expand its hydro energy with at maximum 55% (Smil, 2005). Austria already exploited 72% of its bio-energy potential, whereas Denmark could raise its current consumption level by less than half (Nikolaisen, 2012; Wörgettera et al., 2003). The global potential of geothermal electricity is limited to a few Exajoules (Moriarty & Honnery, 2012). Moreover geothermal energy requires long term investments and heat reservoirs get depleted over time (Barbier, 2002). Of all renewable energy sources wind and solar power have the highest theoretical potential, but due to intermittency problems most countries can only integrate 20% energy from sun and wind in their grids, before massive dumping is needed (Moriarty & Honnery, 2012). Because Denmark has a very dense energy grid, that specific country could possible raise its share to 40% or 50% on the long term (Smil, 2010). The theoretical and technical potential for renewable energy may be large, but integrating them with the existing energy mix requires huge investments and the instalment of wind and hydro energy often lacks social acceptance (Moriarty & Honnery, 2012). Moreover due to the size and costs and impact of energy transitions these processes unfold gradually (Smil, 2000, 2013a). Therefore the share of renewables is not likely to increase by more than 10% till the year of 2030. Nuclear energy is only used in France and is also not expected to experience a substantial increase the oncoming decades. Production costs for nuclear energy rose exponentially over the past decades and many of the 54 reactors dating from before 1995 are aging (Energy, 2008; Grubler, 2010; Smil, 2010).

5.3 ENERGY EFFICIENCY

It is highly probable that the flow of fossil fuels will decline during the oncoming decades. In the previous section we saw that substitutes can only partially replace future energy demand. Moreover most of the energy sources are expensive to develop and lack the desired properties. Therefore the energy intensity of goods and services needs to be reduced in order to adjust for these constrains. Efficiency improvements can be induced by governmental regulations or may occur autonomously. As more technical abilities are applied and thermodynamic limits to energy efficiency are approached, the marginal contribution of each new measure decreases (Heinberg, 2011). Gutowski et al. (2013) estimated that when using best practices, emerging techniques and recycling, the energy efficiency of material production can be raised by 50-56%. Graus et al. (2011) estimated the technical potential for global energy efficiency improvement for the period from 2005 till 2050. They estimated that technical change could increase the global energy efficiency level with 55%. Notice that the authors only investigated the technical potential for energy efficiency improvements. Most likely only a small part of this potential would also be feasible from an economic perspective (Heinberg, 2011).

5.4 STRUCTURAL CHANGE

The classical argument for energy decoupling by means of structural change holds that the shift to the service sector saves energy while creating the same amount of welfare. Low energy demanding services are supposed to replace energy intensive goods (Heiskanen & Jalas, 2000). Jespersen (1999) discovered that in Denmark the production of a unit of financial output in public services required only 36.6% the amount of energy needed to produce manufacturing output. Laitner et al. (2000) even discovered that the production of internet activities requires just one fifth of the average energy needed for production. But since we cannot feed ourselves from the internet, the maximum share of services in an entire economy is far more limited. Public services are financed by the private sector and many private services are strongly attached to manufacturing or agriculture (Norgard, 1995). Structural change accounted for 29.8% of the variation in the energy intensity energy of the investigated countries. Boyd and Laitner (2001) came up with similar results for the VS. If we assume structural change to be limited to 33%, it could reduce the energy intensity rates of EU countries by another 27.5% in addition to energy efficiency improvements. But not this entire theoretical potential may be economically feasible. According to Jensen et al. (2005) about one third of all services can be traded, whereas all agricultural products and about 86% of all manufacturing products can be traded. That is why a large service sector reduces the international competitiveness of a country (Søilen, 2012). Moreover markets for services may become saturated at some point (Heiskanen et al., 2001).

5.5 DE-GROWTH AND REACHING A STEADY STATE

The economies of Portugal, France, Denmark and Austria cannot follow their current growth path for a long time for the simple fact that there will not be enough energy available to fuel this growth. Substitution, restructuring and efficiency improvements could weaken our dependency on fossil fuels for a limited time period. Energy intensity declines often indirectly reinforce the demand for energy (Madlener & Alcott, 2009). We saw this happening for two of the countries investigated in chapter two. Furthermore as we saw for

Portugal, it is unlikely that the market on itself will stimulate energy efficiency, structural change and alternative energy (IEA, 2004). Denmark managed to reduce its energy consumption as a result of the many implemented policy-measures (Togeby, 2009). It is important to notice that with each incremental energy intensity improvement additional measures aimed reducing energy intensity rates will get more expensive (Heinberg, 2011). Potentials for renewable energy and increasing energy intensity rates are in first instance determined by technical possibilities, social acceptance and economic feasibility (Smil, 2005). For this reason we would expect energy shortages to take place long before all theoretical limits to substitution and energy intensity improvements have been reached. This is also why the prevailing path of economic growth cannot be extended for a long time. If we want to avoid the scenario of economic downturn or economic collapse, the growth oriented economic framework should be replace by a de-growth framework (Kerschner, 2010). Such a path should be maintained until a sustainable economic state is reached. De-growth aims to reduce a society's throughput, while maintaining the life satisfaction of its inhabitants (Kallis, 2011). It requires the revival of non-financial values. Moreover a de-growth framework could contain measures such as abolishing interest rates, raising taxes on income and reducing those on labour. It would even require population levels to stabilize at a certain moment in time (Daly, 1997; Kallis et al., 2012; Smith, 2010). Considering the consequences, directing modern economies to a sustainable steady situation may seem impossible. There just seem to be no simple solutions.

6 CONCLUSIONS

This chapter captures the most important conclusions of this research. The main question and the sub-questions of this research will be answered in the following sections.

Humans use energy to transform manmade capital and natural capital into goods and services, which represent financial value. For over two centuries cheap fossil fuel energy is used to produce financial capital and to maintain it. Nowadays the world consumes more energy than ever before in human history. About 80% of our energy comes from finite fossil fuels. The relationship between fossil fuel energy and economic growth becomes problematic when realizing that most likely the era of cheap abundant energy will soon be over. Changing the composition of goods and services produced by an economy, called structural change, is often presented as an excellent measure for delinking economic activity from energy consumption. In this research the influence of the expansion of services on energy consumption has been studied by analysing statistical data for Portugal, France, Austria and Denmark over the period from 1970 to 2009. Apart from the influence of structural change, also the influence of the overall level of economic activity, changes in energy efficiency rates and substitution between energy sources has been investigated. If the rise of the service sector would contribute to a declining energy consumption, three requirements should be met:

1. Goods should replace services in terms of absolute financial value added.
2. Services should require less energy per unit of value added than the goods they replace.
3. The energy conservation effect of replacing goods by services should not be offset by economic growth.

