SCHOOL OF ECONOMICS AND MANAGEMENT
Lund University

Does the renewable share of total primary energy supply affect the prospect of economic growth?

A study of the OECD economies

Authors:
Agnes Hedengren
Oliver Petersson

Supervisor:
Karin Bergman

Lund University
Department of Economics
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Abstract

This paper navigates the subject of economic growth and energy use, with a focus on environmental sustainability. The aim is to investigate the relationship between the renewable share of total primary energy supply and the GDP per capita growth rate by conducting an empirical study on the OECD member states. The growth rate of GDP has for a long time been used as a measure of economic growth and overall societal development. However, the topic of quality with regards to growth is more and more frequently brought up as climate change and other environmental issues get more severe. In line with earlier research and economic theory presented in the paper, we conducted an empirical study aiming to see the degree of correlation between economic growth and a higher share of renewable energy supply. The conclusion of this paper is that there is a positive bi-directional relationship between a higher share of renewable primary energy supply and the growth rate of GDP per capita, at least within the OECD. The discussion brings up the economic benefits of developed countries actively diffusing sustainably fueled technology to countries which are still at the beginning of their development trajectory. Based on earlier research, it is the countries that are in between being non-developed and fully developed that lie behind the majority of greenhouse gas emissions. Giving non-developed countries access to efficient, sustainable, technology would thus not only reduce future emissions significantly but also help them establish their economies quicker.

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1. Introduction

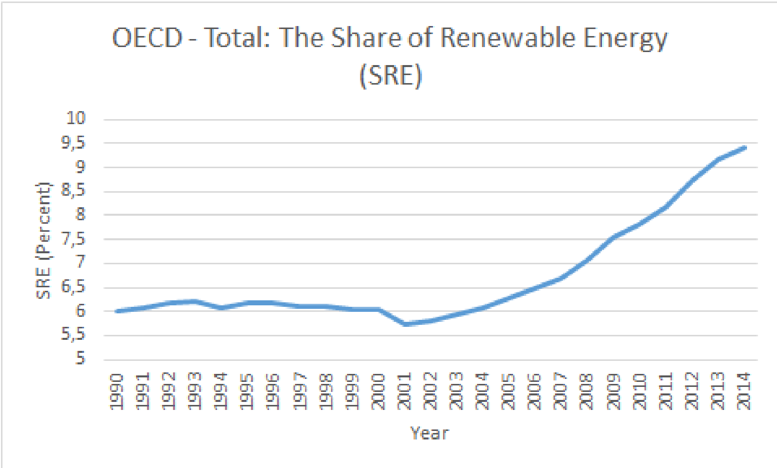
1.1 Our Topic and Research Question

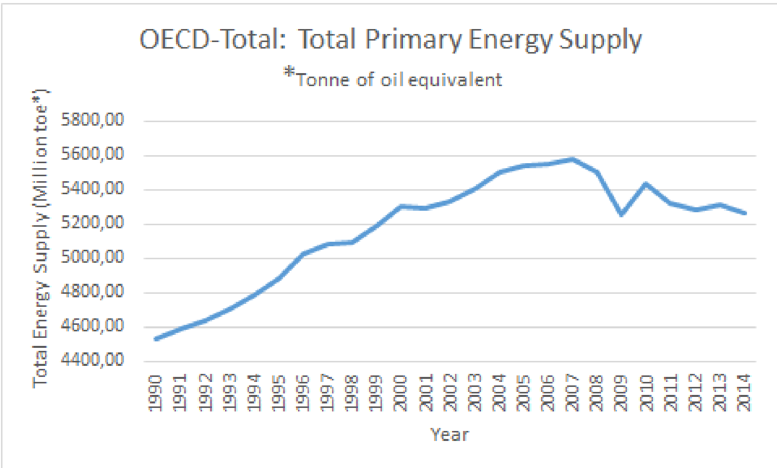
The aim and purpose of this thesis is to conduct an empirical study, followed by a discussion, analysing the effect that the renewable share of total primary energy supply has on economic growth within the Organisation for Economic Co-operation and Development (OECD) over a 25 year period. Although there lies a difficulty in claiming causal relationships, both in the short and long run, the discussion aims to combine earlier research and economic theory with the short-term conclusions of the original study in order to further navigate the topic within a reasonable framework. Political policy making has been and continues to play a large role in the ongoing transition and will thus be treated as well.

Climate change has been on the political agenda for decades and keeps being the source of many debates. Whilst some question its existence, others enter into "blame games" in the hopes of societal stakeholders stepping up and taking responsibility for the environmental issues facing the world. The problematisation of economic growth with respect to increasing CO2 emissions has become somewhat of a go-to as far as connecting economic theory to a more realistic context, with one part of the discussion being that there is a need for a transition from depletable energy to renewable energy.

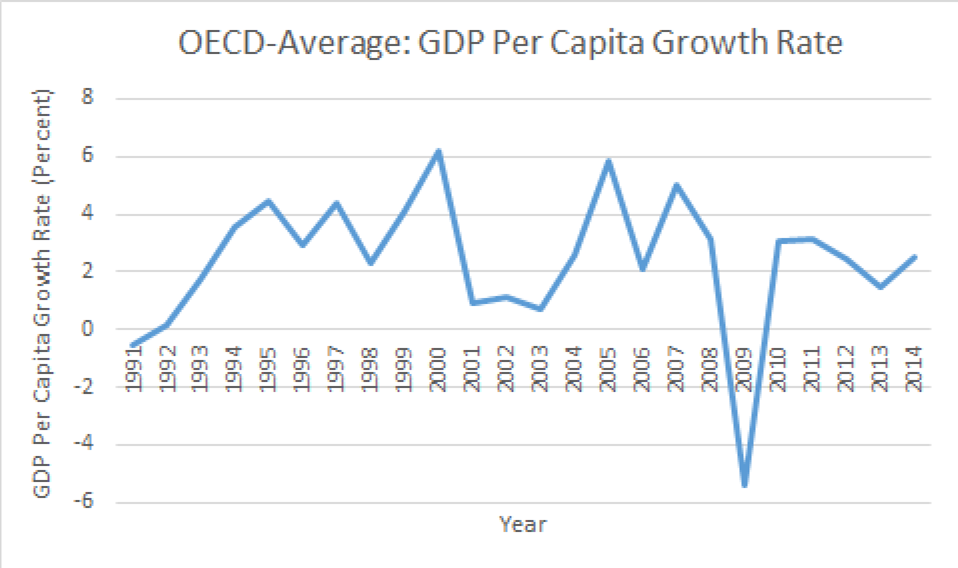
Renewable energy is not only spoken of as a desirable alternative to depletable because it does not rely on the finite natural resources that nonrenewable energy does. Studies also show that increasing the renewable share of energy consumption has a negative effect on CO2 emissions, making it more environmentally friendly (Allard et al. 2017, pg. 5859). When diving into the vast amount of literature available on the environmental aspect of economic growth, it soon becomes clear that there exists a pattern connecting the economic development trajectory and the ratio between renewable and nonrenewable energy.