A strong relationship between energy consumption and price adjusted GDP is observed in three of the four countries. All countries except Denmark saw their absolute energy consumption increase. Energy consumption quadrupled in Portugal, grew by more than half in Austria and France, but slightly declined in Denmark. Price adjusted GDP tripled in Portugal, doubled in Denmark and grew by about 250% in France and Austria. Between 1970 and 2009 the services sectors in all four countries grew fast in both absolute and relative terms. Crucial is the fact that although the relative contribution financial size of agriculture and industry declined in all four countries, the absolute added value of those sectors increased. This means that services did not replace goods in absolute monetary terms. Moreover many private services like transport and Research and Development depend for their existence on the sales of goods and therefore cannot replace them. The same applies for public goods which are financed by taxes coming from the private sector. This research shows that energy intensity rates in France, Denmark and Austria decreased with respectively 29.8%, 42.2% and 27.4%. In contrast Portugal´s energy intensity increased with 48.1%. Denmark´s energy efficiency performance can largely be attributed to its domestic energy policy starting in the 70´s. Portugal´s poor performance is partly the result of its economic expansion, the rising demand for mobility and the absence of well-defined energy targets. Changes in fossil fuel mix accounted for 9.7% of the variation in energy intensity rates. It positively influenced the energy intensity rates of France and Austria, but negatively affected those of Portugal and Denmark. The energy efficiency effect accounted for 60.5% of the variation in the energy intensity rate and structural change accounted for 29.8% of the variation. The energy intensity of services is significantly lower than that of manufacturing, however services accounted for just 21.7% of all variation in energy intensity rates. So the influence of the tertiarisation on the energy consumption of Portugal, France, Austria and Denmark was very limited.

Modern economies require growth, growth requires energy, but within a short period coal and oil will probably reach their peak production rates. That is why fossil fuel alternatives, energy efficiency, and structural change should compensate for the fossil fuel declines. If these measures turn out to be insufficient, de-growth measures could be taken. Non- fossil fuels can replace considerable amounts of fossil energy, but substitutes are qualitatively inferior to fossil fuels, are expensive, highly intermittent or only available in limited amounts. Energy efficiency improvements face thermodynamic limits and could possibly be raised by 55%. Structural change could reduce energy intensity rates with an additional 27.5%. In practice these potentials are far more limited, because of socio-economic aspects. Moreover on the long term none of the measures aimed at decoupling energy are insufficient to offset the influence of economic growth. This means that in order to adapt to a reality of limited available energy, European countries should abandon the driving mechanisms behind economic growth at some point in time.

REVERENCES

Andersen, J. r. G. (2007). The Danish welfare state as 'politics for markets': Combining equality and competitiveness in a global economy. *New Political Economy, 12*(1), 71-78.

Ang, B. (2004). Decomposition analysis for policymaking in energy:: which is the preferred method? *Energy policy, 32*(9), 1131-1139.

Ayres, R. U. (1996). Limits to the growth paradigm. *Ecological economics, 19*(2), 117-134.

Ayres, R. U. (1998a). Eco-thermodynamics: economics and the second law. *Ecological economics, 26*(2), 189-209.

Ayres, R. U. (1998b). *Turning point: An end to the growth paradigm*: Earthscan.

Ayres, R. U., & Warr, B. (2010). *The economic growth engine: how energy and work drive material prosperity*: Edward Elgar Publishing.

Bairoch, P. (1982). *International industrialization levels from 1750 to 1980*.

Bank, D. (2010). Oil and Gas for Beginners: A Guide to the Oil and Gas Industry.

Barbier, E. (2002). Geothermal energy technology and current status: an overview. *Renewable and sustainable energy reviews, 6*(1), 3-65.

Baron, R. (1997). Competitive Issues Related to Carbon/Energy Taxation. Annex I Expert Group on the United Framework Convention on Climate Change: Working paper 14, ECON-Energy, Paris.

Baumol, W. J. (1967). Macroeconomics of unbalanced growth: the anatomy of urban crisis. *The American Economic Review, 57*(3), 415-426.

Behrens, A., Giljum, S., Kovanda, J., & Niza, S. (2007). The material basis of the global economy: Worldwide patterns of natural resource extraction and their implications for sustainable resource use policies. *Ecological economics, 64*(2), 444-453.

Bell, C. S. (1968). Macroeconomics of unbalanced growth: Comment. *The American Economic Review, 58*(4), 877-884.

Bell, D. (1976). *The coming of the post-industrial society.* Paper presented at the The Educational Forum.

Birol, F. (2010). World energy outlook 2010. *International Energy Agency*.

Blankenship, R. E., Tiede, D. M., Barber, J., Brudvig, G. W., Fleming, G., Ghirardi, M., . . . Melis, A. (2011). Comparing photosynthetic and photovoltaic efficiencies and recognizing the potential for improvement. *Science, 332*(6031), 805-809.

Bossanyi, E. (1979). UK primary energy consumption and the changing structure of final demand. *Energy policy, 7*(3), 253-258.

Boyd, G., & Laitner, J. (2001). Recent Trends in the US Energy Intensity. *IAEE Newsletter*.

Brown, J. H., Burnside, W. R., Davidson, A. D., Delong, J. R., Dunn, W. C., Hamilton, M. J., . . . Woodruff, W. H. (2011). Energetic limits to economic growth. *BioScience, 61*(1), 19-26.

Burda, M., & Wyplosz, C. (2012). *Macroeconomics: a European text*: Oxford University Press.

Campbell, C. (2005). *The end of the first half of the age of oil.* Paper presented at the 4th International Workshop on Oil & Gas Depletion, ASPO, Lisbon.

Campbell, C. (2006). ASPO Newsletter# 62: February.

Chertow, M. R. (2000). The IPAT equation and its variants. *Journal of industrial ecology, 4*(4), 13-29.

Chontanawat, J., Hunt, L. C., & Pierse, R. (2006). Causality between Energy Consumption and GDP: Evidence from 30 OECD and 78 non-OECD Countries: Surrey Energy Economics Centre (SEEC), School of Economics, University of Surrey.

Clark, C. (1940). *The conditions of economic progress* (Vol. 195): Macmillan London.

Clark, C. (1967). The conditions of economic progress. *The conditions of economic progress.*

Cleveland, C. J., Costanza, R., Hall, C. A., & Kaufman, R. (1984). We approach macroeconomics from a thermodynamic perspective that emphasizes the production of goods, rather than the neoclassical perspective that emphasizes the exchange of goods according to. *Science, 225*, 890.

Cleveland, C. J., & Kaufmann, R. K. (2003). Oil supply and oil politics: déjà vu all over again. *Energy policy, 31*(6), 485-489.