Upon gathering the set of data used for this paper's empirical study and thoroughly examining it, some interesting patterns became increasingly visible. Two such patterns helped immensely in deciding on an empirical question to examine more closely. One is the clear trend of the OECD increasing the renewable share of its total energy supply. This trend is especially apparent from the turn of the century and onward. The second trend shows the tendency for the OECD to lower its total energy consumption after the year of 2007.





Combined, these two trends ultimately tell us about the ongoing transition from nonrenewable towards renewable energy resources, but also that the total use of nonrenewable resources has decreased within the group of countries. Thus, active choices have been made to use less energy resources that carry with them substantial negative externalities, and to increase usage of those that do not. Observing the larger picture the average Gross Domestic Product (GDP) per capita growth rate has been observed to be positive during the entire observed 25 year period, with the sole exceptions being the years of 1991 and 2008.



The collection of observable trends we had found so far sparked our interest. To which degree could the transition account for the almost exclusively positive GDP per capita growth rates? What can be said about the causal effects? Earlier research, such as the Kuznets curve, presents the notion that an increased share of renewable energy is primarily *caused by* higher levels of GDP per capita while there are widely accepted theoretical models that seem to imply that a higher renewable share of energy can be reasonably expected to facilitate economic growth, at least in the long run.

An important ingredient in interlinking these questions is the discussion on the quality of economic growth. Earlier research on the subject supplied us with further insight regarding the intercorrelation of economic growth and different types of qualitative indicators such as anti-corruption and environmental sustainability. Although it is beyond the scope of this thesis to perform any original empirical analysis of such causal relationships, the implications of this feedback-effect very much sparked our interest. Thus we decided to conduct an empirical study of our own examining the following question:

Does the Renewable share of total primary energy supply within the OECD affect the prospect of economic growth?

Whilst going through the process of narrowing down our topic, the nature of our interdisciplinary degree lead us to further want to discuss the implications of our future findings in regards to policy making. Therefore our leading discussion question has become:

What are the characteristics and implications of the relationship between energy use and economic growth? How could they be used as a basis for policy making and to promote "high quality" economic growth?

Ultimately, the conclusions of this paper are intended to inspire further research and discussion regarding if, how and why countries at various levels of development are affected by the pattern of their energy consumption.

1.2 Demarcation

To narrow down the subject and make it manageable, several measures are taken. The first is to geographically delimit the study to include only the OECD countries, allowing it to become more specific. Another important aspect of the geographical delimitation is that the OECD countries are in general fairly similar not only with respect to per capita income levels, but also institutions, openness to trade and other factors which ceteris paribus should mean that they react to shocks to the economy in a fairly similar manner.

There are clear negative externalities associated with nonrenewable alternatives, that are mentioned as a potential reason as to why a transition to renewable energy can be regarded as desirable, however to treat them in any further detail with regard to size or quantifiable consequences is beyond the scope of this paper. The same reasoning applies to the possible externalities of renewable alternatives, as the issue of interest is the macroeconomic mechanisms at play during an occurring transition between nonrenewable and renewable energy resources, not microeconomic or environmental models. Treating externalities in greater detail would have forced a violation of the geographical demarcation as well, since emissions do not necessarily end up doing damage where they were released. Nor can the incurred costs be expected to be distributed evenly across all countries.

The scope of the paper also does not allow for a discussion on a transition between different types of nonrenewable energy resources with different degrees of sustainability. Some argue that nuclear energy should replace fossil fuels, at least in the short run, due to high efficiency, low operating costs and almost non-existent negative externalities. Such a discussion would have made the subject less manageable and thus both oil, nuclear energy and other nonrenewable alternatives are treated in the same fashion without regard to their relative level of sustainability or environmental impact. Nuclear energy is still an interesting alternative and would require a detailed account in a full scale discussion on the subject of environmental policy.

While the question at hand is politically charged, our ambition is to refrain from the use of personal prescriptive and normative statements regarding the research question and its results. Normative arguments can be an occurrence, though only presented in a descriptive manner. Suggestions within the field of energy policy will be judged on the basis of their consequences for the GDP growth rate and its sustainability and not with regard to other kinds of subjective values.

1.3 Disposition

The remainder of this paper is divided into 4 chapters. First a background section is laid out presenting the subject of economic growth and the environment, as well as accounting for some earlier research. This is followed by a theoretical chapter introducing a modification of the Solow model, with nonrenewable energy to further build up the framework within which the discussion is held. After the framework is built an empirical study is performed, investigating whether the share of renewable energy affects the GDP growth rate of OECD countries. Last but not least a discussion is held tying the previous chapters together and reaching the final conclusions of this paper.

2. Background

2.1 Economic Growth and The Environment

Economic growth refers to an increase of economic activity within, for example, a country. This economic activity is commonly depicted through the Gross Domestic Product (GDP), which takes into account all the goods and services produced for final consumption within in a country during a certain period, usually annually, and thus indicates a country's market value. When talking about economic growth, it is commonly the growth rate of GDP that is referred to rather than an absolute increase of GDP. This, in combination with using GDP *per capita* and a common currency in order to adjust for the size of a country's population as well as exchange rates, creates a somewhat standardised measurement of economic performance that can be used in order to make comparisons between different countries and areas of the world (OECD 2017, pg. 38).

This measurement is not only used as a means to compare economies within the field of economic study. It also has an important practical role as the basis for many economically and politically relevant decisions including, but not limited to, policy making. Sustained economic growth has for a long time been a fundamental goal as it symbolises progress and development of some kind. For the rate of GDP growth to improve, more has to be produced during the same amount of time. This is done by altering the use of human capital and physical capital. Human capital is the pool of knowledge and skill amongst the labour involved in production. An increase in human capital could therefore be due to a more educated and knowledgeable workforce (World Bank 2019). Physical capital is any asset used by the human capital in production. This includes all the workspace and machines which enables the human capital, in combination with input factors, to be processed into goods and services (Encyclopedia Britannica 2019). Investing in capital is a means to improve efficiency in production, either in the form of technological innovations allowing the same amount of input to create more output than previously possible, or just an increased amount of the same types of machines already used, thus enabling production on a bigger scale.