Cleveland, C. J., Kaufmann, R. K., & Stern, D. I. (2000). Aggregation and the role of energy in the economy. *Ecological economics, 32*(2), 301-317.

Cleveland, C. J., & Ruth, M. (1998). Indicators of dematerialization and the materials intensity of use. *Journal of industrial ecology, 2*(3), 15-50.

Cobb, C. e. a. (1995). If the GDP is up, why is America down? *ATLANTIC-BOSTON-, 276*, 59-79.

Cohen, J. E. (1995). Human carrying capacity. *Science, 269*, 341.

Commission, E. E. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30. *Official Journal of the European Union Belgium*.

Costanza, R., Hart, M., Talberth, J., & Posner, S. (2009). Beyond GDP: The need for new measures of progress.

Cowen, T. (1996). Why I do not believe in the cost-disease. *Journal of Cultural Economics, 20*(3), 207-214.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*: Sage.

Curtis, D. C., & Murthy, K. (1998). Economic growth and restructuring: a test of unbalanced growth models-1977-1992. *Applied Economics Letters, 5*(12), 777-780.

Daly, H. (2005). Operationalising sustainable development by investing in natural capital. *Dimensions of environmental and ecological economics*, 481-494.

Daly, H. E. (1992). Allocation, distribution, and scale: towards an economics that is efficient, just, and sustainable. *Ecological economics, 6*(3), 185-193.

Daly, H. E. (1997). *Beyond growth: the economics of sustainable development*: Beacon Press.

Daly, H. E. (2005). Economics in a full world. *Scientific American, 293*(3), 100-107.

Daly, H. E., & Farley, J. (2010). *Ecological economics: principles and applications*: Island Press.

Davis, G. (1997). Exploring Sustainable Development, WBSCD Global Scenarios 2000-2050, 2014

Day, J. W., Hall, C. A., Yáñez-Arancibia, A., Pimentel, D., Martí, C. I., & Mitsch, W. J. (2009). Ecology in times of scarcity. *BioScience, 59*(4), 321-331.

De Bruyn, S. M. (2000). *Economic growth and the environment: an empirical analysis* (Vol. 18): Springer.

De Vries, B. J., van Vuuren, D. P., & Hoogwijk, M. M. (2007). Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy policy, 35*(4), 2590-2610.

Dhawan, R., & Jeske, K. (2006). How resilient is the modern economy to energy price shocks? *ECONOMIC REVIEW-FEDERAL RESERVE BANK OF ATLANTA, 91*(3), 21.

Dietrich, A. (2009). Does growth cause structural change, or is it the other way round?: a dynamic panel data analyses for seven OECD countries: Jena economic research papers.

Dietrich, A., & Krüger, J. J. (2010). Long-run sectoral development: Time-series evidence for the German economy. *Structural Change and Economic Dynamics, 21*(2), 111-122.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecological economics, 49*(4), 431-455.

Duncan, R. C. (2000). *The peak of world oil production and the road to the Olduvai Gorge.* Paper presented at the Pardee Keynote Symposia Geological Society of America, Summit.

Easterlin, R. A. (1974). Does economic growth improve the human lot? Some empirical evidence. *Nations and households in economic growth, 89*.

EC. (2002). *'Intelligent Energy for Europe', Multiannual Action Programme 2003 - 2006*. European Commission, Directorate General for Energy and Transport Retrieved from http://ec.europa.eu/energy/res/intelligent_energy/doc/memo_en.pdf.

EC. (2013). Renewable energy progress report. In E. Commission (Ed.), *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE*

COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE

COMMITTEE OF THE REGIONS (pp. 15).

Echevarria, C. (1997). Changes in sectoral composition associated with economic growth. *International Economic Review*, 431-452.

Ekins, P. (1997). The Kuznets curve for the environment and economic growth: examining the evidence. *Environment and planning a, 29*(5), 805-830.

Ekins, P., Simon, S., Deutsch, L., Folke, C., & De Groot, R. (2003). A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecological economics, 44*(2), 165-185.

Energy, I. (2008). electricity and nuclear power estimates for the period up to 2030. *Reference Data, 3*.

Eurostat. (2013). *EU27 energy dependence rate at 54% in 2011, 2014*(28-7-2014). Retrieved from http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/8-13022013-BP/EN/8-13022013-BP-EN.PDF

Eurostat. (2014). Energy production and imports, 2014, from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Energy_production_and_imports

Fisher, A. G. (1939). Production, primary, secondary and tertiary. *Economic Record, 15*(1), 24-38.

Foster, J. B. (2005). The vulnerable planet. *Environmental Sociology: From Analysis To Action*, 3.

Fuchs, V. R. (1968). The service economy. *NBER Books*.

Fuentes, D. D. (1999). On the Limits of the Post-Industrial Society Structural Change and Service Sector Employment in Spain. *International Review of Applied Economics, 13*(1), 111-123.

Gagnon, N., Hall, C. A., & Brinker, L. (2009). A preliminary investigation of energy return on energy investment for global oil and gas production. *Energies, 2*(3), 490-503.

Geller, H., Harrington, P., Rosenfeld, A. H., Tanishima, S., & Unander, F. (2006). Polices for increasing energy efficiency: Thirty years of experience in OECD countries. *Energy policy, 34*(5), 556-573.

Gerring, J. (2011). *Social science methodology: a unified framework*: Cambridge University Press.

Goldemberg, J., Johansson, T. B., Reddy, A. K., & Williams, R. H. (1985). Energy for a sustainable world. *PU/CEES Report*(194A-B).

Graus, W., Blomen, E., & Worrell, E. (2011). Global energy efficiency improvement in the long term: a demand-and supply-side perspective. *Energy efficiency, 4*(3), 435-463.

Greenhalgh, C., & Gregory, M. (2001). Structural change and the emergence of the new service economy*. *Oxford Bulletin of Economics and Statistics, 63*(s1), 629-646.

Griliches, Z. (1992). Introduction to" Output Measurement in the Service Sectors" *Output measurement in the service sectors* (pp. 1-22): University of Chicago Press.

Grossman, G. M. (1995). 2 Pollution and growth: what do we know? *The economics of sustainable development*, 19.

Grossman, G. M., & Helpman, E. (1991). Quality ladders in the theory of growth. *The Review of Economic Studies, 58*(1), 43-61.

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement: National Bureau of Economic Research.

Grubler, A. (2010). The costs of the French nuclear scale-up: A case of negative learning by doing. *Energy policy, 38*(9), 5174-5188.

Gupta, A. K., & Hall, C. A. (2011). A review of the past and current state of EROI data. *Sustainability, 3*(10), 1796-1809.

Gutowski, T. G., Sahni, S., Allwood, J. M., Ashby, M. F., & Worrell, E. (2013). The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 371*(1986), 20120003.

Haas, R., Eichhammer, W., Huber, C., Langniss, O., Lorenzoni, A., Madlener, R., . . . Oniszk, A. (2004). How to promote renewable energy systems successfully and effectively. *Energy policy, 32*(6), 833-839.

Hall, C. A., Balogh, S., & Murphy, D. J. (2009). What is the minimum EROI that a sustainable society must have? *Energies, 2*(1), 25-47.

Hall, C. A., & Klitgaard, K. A. (2011). *Energy and the wealth of nations: understanding the biophysical economy*: Springer.

Hall, C. A., Lambert, J. G., & Balogh, S. B. (2014). EROI of different fuels and the implications for society. *Energy policy, 64*, 141-152.

Hall, C. A., Powers, R., & Schoenberg, W. (2008). Peak oil, EROI, investments and the economy in an uncertain future *Biofuels, solar and wind as renewable energy systems* (pp. 109-132): Springer.

Hallock Jr, J. L., Tharakan, P. J., Hall, C. A., Jefferson, M., & Wu, W. (2004). Forecasting the limits to the availability and diversity of global conventional oil supply. *Energy, 29*(11), 1673-1696.

Hamilton, J. D. (1996). This is what happened to the oil price-macroeconomy relationship. *Journal of monetary economics, 38*(2), 215-220.

Hamilton, J. D. (2011). Historical oil shocks: National Bureau of Economic Research.

Heinberg, R. (2011). *The end of growth*: New Society Publishers.

Heinberg, R., & Fridley, D. (2010). The end of cheap coal. *nature, 468*(7322), 367-369.

Heiskanen, E., Halme, M., Jalas, M., Kärnä, A., & Lovio, R. (2001). Dematerialization: the potential of ICT and services.

Heiskanen, E., & Jalas, M. (2000). Dematerialization through services-A review and evaluation of the debate.

Herring, H. (1999). Does energy efficiency save energy? The debate and its consequences. *Applied Energy, 63*(3), 209-226.

Herring, H. (2006). Energy efficiency—a critical view. *Energy, 31*(1), 10-20.

Hicks, J. R. (1946). *Value and capital* (Vol. 2): Clarendon Press Oxford.

Hirsch, R. L. (2008). Mitigation of maximum world oil production: Shortage scenarios. *Energy policy, 36*(2), 881-889.

Hirsch, R. L., Bezdek, R., & Wendling, R. (2005). *Peaking of world oil production.* Paper presented at the Proceedings of the IV International Workshop on Oil and Gas Depletion.

Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO< sub> 2</sub> emissions and economic growth. *Journal of Public Economics, 57*(1), 85-101.

Hong, L., Pei Dong, Z., Chunyu, H., & Gang, W. (2007). Evaluating the effects of embodied energy in international trade on ecological footprint in China. *Ecological economics, 62*(1), 136-148.

Hospers, G.-J. (2003). Fourastié's foresight after 50 years. *foresight, 5*(2), 11-14.

Huws, U. (1999). Material world: the myth of the weightless economy. *Socialist register, 35*(35).

IEA. (2004). Energy Policies of IEA Countries, Portugal 2004 Review *Energy Policies of IEA Countries* (pp. 113): OECD.

IEA. (2006a). Energy Policies of IEA Countries, 2006 Review (pp. 400).

IEA. (2006b). Energy Policies of IEA Countries, Denmark 2006 Review. 176.

IEA. (2008). Worldwide Trends in Energy Use and Efficiency.

IEA. (2009a). Energy Policies of IEA Countries, Austria 2009 Review *Energy Policies of IEA Countries* (pp. 124).

IEA. (2009b). Energy Policies of IEA Countries, France 2009 Review *Energy Policies of IEA Countries* (pp. 160): International Energy Agency.

IEA. (2009c). Energy Policies of IEA Countries, Portugal 2009 Review *Energy Policies of IEA Countries* (pp. 178): OECD.

IEA. (2011). Energy Policies of IEA Countries, Denmark 2011 Review *Energy Policies of IEA Countries* (pp. 139).

Inglehart, R. (1981). Post-materialism in an environment of insecurity. *The American Political Science Review*, 880-900.

Jackson, T. (2011). *Prosperity without growth: Economics for a finite planet*: Routledge.

Jänicke, M., Binder, M., & Mönch, H. (1997). 'Dirty industries': Patterns of change in industrial countries. *Environmental and resource economics, 9*(4), 467-491.

Jensen, J. B., Kletzer, L. G., Bernstein, J., & Feenstra, R. C. (2005). *Tradable services: Understanding the scope and impact of services offshoring [with comments and discussion].* Paper presented at the Brookings trade forum.

Jespersen, J. (1999). Reconciling environment and employment by switching from goods to services? A review of Danish experience. *European Environment, 9*(1), 17-23.

Kahilainen, J. (2000). Sustainable Development and the Information Society–Towards a Sustainable Network Society: The Finnish Environment.

Kallis, G. (2011). In defence of degrowth. *Ecological economics, 70*(5), 873-880.

Kallis, G., Kerschner, C., & Martinez-Alier, J. (2012). The economics of degrowth. *Ecological economics, 84*, 172-180.

Kaufmann, R. K. (2004). The mechanisms for autonomous energy efficiency increases: A cointegration analysis of the US energy/GDP ratio. *The Energy Journal*, 63-86.

Kelly, K. (1999). *New rules for the new economy*: Penguin. com.

Kerschner, C. (2010). Economic de-growth vs. steady-state economy. *Journal of Cleaner Production, 18*(6), 544-551.

Klodt, H. (1997). The transition to the service society: prospects for growth, productivity and employment: Kiel Working Papers.

Kümmel, R. (1989). Energy as a factor of production and entropy as a pollution indicator in macroeconomic modelling. *Ecological economics, 1*(2), 161-180.

Laitner, J., Koomey, J., Worrell, E., & Gumerman, E. (2000). *Re-estimating the Annual Energy Outlook 2000 forecast using updated assumptions about the Internet economy.* Paper presented at the Eastern Economics Association Conference, Crystal City, VA.

Lawn, P. A. (2003). A theoretical foundation to support the Index of Sustainable Economic Welfare (ISEW), Genuine Progress Indicator (GPI), and other related indexes. *Ecological economics, 44*(1), 105-118.

Layard, R. (2011). *Happiness: Lessons from a new science*: Penguin UK.

Lipp, J. (2007). Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy policy, 35*(11), 5481-5495.

Liu, N., & Ang, B. (2007). Factors shaping aggregate energy intensity trend for industry: Energy intensity versus product mix. *Energy Economics, 29*(4), 609-635.