Economic growth does come with a cost, however. In his paper titled “Life and Growth” (2016), Charles I. Jones brings up the potentially massive costs of new ideas through his Russian Roulette Model. Even though today's modern societies have benefited massively from technological innovations, once in a while they have come to result in extensive costs as well. The internal combustion engine, which paved the way for industrialisation and mass production, also marks the starting point of pollution and other environmental issues. Similarly, the development of biomedicine has revolutionised healthcare but also lead to the weaponisation of viruses. There are also many examples of more ‘minor’ new technologies that gained worldwide recognition, were seen as revolutionary, and then later have turned out to be extremely harmful and dangerous. Cigarettes, drug side effects, certain types of makeup, lead paint, just to mention a few. These are just some examples of how sources of fundamental economic growth also can happen to create costs that have massive worldwide consequences (Jones 2016, pg. 541).

As one looks into both the prerequisites and the consequences tied to the phenomenon of economic growth, it becomes clear that other aspects besides just quantity deserves mentioning. One such aspect can be characterised as the quality of growth. The qualitative features of economic growth mainly include: the distribution of opportunities such as education, management of risks, governance and anticorruption as well as environmental sustainability. The nature of intercorrelation between these features and the prospect of economic growth, in the long run, is what fortifies their role as qualitative measures. Paying attention to these types of qualitative measures can contribute to the well being both populations and the environment, resulting in more stable and sustainable economic growth. It also creates a clearer basis on which to manage trade-offs in policy making situations (Thomas et al. 2000, pg. 172, 176).

The subject of this paper mainly emphasises the aspect of economic growth which relates to environmental sustainability and does so by looking into the use of renewable and nonrenewable energy resources. The distinction between renewable and nonrenewable (depletable) energy is made based on the amount of time the formation process of the natural resource takes. Non-storable energy can either be used, or not be used, at a single moment and regardless it does not directly affect the amount that is still available afterward (wind, solar radiation). This non-storable energy is seen as renewable. Energy commodities are more often than not storable although they are stored as potential energy instead of ready to use electricity. Depletable resources take such a long time to be produced in nature that it leads us to treat them as if there is only a finite amount created and available to us (crude oil, natural gas, coal, uranium) (Sweeney 2000, pg. 10).

2.2 Earlier Research

A lot has occurred in the last century within the field of economic growth. Great progress has been made with regards to modeling the accumulation of both human and physical capital, technology, the importance of well functioning institutions and even limitations of economic growth in the shape of finite energy resources. The latter touches upon an increasingly discussed subject, which acts as inspiration for this thesis. This section is intended to give further insight into previous research related to the energy aspect of economic growth.

2.2.1 The Role of Depletable Energy (A Brief Historical Account)

Although nonrenewable energy has gotten a worse reputation in light of the rising environmental issues, it has played a fundamental role in the development of human societies. One could claim that the first use of energy to revolutionise human technological development was the domestication of fire. It is interesting pondering the cataclysmic role the ability of using different sources of energy has had in the development of economies and societies. Similarly to the aforementioned ability to create and control fire, the thermo-industrial revolution during the 19th century makes it clear how the technological development of energy use has a fundamental role in economic development. It is of pivotal importance mentioning that to begin with, societies have been able to be industrious without having gone through “industrialisation”. The energy used at this, contextually primitive, stage was renewable in the above defined sense.

However, pioneering forms of energy generating technologies, such as water mills, animal power and harvesting of wind power through sailing and turbines were soon to be seen as limiting, with the realisation of what economic growth could truly become. Mass production, mobility and lower levels of strain on animals and workers became a reality with the industrial revolution, which relied heavily on the use of machines fueled by nonrenewable energy resources. The dawn of exponential growth rates as we have come to know them has therefore been heavily related to the use of coal and oil as a means of extracting energy (Carbonnier and Grinevald 2011, pg. 12).

Taking a large temporal step out of the industrial revolution and into the present day, a study made by Apergis and Payne (2010), brings to attention a line of empirical questioning sharing a close connection to the one present in this paper. However, it observes the level of consumption of renewable energy rather than the ratio of renewable energy in relation to the total primary energy supply. The conclusion of the said study is that there exists a long-run relationship in the steady-state (the equilibrium level of an economy) between real GDP, renewable energy consumption, real gross fixed capital formation (investment in fixed assets) as well as the labour force. Further analysis also insinuated a bidirectional causality between renewable energy consumption and economic growth existing in both the short-run as well as the long-run, supporting the quality-affecting feature of differences in type of energy consumption (Apergis & Payne 2010, pg. 659), something that will later be discussed in light of the results of the empirical study.

2.2.2 The Importance of Technology

Technological innovation, be it in the form of new ideas or new machinery, plays a central role in economic growth and development. The subject of technology diffusion, the fashion in which ideas and technology spread, is especially interesting from an economic point of view. Even though differences in productivity are usually accredited to technology gaps between countries or industries, less is known regarding the way technology transfers from one place to another. Some patterns are recognised, for example, the tendency of standardisation of new types of technology to eventually slow down the rate of innovation, unless in the presence of well established and balanced intellectual property rights. Countries with strict property rights are more likely to embrace and facilitate the trait of entrepreneurship, a central component in attaining higher technological growth (Acemoglu 2012, pg. 546-549). Technological development lies at the heart of the economy and it is fairly easy to understand why the concept of its diffusion is of great interest.

Since this paper aims to conduct a study and discussion within the context of the OECD, a brief explanation of conditional convergence is in order. Convergence clubs, the observable phenomenon that most rich and middle-income countries converge to similar growth rates, are important to account for in the context of economic and technological growth. Growth models having implemented the concept of a technological gap are especially well armed for such a task. Shortly summarised, theory implies that the rate of innovation in a country, given that it is positive and different from zero, is larger the further its technological level lies below the most technologically advanced country in the world. Eventually, these technological growth rates will converge. Significant investments in research and development as well as improvements to the accumulation of human capital in the form of better education can help narrow the technological gap, while legal and financial institutions of poor quality have the reverse effect due to lack of intellectual and physical property rights, among other things (Aghion & Howitt 2009, pg. 151-152, 156-158).

Conducting a discussion on the environmental impact of economic growth requires predictions of some kind with regard to the expected extent of negative externalities caused by nonrenewable energy consumption. To successfully attempt predictions of this kind has its difficulties, since the predictions will be heavily reliant on the size and rate of technological growth. Oil, for example, is continually becoming more difficult to harvest in its crude form, and will thus become increasingly expensive, in conjunction with its further depletion. This particular drawback is exclusive to the nonrenewable resources. The abundance in supply of renewable energy resources suggests that the fixed cost of inventing more efficient harvesting and storable technology could quite quickly be covered due to the fact that the technology does not have to adapt to new locations and more difficult extraction because of a continually decreasing supply (Tahvonen & Salo 2001, pg. 1394-1396).

2.2.3 The Environmental Kuznet Curve

The relationship between national income and pollution can be depicted by the Environmental Kuznet Curve hypothesis (EKC), which implies that the relationship between GDP growth and greenhouse emissions is that of an inverted U-shape. In line with the hypothesis, it is shown that countries who are at the beginning of their development trajectory are the major driving force behind the increase in energy consumption. The observation that some of the most developed countries of today are historically responsible for the majority of greenhouse gas emissions further supports the theory. As a country becomes wealthier and more developed, the "luxury" of safety and move toward a more sustainable "*high quality*" growth appears as more affordable (Dinda 2004, pg. 434).

Another way to go about understanding this topic, is through discussing it in terms of a trade off between safety and growth. Jones (2016) brings this trade-off to life, in his paper "Life or Growth", through different scenarios of how the utility function of consumption affects economic growth. The conclusion is that if the marginal utility of consumption falls relatively quickly as the economy grows, then the concerns for safety can slow growth as we obtain more utility from tending to our demand for safety (Jones 2016, pg. 21). The grow-now-clean-up-later approach seems to be a common denominator for many of today's most developed countries. However an increasingly urgent question is whether the negative effects of "*low quality"* growth are reversible to a sufficient degree for the countries still in the beginning section of their development to be able to follow in the footsteps of economies like the United States of America (Thomas et al. 2000, pg. 89).

The topic has seen extensive research endeavors ever since it was initially studied by Grossman and Krueger in 1991 (Dinda 2004, pg. 433). A recent study, published in march of 2019, looks into both developed and developing countries and examines their degree of environmental pollution caused by economic growth as well as their relationship with the environmental Kuznet curve. The study further confirms the EKC hypothesis with regard to several different types of emissions, including solid, liquid and fuel consumption emissions as well as CO_2 emissions (Kong & Khan 2019, pg. 15-17). There are numerous empirical observations confirming that the negative environmental impact of emissions increases more rapidly than a country's GDP at earlier stages of economic development, as well as there are observations of the environmental impact to subsequently decrease as national income increases even further. However, the level at which this threshold of economic growth is located is yet to be determined with precision. Thus, the vertex of the Kuznet curve is widely confirmed to exist, but more specific values regarding the level of GDP growth needed to initiate a decline of the environmental impact are yet unknown (Dinda 2004, pg. 450).

Other pieces of research also suggest that the traditional visualisation of the inverted U-shape of the EKC might actually need to be reimagined as more reminiscent of an N-shape. This would imply that the negative environmental impact might increase again when an even higher level of economic growth and development is reached. Perhaps this would be due to large technological breakthroughs requiring immense amounts of energy. Although the exact shape is not as distinct or subject to empirical proof as the bow usually associated with the EKC, the possibility of this rebounce is interesting. The study examining the subject also observed that the upper-middle-income countries differed in results from the lower-middle-income and high-income countries (Allard et al. 2017, pg. 5859). This might signify that these countries are in the midst of transitioning from one convergence club to another.

Upon discussing these types of issues it becomes necessary to note how increasing the sheer amount of renewable energy used requires the production of sufficient tools for harvesting and processing this renewable energy in an efficient manner, regardless of when the transition between renewable and nonrenewable energy resources occurs. The technology needed to do so is inevitably developed and constructed in factories fueled by nonrenewable energy resources. Before a complete transition is even remotely close to becoming reality, mass production of a new, or at least altered, system for energy harvesting, processing and distribution has to be constructed (Stern 2011, pg. 42).

2.2.4 Energy Policy and Economic Growth

Closely related to energy use and technological growth is the subject of policy making. As a basis for every substantial political decision lies policy, dictating which changes are made and in which fashion. Thus it would be leaving out an important part subject not reviewing some earlier research findings and happenings within a political context.

Returning briefly to the subject of convergence clubs, but this time in the context of political unions, a study was conducted where ten formerly Soviet european countries transitioning to the market economy of the European Union (EU) were analysed. The study concluded that the effect the transition has on economic growth varies strongly in the short-run and the long-run. Initially economic growth slows down drastically as a response to new legislation and fundamental remodeling of institutions, creating a sudden need to change and adapt. Eventually, as these countries had integrated into the EU and the new type of economy, their economic growth thrived. In accordance with the EKC, economic growth spurts made it easier for these countries to adapt to the environmental strategies of the EU as they converged with the established EU member states through their institutions, which has stimulated increased use of renewable energy (Marinaș et al. 2018, pg. 23).

According to Acemoglu, Aghion, Bursztyn and Hemous (2012, pg. 18, 40), a delay in policy response to the negative effects of nonrenewable energy consumption is likely to prove very costly. Swift and strong policy action is claimed to considerably decrease the risk of extensive periods of lower growth. Existing attempts to unite the international community in the energy issue, while certainly having had mainly positive effects, are also associated with certain concerns. The Europe 2020 Strategy is one example. Significant progress has been made with respect to the goal of reducing greenhouse gas emissions, increasing the share of renewable energy consumption and improving energy efficiency (Eurostat 2016, pg. 88-93). Despite this, concerns have been raised regarding the choice to include the use of bioenergy in the classification for renewable energy resources, despite the burning of wood being inefficient due to its carbon emissions (Searchinger 2018, pg. 1). Similarly, the Kyoto agreement has also been criticised, but due to the estimations of future emissions being gravely overestimated. The error is mainly due to the lack of consideration with regard to backstop technology, that renewable resources will appear as a more attractive alternative as commodity prices of nonrenewable resources start increasing (Tahvonen & Salo 2001, pg. 1380).

Many countries have overexploited their natural resources in order to achieve increased short term growth. Different countries have different natural resources and, in turn, experience different types of environmental depletion. Therefore the policies intended to act as solutions also might differ immensely across countries, depending on their institutional and economical setting. It is important to note that the countries differing in the above sense do not necessarily need to be different in other respects at all (Thomas et al. 2000, pg. 84). For the developed countries having consumed a large share of their natural resources in order to facilitate significant economic growth, a challenge lies ahead. That challenge is planning how the remaining reserves are to be used while moving toward more sustainable economic and consumption patterns, while simultaneously supporting the development capacities of the most disadvantaged countries (Carbonnier - Grinevald 2011, pg. 22).