Lucas Jr, R. E. (1988). On the mechanics of economic development. *Journal of monetary economics, 22*(1), 3-42.

Lvovsky, K., Hughes, G., Maddison, D., Ostro, B., & Pearce, D. (2000). Environmental costs of fossil fuels: a rapid assessment method with application to six cities.

Maddison, A. (2007a). *Contours of the world economy 1-2030 AD: Essays in macro-economic history*: Oxford University Press.

Maddison, A. (2007b). *The world economy volume 1: A millennial perspective volume 2: Historical statistics*: Academic Foundation.

Madlener, R., & Alcott, B. (2009). Energy rebound and economic growth: A review of the main issues and research needs. *Energy, 34*(3), 370-376.

Maslow, A. H., Frager, R., & Fadiman, J. (1970). *Motivation and personality* (Vol. 2): Harper & Row New York.

Miles, I. (1993). Services in the new industrial economy. *Futures, 25*(6), 653-672.

Mol, A. P. (1997). Ecological modernization: industrial transformations and environmental reform. *The international handbook of environmental sociology*, 138-149.

Moriarty, P., & Honnery, D. (2012). Preparing for a low-energy future. *Futures, 44*(10), 883-892.

Mulder, P., & de Groot, H. L. (2012). Structural change and convergence of energy intensity across OECD countries, 1970–2005. *Energy Economics, 34*(6), 1910-1921.

Mulder, P., & Groot, H. L. F. (2011). *Energy Intensity Across Sectors and Countries: Empirical Evidence 1980-2005*: CPB Netherlands Bureau for Economic Policy Analysis.

Murphy, D. J., & Hall, C. A. (2010). Year in review—EROI or energy return on (energy) invested. *Annals of the New York Academy of Sciences, 1185*(1), 102-118.

Murphy, D. J., & Hall, C. A. (2011). Adjusting the economy to the new energy realities of the second half of the age of oil. *Ecological Modelling, 223*(1), 67-71.

Nikolaisen, L. (2012). IEA Bioenergy task 40, Country report 2011 for Denmark *IEA Bioenergy*, 19.

Nordhaus, W. D. (2008). Baumol's diseases: a macroeconomic perspective. *The BE Journal of Macroeconomics, 8*(1).

Norgard, J. (1995). Efficient technology in an inefficient economy. *Proceedings of the 1995 ECEEE Summer Study: Sustainability and the Reinvention of Government-A Challenge for Energy Efficiency, ed. A. Persson, The European Council for an Energy-Efficient Economy, Stockholm, Sweden*.

Oecd. (2014). *ALFS Summary tables*. Retrieved from: http://stats.oecd.org/Index.aspx?DatasetCode=ALFS_SUMTAB#

Ozturk, I. (2010). A literature survey on energy–growth nexus. *Energy policy, 38*(1), 340-349.

Petroleum, B. (2011). BP statistical review of world energy.

Pfeiffer, D. A. (2013). *Eating fossil fuels: oil, food and the coming crisis in agriculture*: New Society Publishers.

Punch, K. (2000). *Developing effective research proposals*: Sage.

Quah, D. (1996). The invisible hand and the weightless economy.

Rogoff, K. (1996). The purchasing power parity puzzle. *Journal of Economic literature*, 647-668.

Romer, P. M. (1990). Endogenous technological change. *Journal of political Economy*, S71-S102.

Romm, J., Rosenfeld, A., & Herrmann, S. (1999). *The Internet economy and global warming: A scenario of the impact of e-commerce on energy and the environment*: Center for Energy and Climate Solutions, Global Environment and Technology Foundation.

Rothman, D. S. (1998). Environmental Kuznets curves—real progress or passing the buck?: a case for consumption-based approaches. *Ecological economics, 25*(2), 177-194.

Rowthorn, B., Rowthorn, R. E., & Rasmaswamy, R. (1997). *Deindustrialization: its causes and implications* (Vol. 10): International Monetary Fund.

Rowthorn, R., & Ramaswamy, R. (1997). *Deindustrialization: causes and implications*: International Monetary Fund Washington, DC.

Rubin, J. (2008). Just How Big is Cleveland? : StrategEcon, CIBC World Markets Inc.

Rubin, J. (2009). *Why your world is about to get a whole lot smaller: what the price of oil means for the way we live*: Random House.

Schettkat, R., & Salverda, W. (2004). Demand Patterns and Employment Growth, Consumption and Services in France, Germany, the Netherlands, the United Kingdom and the United States: AIAS, Amsterdam Institute for Advanced Labour Studies.

Schettkat, R., & Yocarini, L. (2006). The shift to services employment: A review of the literature. *Structural Change and Economic Dynamics, 17*(2), 127-147.

Schneider, F. (2005). Shadow economies around the world: what do we really know? *European Journal of Political Economy, 21*(3), 598-642.

Schneider, F., Kallis, G., & Martinez-Alier, J. (2010). Crisis or opportunity? Economic degrowth for social equity and ecological sustainability. Introduction to this special issue. *Journal of Cleaner Production, 18*(6), 511-518.

Schumpeter, J. A. (1939). *Business cycles* (Vol. 1): Cambridge Univ Press.

Singelmann, J. (1978). *From agriculture to services: The transformation of industrial employment* (Vol. 69): Sage Publications.

Smil, V. (2000). Perils of long-range energy forecasting: reflections on looking far ahead. *Technological forecasting and social change, 65*(3), 251-264.

Smil, V. (2004). World history and energy. *Encyclopaedia of Energy, 6*, 549.

Smil, V. (2005). *Energy at the crossroads: global perspectives and uncertainties*: MIT press.

Smil, V. (2010). *Energy myths and realities: bringing science to the energy policy debate*: Government Institutes.

Smil, V. (2013a). The Long Slow Rise of Solar and Wind. *Scientific American, 310*(1), 52-57.

Smil, V. (2013b). *Making the Modern World: Materials and Dematerialization*: John Wiley & Sons.

Smith, R. (2010). Beyond growth or beyond capitalism. *Real World Economics Review, 53*, 28-36.

Soddy, F. (1933). *Wealth, virtual wealth and debt, The Solution of the Economic Paradox*.

Søilen, S. K. (2012). The Service Economy Fallacy: A Materialist Perspective.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics, 70*(1), 65-94.

Sovacool, B. K., Lindboe, H. H., & Odgaard, O. (2008). Is the Danish wind energy model replicable for other countries? *The Electricity Journal, 21*(2), 27-38.

Spangenberg, J. H. (2010). The growth discourse, growth policy and sustainable development: two thought experiments. *Journal of Cleaner Production, 18*(6), 561-566.

Stern, D. I. (2004a). Economic growth and energy. *Encyclopedia of Energy, 2*(00147).