Finally, it's of utmost importance to note that even though most developed countries (and thus most OECD members) seem to experience positive growth effects by renewable energy consumption, this can not be said for all. In particular, countries that are heavily reliant on nonrenewable resources to supply energy (a prime example being the US), are more likely to experience negative growth effects if transitioning too fast. Some of the OECD economies experience no clear effects of renewable energy consumption, possibly due to insufficient implementation in production processes (Bhattacharya et al. 2016, pg. 16-18). International cooperation on energy issues is commonly claimed to be crucial and while that may be true, it is clear that consideration has to be taken of the prerequisites of each individual country.

3. Theory

3.1 The Solow Model with Nonrenewable Energy

This section introduces an endogenous growth model which acknowledges the growth dynamics accompanied with the usage of finite energy resources, as well as the important role of technological development which allows us to harness the energy these resources harbour in an increasingly efficient manner. The model, including its GDP per capita growth calculations and growth dynamics, is very similar to the one presented by Charles Jones and Dietrich Vollrath in their educational literature on economic growth (Jones & Vollrath 2013, pg. 228-237). Complete calculations can be found in Appendix A for the interested reader.

$$Y = BK^{\alpha}E^{\gamma}L^{1-\alpha-\gamma}$$

The production function presented above explains the dependence of a country's GDP (Y) on technology (B), capital (K), energy input into production (E) and labour (L). For simplicity, γ is assumed to be between zero and one and $\alpha + \gamma$ is assumed to be less than one. These assumptions force the model to exhibit constant returns to scale, which in short means that if all inputs double, so will the GDP level of the country examined. The accumulation of technology is made exogenous in this model, as is population growth. Their respective growth rates are labeled g_B and n.

The individual components of the production function all develop in their own specific fashion. The function below describes the accumulation of physical capital, which is positively related to the share of GDP which is saved instead of spent on consumption (SY), while negatively related to the capital level multiplied with the depreciation rate of physical capital (δK). The negative effect is due to the fact that machines, buildings, etc. require maintenance and replacements over time.

$$\dot{K} = SY - \delta K$$

An important result implicit in this function is that the growth rate of K needs to be constant in the economy's steady state (its long run equilibrium), which introduces the requirement that Y and K need to grow at the same rate . This applies to their respective per capita expressions as well.

E is the share of the nonrenewable energy stock used within domestic production over a defined period of time, usually a year, while R stands for the nonrenewable energy stock. The energy input that goes into production naturally causes a decline of the total stock of nonrenewable resources possessed by a country.

$$\dot{R} = -E$$

The usage of nonrenewable resources is thus equal to the change in the total stock of nonrenewable energy resources in possession. This relationship causes R to diminish by the level of -E. The growth rate of both R and E, the pace at which they decline respectively increase, is in turn equal to $-S_E$ (S_E being the rate of depletion of the stock of nonrenewable energy resources).

Finally, the following expression describes the growth rate of GDP per capita in the steady state, and allows us to observe what facilitates and what hampers economic growth in an economy.

$$g_y = \left(\frac{1}{1-\alpha}\right)g_B - \left(\frac{\gamma}{1-\alpha}\right)(S_E + n)$$

Technological growth has a positive effect on growth in GDP per capita due to increased productivity, while both the growth rate of energy input into production and a positive population growth rate reduce the GDP per capita growth rate, due to increased pressure on finite resources. The size of γ determines the importance of E in the original production function and thus determines the size of the negative growth effect as well.

One important detail to remember is that even though technological growth is made exogenous in this model, the accumulation of ideas is needed for it to take place. Another model presented in the same book, the Romer model, does account for this with a function for endogenous technological growth. When deriving its steady state level, it is found that the technological growth rate depends positively on both the productivity of workers in the research and development sector as well as on the population growth rate (Jones & Vollrath 2013, pg. 103-104). Therefore, technological growth, g_B, can be reasonably expected to harbor an implicit positive effect of population growth in the examined version of the Solow model as well.

Jones and Vollrath use the parable “race” to describe the relationship between technological development and resource depletion. The reason behind this is the thought that even though these types of resources are finite, new innovations help make extraction of their energy more efficient. If the technology growth surpasses the growth in nonrenewable resource depletion, less input is required for the same amount of output. Whether this is actually the case will be examined as a part of the discussion later on.

To connect the theory further to the empirical research question at hand, one can imagine an attempt to modify the model further, where E as before stands for the energy input depleting the stock of nonrenewable resources, but another variable is introduced to account for the energy input from renewable sources. Such a model could potentially account both for an increase in the share of renewable energy resources used and a maintained or increased GDP per capita growth rate, while the current model can only attain that through technological progress which makes use of nonrenewable resources more efficiently.

4. Empirical Study

4.1 Method

4.1.1 Data and Variables

The empirical study of this paper uses panel data as a means to capture the effects of both time and differences between the OECD countries. The data has been collected from reliable and established sources, such as Penn World Tables and the OECD's own database. The structure of the panel data is unbalanced. However, when testing for robustness a regression with a balanced data set is performed alongside the main one. Any adaptations or calculations done in order to facilitate and enable the econometric execution as well as data sources are accounted for in Appendix B.

All included countries are part of the OECD and observed between the years 1990-2014 in 5 year periods. The reason for using the OECD as a way to delimit the scope of the empirical study, in addition to the institutional similarities and expected club convergence, is the availability of data and the fact that the member countries have significant influence on world economics and politics, partly since they account for about half of the world's aggregated GDP. The different countries act as the cross-sections in the empirical study. A full list of countries and limitations regarding their data can be found in Appendix B as well.

The dependent variable in this study is economic growth in the form of the average growth rate of real GDP per capita. The growth rate of GDP per capita (GDPPCG) is what we aim to explain using the independent variables. As a reminder, GDP is a measure of economic activity in a country and is commonly used in order to classify countries as well as guide strategic decision making within economics and politics. In order to obtain a more comparable measurement one divides a country's GDP by its population, making the unit per capita, before calculating the average growth rate for each time period. Observing the percentage changes makes it easier to analyse and compare over time and between countries.

The main independent variable of our regression is the share of total primary energy supply that is renewable (SRE). This is what we are most interested in observing with regard to how it affects our dependent variable. A country's total primary energy supply is all the energy it has access to which is obtained directly from natural resources, whether that be from harvesting it domestically or importing it from abroad. The net export of primary energy is therefore accounted for, meaning we add the supply gained through imports and disregard from that lost from exporting (OECD 2019b). Primary energy is classified as renewable or nonrenewable based on how long it takes for the natural resource the energy comes from to be produced in nature. Some resources take so long for nature to create that their supply is regarded as finite while other resources are seen as having an infinite supply due to the process of harvesting energy from them does not affect future availability. Using the share of renewable energy a country has access to is due to the fact that it indicates the ratio between renewable and nonrenewable energy use. This enables observation of how a transition from one energy type to another affects GDP.

In order to create a model that explains the dependant variable as realistically as possible, control variables are used alongside the main independent variable as a way to account for other possible affecting factors. For this study, the control variables are: Investment growth rate (InvG), average years of schooling for the population over 15 years old (AvgEdu), total factor productivity (TFP) and population growth rate (PopG). All of these variables serve as representatives for different areas of the economy that are known to affect economic growth, including human capital and technology.

As of now, a brief hypothesis on the expected results with regard to each variable is in place. Drawing upon the theoretical implications of the modified Solow model, as well as the environmental kuznet curve, the renewable share of energy can be expected to have a positive effect on the GDP per capita growth rate in the long run. However, it is not apparent beforehand whether the chosen 25-year period is long enough for this effect to be significant. Some of the previous empirical research conducted on the subject claims to have found short-run as well as long-run effects. One difference which might prove to be significant is that the model at hand uses the share of renewable energy as its primary independent variable, whilst most of the earlier research instead uses the total amount consumed. It remains to be seen whether the difference matters or not in this aspect.

A positive investment growth rate leads to continuous increases in the steady state level of the economy and is observably one of the variables which differs the most in a cross-section perspective, likely due to national lending and borrowing being implicitly present in the data. This leads us to think it will likely be associated with both a positive and significant effect.

The effects of the remaining three independent variables are less easily hypothesised. The education variable varies little during the time period. In general, a higher number of average years in education can be expected to result in a more productive workforce. However, it also inevitably means that a larger share of the population spends less time as part of the production sector. Thus, the effect is less clear.

The total factor production variable reflects the relative level of the technology between different countries. It can be useful to think of this variable as an approximation of the technology gap, which was explained in a previous section. The OECD countries are in general well developed in this respect which might suggest that the effect, whether it is positive or negative, is not significantly large. This seems likely observing the variations in the data set.

Population growth is in part the source of ideas and technological growth (Jones & Vollrath 2013, pg. 123). This might indicate a positive effect of population growth on the GDP per capita growth rate. However, there are also negative effects associated with an increasingly growing population, such as the aforementioned increased pressure on finite resources and the trivially obvious negative level effect with respect to GDP *per capita*. Thus, it is slightly unclear what to expect of the results.

Since the fashion in which the economy evolves is dependent on past occurrences and trends, it is common to add lagged versions of certain independent variables. After a period of trial and error attempting to implement such lags, whilst also keeping in mind that lagging one variable means losing an entire time period of observations, the decision was made to refrain from lagging even though in theory it could be beneficial. In practice this rose suspicions of autocorrelation and/or endogeneity.

Another type of variable that can be added as a means to maximize accuracy are dummy variables that take into account the effect of various differences between the countries or time periods. For example, a dummy was initially added to this study dividing our time periods into two eras, namely before and after the financial crisis 2008. When looking at any data remotely related to economics, it is common to see the shock that the financial crisis of this time created. Since this is the most prominent, and nearly single, effect that is fixed to a certain time period, a dummy could be used to catch this effect while enabling all other period effects to be non-fixed. This was an attempt to fix some variations between the time periods, since having both cross-section and period effects be fixed was an unavailable option due to unbalanced data. As the attempts did more harm than good with regard to our results, we instead used our balanced data regression to fix all effects and rejected use of the dummy.

Summary of Variables All variables are in averages for each time period (1990-1994, … , 2010-2014)	
Description	**Code**
GDP per capita growth rate.	GDPPCG
The share of total primary energy supply which is renewable.	SRE
Investment growth rate.	InvG
Average years of schooling for population age 15 and above.	AvgEdu
Total factor productivity.	TFP
Population growth rate.	PopG

4.1.2 The Empirical Model

Using the variables introduced above, the main econometric specification of the study takes form. The model is estimated using the econometric software eViews 10. In order to establish the fashion in which the regression is to be performed, some testing of the data and reasoning regarding the shape of the model is in order. It is worth mentioning that eViews is limited in some aspects with regard to the options and amount of tests available in a panel data setting.

Main Specification:

$$GDPPCG_{it} = \beta_0 + \beta_1 * SRE_{it} + \beta_2 * InvG_{it} + \beta_3 * AvgEdu_{it} + \beta_4 * TFP_{it} + \beta_5 * PopG_{it} + \varepsilon_{it}$$

The Hausman Test is performed to test for endogeneity and to aid in the choice between a fixed or random effects model. If a panel data set is characterized by individual specific effects with regard to its cross-sections or periods and is estimated with a random effects model anyway, it is likely to become subject to unobserved heterogeneity bias (Dougherty 2016, pg. 540). The test result specifies a model with fixed cross-section effects to be the better choice given the structure and nature of the data set. This applies for all four regressions and it seems reasonable to allow for country-specific effects. As mentioned, the balanced regression uses fixed cross-period effects as well, an option unavailable in the case of the others.

Unbalanced data needs to be interpreted with caution, since the data omitted from the set might have otherwise introduced endogeneity into the model. Additionally, if a balanced regression is made by removing unwanted cross sections or periods, it is of importance to determine that the loss of explanatory power is not of great importance to the final results (Dougherty 2016, pg. 530). The model of this paper is subject to precisely this potential issue, however the balanced panel contains only two countries less than the unbalanced one, which possesses a total of 34. This leads us to suspect that the potential problems introduced by balancing will not outweigh the potential benefits of the formerly unavailable option to use fixed time period effects.

Estimating the coefficient covariance method for the model requires some idea of whether there is any kind of correlation between its cross-sections. Due to the interconnected nature of economics, as well as politics, within and between the OECD member states, it can be argued that such correlation effects exist. There is evidence of bilateral trade acting as a transmission mechanism for different types of shocks. The same line of reasoning is thought to apply to similarity with regard to institutions as well (Otto, Voss, Willard, 2001. pg. 43). Due to the probability of such correlation effects, 'White cross-section' is the chosen coefficient covariance method for the specified model. This precaution was inspired by the approach of another panel analysis, treating the 38 countries in the world which consume the most renewable energy (Bhattacharya et al, 2016, pg. 4).