Stern, D. I. (2004b). Energy and economic growth. *Encyclopedia of Energy, 2*, 35-51.

Stern, D. I. (2004c). The rise and fall of the environmental Kuznets curve. *World development, 32*(8), 1419-1439.

Stern, D. I., Common, M. S., & Barbier, E. B. (1996). Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. *World development, 24*(7), 1151-1160.

Stiroh, K. J. (2002). Information technology and the US productivity revival: what do the industry data say? *The American Economic Review, 92*(5), 1559-1576.

Stonier, T. (1983). *The wealth of information: A profile of the post-industrial economy*: Thames Methuen London.

Suri, V., & Chapman, D. (1998). Economic growth, trade and energy: implications for the environmental Kuznets curve. *Ecological economics, 25*(2), 195-208.

Talberth, J., Cobb, C., & Slattery, N. (2007). The genuine progress indicator 2006. *Oakland, CA: Redefining Progress, 26*.

Togeby, e. a. (2009). Danish energy efficiency policy: revisited and future improvements. *Summer Study, Panel, 2*.

Triplett, J. E., & Bosworth, B. (2000). *Productivity in the services sector.* Paper presented at the presentation at the American Economic Association meetings, January.

Triplett, J. E., & Bosworth, B. P. (2003). Productivity measurement issues in services industries:'Baumol's Disease'has been cured. *FRBNY Economic Policy Review, 9*(3), 23-33.

Triplett, J. E., & Bosworth, B. P. (2006). Baumol's Disease'has been cured: IT and multifactor productivity in US services industries. *The new economy and beyond: Past, present, and future*, 34-71.

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business strategy and the environment, 13*(4), 246-260.

Uppenberg, K., & Strauss, H. (2010). *Innovation and productivity growth in the EU services sector*: European Investment Bank.

Van Ark, B., & Piatkowski, M. (2004). Productivity, innovation and ICT in Old and New Europe. *International Economics and Economic Policy, 1*(2-3), 215-246.

Warr, B. S., & Ayres, R. U. (2010). Evidence of causality between the quantity and quality of energy consumption and economic growth. *Energy, 35*(4), 1688-1693.

Weisz, H., Krausmann, F., Amann, C., Eisenmenger, N., Erb, K.-H., Hubacek, K., & Fischer-Kowalski, M. (2006). The physical economy of the European Union: Cross-country comparison and determinants of material consumption. *Ecological economics, 58*(4), 676-698.

WEO, I. (2009). World Energy Outlook 2009. *International Energy Agency. Paris*.

WEO, I. (2012). World Energy Outlook 2012. *International Energy Agency. Paris*.

Withers, G. A. (1980). Unbalanced growth and the demand for performing arts: An econometric analysis. *Southern Economic Journal*, 735-742.

Wörgettera, M., Rathbauera, J., Lasselsbergera, L., Dissemondb, H., Kopetzc, H., Plankc, J., & Rakosd, C. (2003). Bioenergy in Austria: Potential, strategies, success stories. *gas, 13*(17), 22.

WorldBank. (2014). World Development Indicators (WDI) 22-07-2014. from http://data.worldbank.org/indicator/

Wrigley, E. A. (1990). *Continuity, chance and change: The character of the industrial revolution in England*: Cambridge University Press.

Ziolkowska, J. R., & Ziolkowski, B. (2011). Product generational dematerialization indicator: A case of crude oil in the global economy. *Energy, 36*(10), 5925-5934.

Zou, K. H., Tuncali, K., & Silverman, S. G. (2003). Correlation and Simple Linear Regression 1. *Radiology, 227*(3), 617-628.

APPENDIX 1 STRUCTURAL CHANGE THEORY

Structural change theories try to explain the sectorial shift from the agricultural sector to the industrial sector. Clark (1967) divided the economic activities into the three sectors. He expected that due to productivity improvements employment will shift from the primary sector (agriculture) to the secondary sector (Industry) and finally to the tertiary sector (services) (Singelmann, 1978). This set of assumptions is called 'the three sector hypothesis'. In line with the hypothesis most of the employees in OECD countries today work in the tertiary sector (Hospers, 2003).

Market type	Production type	Examples
Primary: Agriculture	Fishery, Forestry, livestock farming	Cattle raiser
Secondary: Industry	Mining	Coal mines
	Manufacturing	Automotive industry
	Electricity, gas, water	Energy providers
	Construction	Building company
Distributive services	Retail trade	Grocery store
	Wholesale trade	Food wholesale
	Transportation	Truck, ship, or train transport
	Communication	Internet, phones
Producer services	Business and professional	Investment funds
	Financial	Banks
	Insurance	Insurance companies
	Real estate	Brokers
Social services	Governmental	National government
	Health	Hospital
	Educational	Primary and secondary school
	Miscellaneous	Social work, police
Personal services	Hotels and restaurants	Restaurant
	Recreational and personal services	Holiday resort
	Domestic services	Barber, gardener
	Other personal services	Taxi

Classification of economic activities. Based upon Singelman: (1978).

Services do not just provide most of the employment of European countries. In 2005 they also accounted for four-fifths of the economic growth and 2/3 of all the value added activities (Uppenberg & Strauss, 2010). The shift from agriculture to services is explained in three different ways, which will be discussed subsequently.

DEMAND SIDE EXPLANATIONS

Demand side theorists assume a certain hierarchy in needs. Colin Clark (1940) was one of the first scholars who explained structural change based upon the demand side theory. Although he recognises the influence of productivity increases, he thought that consumers' preferences shifts from goods towards services as their income rises. Demand side theories build upon Maslow's (1970) pyramid. The latter suggests that the relative contribution of agricultural basic needs to the GDP will decrease, when a country gets richer. Some demand side theorists even expect that income growth leads to the saturation of markets for primary goods and secondary goods. Only the tertiary sector will always keep market potential (Dietrich, 2009). The evolutionary theory of industrial society can only be true under the condition that services replace goods instead of constituting an additional category of demand next to goods. Dietrich and Krüger (2010) found empirical evidence for the suggested hierarchy of needs in Germany which is expressed by a higher price elasticity of demand for goods and services in the industrial and service sector. The same applied for Victor Fuchs (1968) who discovered income elasticity's for goods of 0.92 compared to 1.12 for services. Curtis and Murthy (1998) found similar results. Ronald Inglehart (1981) associated the growing importance of services to the rise of post-material values. Under wealthy conditions, people are expected to prefer aesthetic and intellectual goals above materialistic ones. These results indicate a more stable demand for goods than for services.