The Durbin-Watson statistic of a regression is used to test for autocorrelation. The statistic takes on a value between zero and four, where a value close to the prior indicates positive autocorrelation and a value close to the latter indicates negative autocorrelation (Dougherty 2016, pg. 451-452). Thus, a value sufficiently close to two is a clear indication that autocorrelation is absent within the model. Neither the main regression or any of the ones performed for robustness exhibit any mentionable level of autocorrelation.

A unit root test was performed to address the potential issue of non-stationarity. The null hypothesis of the unit root test, that the data has a unit root, is rejected in the case of our model. Most of the data shows no trend at all to continuously increase or decrease during the specified time period. The only two types that do are the share of renewable energy and average years of education. However, these trends are only weakly positive and will likely not introduce any mentionable degree of stationarity bias into the final results of the regression.

One potential issue is that of *omitted variables*. The definition of an omitted variable is that it has been left out of the regression despite having some degree of explanatory power towards variations in the dependent variable. This might cause variables that are included in the regression to appear more significant than they truly are, due to them being biased (Dougherty 2016, pg. 261-262). Primarily, two variables were excluded with this potential trait, in both cases due to data limitations.

The first of the two omitted variables previously mentioned is some kind of estimation of a country's openness. Some approximation of the volume of exports and imports as a share of GDP is usually employed to achieve this. Openness is generally expected to have a positive effect on economic growth. The second variable is investment in research and development, which could also be expressed as a share of GDP. Due to the role of technological growth in augmenting GDP per capita growth, increased investment in research can be expected to lead to an increase in growth rates for both technology and GDP per capita.

Had they been included, the amount of cross sections would have diminished instead, which we deemed to be the more undesirable option. It is worth noting that there are most certainly other variables that share this trait of explanatory power to some degree.

4.2 Results

The previously introduced econometric model is utilised to analyse the correlation between the renewable share of total primary energy supply and the GDP per capita growth rate. To test for robustness one regression was performed with a balanced data set, a second where six potential outliers were identified and removed, and finally a third where only the EU members of the group were included. As previously mentioned, the balanced version of the regression can be expected to improve the overall estimation due to the probable presence of cross-period fixed effects. A list of the countries included in each regression can be found in Appendix B.

The results from the main regression are presented in table 2.1. The results from the remaining three regressions, the ones testing for robustness, are showcased in table 2.2.

Table 2.1

Variable	Main Regression
Constant (C)	-0,017 (0,412)
Share of renewable energy (SRE)	0,287** (0,046)
Investment growth rate (InvG)	0,148*** (0,006)
Average years of education (AvgEdu)	-0,001 (0,526)
Total factor productivity (TFP)	-0,002 (0,839)
Population growth (PopG)	0,591 (0,579)
R^2	0,345
Adjusted R^2	0,153

*P < 0,1   **P < 0,05   ***P < 0,01
P-values are presented within the parenthesis below their corresponding coefficients.

Noticeably, the renewable share of the total primary energy supply has some degree of significance within all four models. In the main regression above it is statistically significant at a five percent level and is correlated to a positive coefficient with a value of 0,287. Thus, an increase in the renewable share by one percentage point is accompanied by an increase in the GDP per capita growth rate by approximately 0,287 percentage points.

The investment growth rate is significant at all levels and has a positive coefficient with the value of 0,148. Thus, an increase in the investment growth rate by one percentage point is correlated to an increase in the GDP per capita growth rate by approximately 0,148 percentage points. This is in line with the expectations presented beforehand.

The remaining control variables are all insignificant. Average years of education and total factor productivity are observed to have very small positive coefficients, possibly signifying that their effect is negligible. The population growth rate has a positive coefficient with the value of 0,591, however no informative conclusion can be drawn from it due to the insignificance.

The slightly low level of R^2 and especially the adjusted R^2 might be problematic, however not necessarily. Sometimes a large difference between the two hints at the inclusion of too many explanatory variables which lack explanatory value. In an attempt to account for this issue, an estimation was made with only the significant variables. Both the normal and adjusted R^2 remained at roughly their previous levels leading us to suspect that the problem instead might be one of omitted variables, which was discussed in more detail in the previous section.

If this is the case, then the low R^2 levels seem to mainly imply that all variations within the dependent variable can not be accounted for with the selected independent ones. This is not necessarily an issue, since the significance levels of the share of renewable energy and investment growth rate are relatively high. Thus, even though they are only able to explain part of the variations in the GDP per capita growth rate, that part is likely explained well. For further discussion on the interpretation of this statistic, see Dougherty (2016).

Table 2.2

Variable	Balanced	Without outliers	Only EU members
Constant (C)	-0,086** (0,012)	-0,005 (0,741)	0,001 (0,961)
Share of renewable energy (SRE)	0,330** (0,049)	0,360* (0,061)	0,388* (0,059)
Investment growth rate (InvG)	0,097** (0,017)	0,143*** (0,009)	0,151** (0,014)
Average years of education (AvgEdu)	0,004*** (0,002)	-0,002 (0,486)	-0,003 (0,380)
Total factor productivity (TFP)	0,007 (0,378)	-0,009 (0,441)	-0,003 (0,878)
Population growth rate (PopG)	0,730 (0,473)	0,645 (0,174)	0,644 (0,579)
R^2	0,379	0,328	0,364
Adjusted R^2	0,171	0,126	0,162

*P < 0,1 **P < 0,05 ***P < 0,01
P-values are presented within the parenthesis below their corresponding coefficients.

A clear consequence of estimating the balanced regression with fixed cross-period effects is a better overall fit and higher significance in the case of almost all variables. Had the aforementioned attempts to incorporate time-specific dummies in the other regressions been successful, perhaps the significance would be slightly higher across the board. Whether that statement holds some kind of truth is of course purely speculative.