SUPPLY SIDE THEORY

William Baumol (1967) challenged the demand side explanation. According to him productivity increases in the agricultural and industrial sectors, would lead to a 'cost disease'. He divided economic activities into two sectors. One sector in which labor- productivity improvements are possible, called the progressive sector and another sector with stable productivity rates, denoted as the non-progressive sector. According to Baumol agricultural and industrial activities are part of the progressive sector, while services belong to the non-progressive sector (Uppenberg & Strauss, 2010). He substantiates his view with a model with three underlying assumptions:

1. Other outlays than labor costs are ignored,
2. Wages in the two sectors rise and fall together, and
3. When wages increase at the same pace as productivity increase,

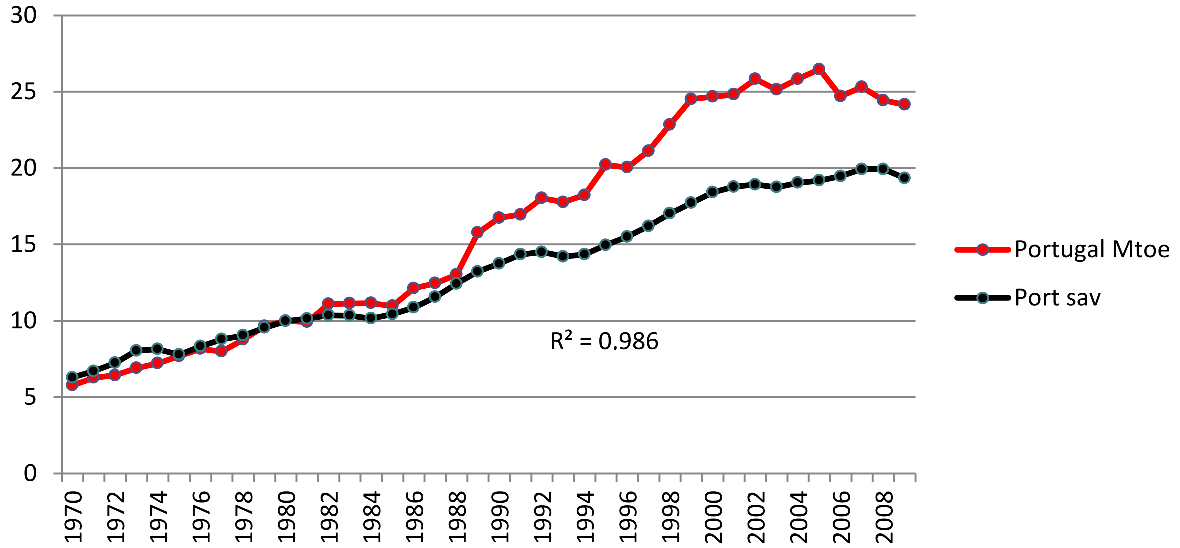
The costs of the non-progressive sector tends to increase, while the costs in the progressive sector remains constant. That is why he expects the costs of services to rise at the same rate as productivity improvements take place in the progressive sector. Gershuny and Miles (1993) also pointed at the influence of relative price increases of services (Heiskanen & Jalas, 2000). Various authors found empirical evidence for the 'cost disease' described by Baumol. Rowthorn and Ramswamy (1997) found annual productivity rates of 3,6% for manufacturing and 1,6% for services between 1960 and 1994. Nordhause (2008) studied global data for the period between 1948-2001 and also provides evidence for the theory of unbalanced growth. He discovered that 85% of the relative US' price changes of goods and services can be attributed to productivity differences. Baumol's reasoning has been criticized for many reasons, but the supply side theory itself makes good sense (C. S. Bell, 1968; Cowen, 1996; Withers, 1980). The last two decades show fast productivity increases in the service sector (Stiroh, 2002; Triplett & Bosworth, 2000; 2003; Van Ark & Piatkowski, 2004). Triplett and Bosworth (2006) for example found that from the year of 1995 productivity rates in the U.S. service sector have grown at a faster rate than those in industry, due to IT, capital deepening and subcontracting. Measuring labor productivity also involves an intrinsic difficulty which relates to the nature of services (Griliches, 1992). These consist of separating services from industrial activities, accounting for heterogeneity, the emergence of new products and the disappearance of old ones. However a general pattern of an increasing quantity of increasing productivity rates for goods can be observed. Bairoch (1982) discovered that between 1750 and 1980 world manufacturing output increased by more than 80 times, while the population rose with a factor 7.5 during that period. Between 1870 and 1998, productivity rates in most Western countries rose with more than a factor ten (Maddison, 2007b).

THE OUTSOURCING THEORY

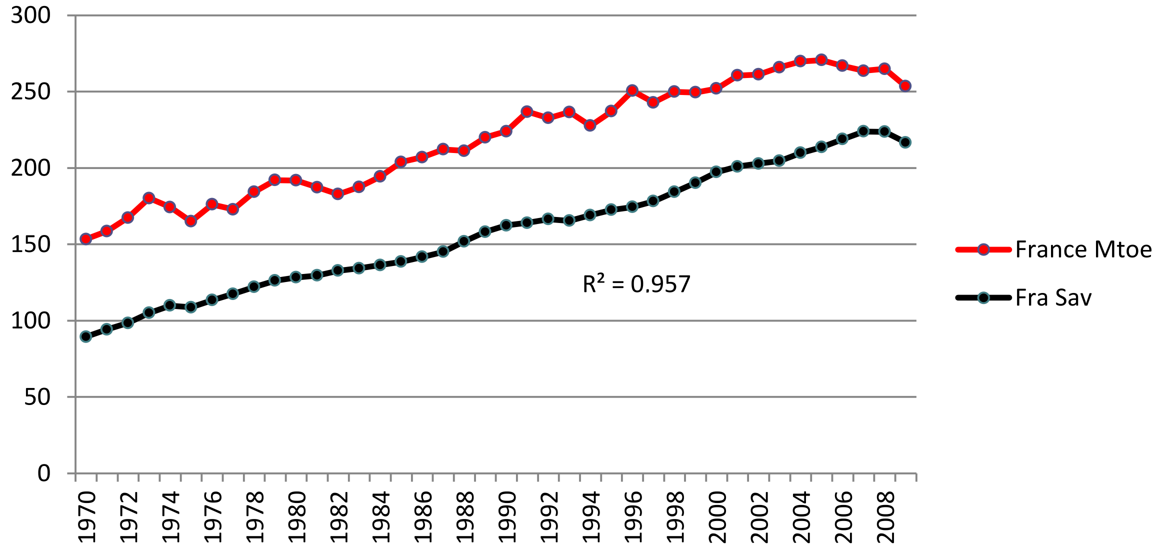
A third explanation for the rise of the service sector concerns the outsourcing of industrial activities. The outsourcing theory assumes that industrial companies tend to outsource service activities like catering, transport activities etcetera (Schettkat & Yocarini, 2006). Input output analysis can be used to split up goods and services. Russo and Schettkat (2006) show that intermediate services provided 11.9% of the industrial output in 1972 and 13.2% in 1990 in the US. They discovered that intermediate services in European countries grew at a faster pace, but not fast enough to explain the total rise of the sector. Greenhalgh and Gregory (2001) found similar results for the United Kingdom. So all authors confirm that outsourcing from the secondary sector takes place and contributes to some degree to the growth of the services. However it cannot explain the rise of the service sector to a large extent. Also the future potential for outsourcing is limited. Furthermore outsourcing only involves a sectorial shift of existing activities, but no change in real energy consumption (Schettkat & Yocarini, 2006).

APPENDIX 2: ENERGY ADJUSTED SAVINGS CORRELATION

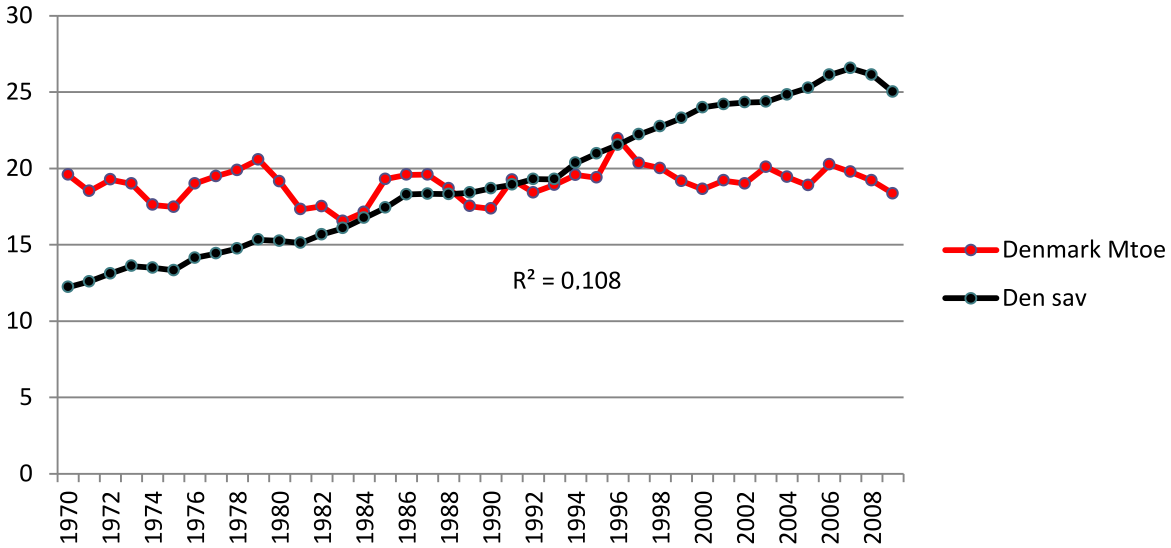
Price adjusted GDP does not reflect the actual income of a country in a proper way, because the aim of income accounting is to discover how much one can consume without impoverishing himself (Hicks, 1946). That is why fossil fuel revenues should be subtracted from the adjusted GDP in order to come up with a more reliable presentation of the energy, GDP relationship (Talberth et al., 2007). It is interesting to investigate how the correlation between energy and price adjusted GDP changes when we subtract adjusted savings energy depletion from price adjusted GDP, measured in constant 2005 dollars. The graph's presented below picture the correlations and are drawn based upon WorldBank (2014) data.



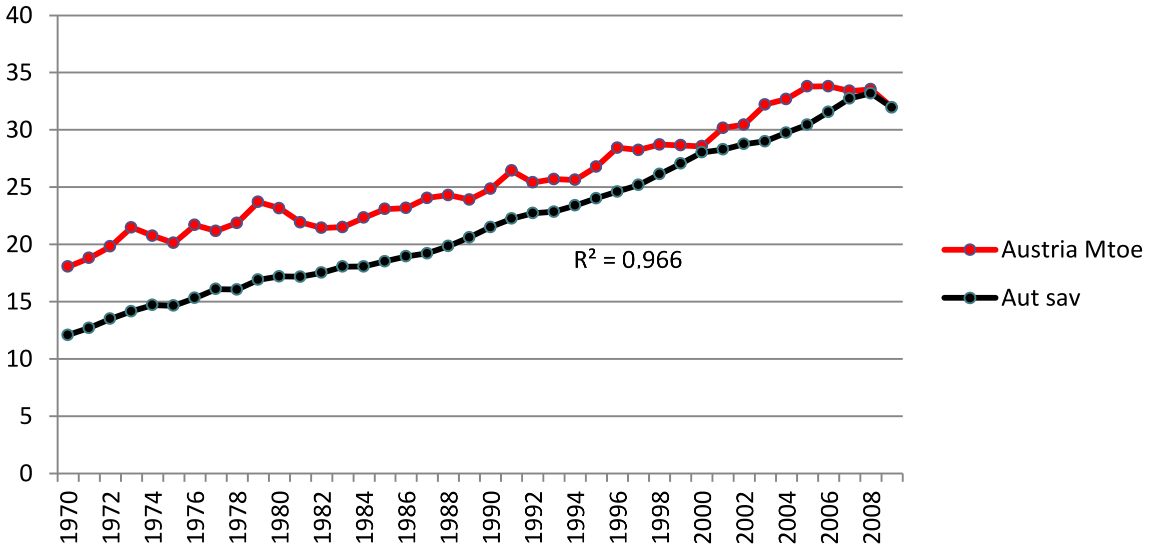
Dynamics between energy and economic growth, controlled for adjusted savings for Portugal Based upon: (WorldBank, 2014)



Dynamics between energy and economic growth, controlled for adjusted savings France Based upon: (WorldBank, 2014)



Dynamics between energy and economic growth, controlled for adjusted savings Denmark. Based upon: (WorldBank, 2014)



Dynamics between energy and economic growth, controlled for adjusted savings Austria Based upon: (WorldBank, 2014)

The association between energy and GDP didn't saw major changes. Part of the reason may be that France, Austria and Portugal do not possess oil and gas stocks and only France possesses small amounts of coal. From 1999 till 2009 Denmark's fossil energy production level covered their domestic energy demand (Petroleum, 2011). WorldBank (2014) data reveal that the country exported 93.75 Mtoe energy between 1998 and 2009. Oil revenues amounted 2% of its GDP in 2005 and were used to pay governmental debts (Andersen, 2007). The fact that energy usually accounts for only 5-6% of the production costs in industrialized countries, may explain the absence of major changes in the energy/ GDP correlation (Baron, 1997; Warr & Ayres, 2010).