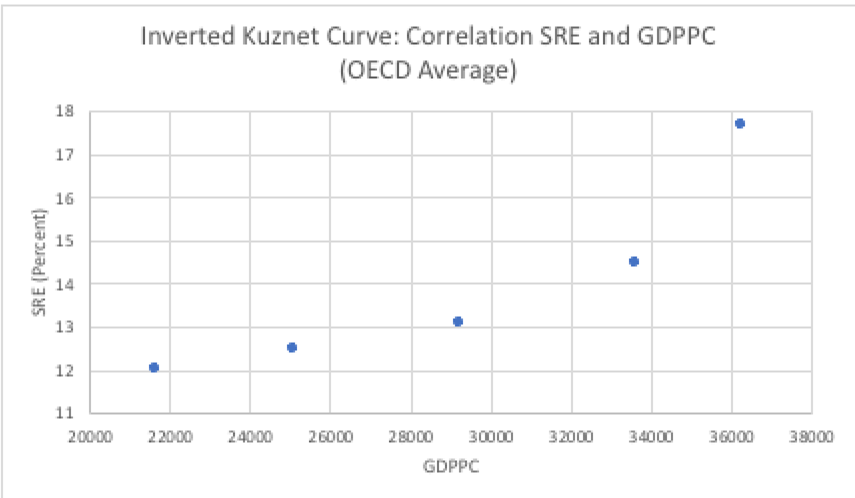
A noticeable difference worth mentioning is the sudden significance of average years of education at a one percent level. A possible explanation might be small variation within the sample with regard to average years of education, which is not unthinkable in the context of the OECD. Due to the small associated coefficient, though, the effect is likely completely negligible.

To summarise, the main independent variable measuring the renewable share of total primary energy supply seems to have a positive and statistically significant effect on the GDP per capita growth rate, as does the investment growth rate. It became clear that the balanced regression with fixed cross-period effects resulted in a better estimation, as hypothesised. The slightly low R^2 level is possibly due to omitted variables with explanatory value and does not necessarily mean the estimation is of poor quality (even though it might, something that needs to be accounted for).

5. Discussion, Summary and Conclusion

5.1 Discussion

The results of our empirical study show that a higher share of renewable energy can be expected to have a positive and significant effect on the GDP per capita growth rate. This is in line with the corresponding results of both earlier research and theory, which claimed causal relationships in both directions, and gives weight to the claim that economic growth and increased use of renewable energy resources dynamically empower one another, both in the short and long run. Also in line with earlier research is the positive effect and significance of investment growth. Investment in new capital helps improve the efficiency of production and aids countries in their endeavor to catch up to or remain close to the world technological frontier. With regard to the concept of conditional convergence, both education and total factor productivity can be reasonably expected to have a positive effect on economic growth. The results section contains a discussion on the potential reasons as to why they do not in the case of our study.



As can be observed by inspecting the diagram above, replacing the environmental degradation present on the y-axis of the original Kuznet curve with the share of renewable energy, showcases a positive relationship between GDP per capita and the mentioned share. We choose to call this relationship "The Inverted Kuznet Curve" and while it does tell the same story as the original one, we feel that this iteration contains more explanatory value for the forthcoming discussion. The average economic development of the OECD countries has allowed them to decrease their environmental impact by transitioning towards more sustainable energy alternatives. An important point to make is that if the observations of bi-directional causality truly hold, the identified transition should ceteris paribus be expected to pick up speed as it progresses. Another observation of importance is linked to the successfully maintained positive GDP per capita growth rate. This implies that the technological growth in the renewable energy sector has, seemingly, so far been able to offset the loss of potential growth associated with nonrenewable resource use.

Drawing upon the “race” parable briefly presented in the section on the Solow model might shine some light upon whether the gains in the field of technology can truly offset the depletion effect of nonrenewable resources. In the case of oil, perhaps the most central resource of this kind, technological growth seems to have made up for depletion in the global industry up until the middle of the nineties. Since then, the reduced research and development activity among many oil companies seems to have caused a reverse effect (Lindholt 2015, pg. 1612-1613). This observation, combined with the other empirical results presented in this paper, might make a fairly strong case for oil-dependent countries and industries to initiate or accelerate the transitioning to non-depletable alternatives, at least at a rate fast enough to again offset the depletion effect.

A potentially important, and easily overlooked, point to make is that, following the earlier made theoretical predictions, the nonrenewable energy resources saved today still have to be used in the future in order to capture the higher economic growth technological progress has made possible, in accordance with the theoretical predictions made earlier. This is one of the main points of the modified Solow model. Alongside increasing concerns about the associated negative externalities of these types of resources, it might prove to be more difficult motivating their use in the future than it is today. This can potentially pose an even greater problem to the countries that are currently more reliant on their nonrenewable energy consumption, as the incentive to postpone the economic growth relies on a more insecure prospect of future economic growth. This point suffices as a transition into the pivotal discussion of energy policy, since having to accept lower growth for prolonged periods of time is a scenario most politicians likely wish to avoid, and swift policy action is required to minimise the risk of that scenario becoming reality (Acemoglu et al. 2011).

On the subject of the less explored N-shaped Kuznet curve, what lies behind the prediction that countries that become even more wealthy will begin to increase their environmental damage yet again? It seems likely that this would follow a surge in energy demand, but perhaps it is due to technological advances requiring immense amounts of energy, amounts the renewable alternatives at the present can not be expected to supply. Whatever causes this potential surge in energy demand, it can be argued that the policy actions taken today influence which energy type is mainly used to fuel the future increased demand. This potential scenario further supports the claim regarding the importance of swift and decisive policies of transition, however it is also important to acknowledge the difficulties of making these kinds of predictions due to the irregular nature of technological growth. Such difficulties played a role in the overestimation of emissions associated with the case of the Kyoto Protocol.

A final concern revolving around the concept of the Kuznet curve is that the OECD as a whole has passed the hill of the curve and has thus initiated a reduction of their harmful emissions. Not all regions of the world are fortunate enough to have the luxury of being at this stage of their economical and societal development. In the earlier sections of this paper we have accounted for both the tendency of less developed countries to continually increase their emission levels (due to them being located earlier in the Kuznet trend) as well as the property of emissions not to remain in the same place where they were released into the atmosphere. Since the negative externalities of nonrenewable resource usage in production has a proven negative effect on economic growth in the future, the same applies for negative externalities of other countries as well. Add to this the feasibility of large migrant movements from regions struck harder by these externalities and it becomes clear that these environmental issues might need to be accounted for on a global scale.

Thus, the OECD has as much reason to care about emissions originating elsewhere, since it could potentially worsen the prospect of their own economic growth. A suggestion of how to hinder such a scenario might be to aid these countries in attaining economic development without having to rely on nonrenewable resources and technology. Targeted technology diffusion with the objective to spread ideas and create renewable technology growth in less wealthy regions of the world could be a reasonable place to begin. That way, the anticipated enormous increase in greenhouse gas emissions from these regions might still be partially avoided. Failure to address this concern will, in line with the entirety of the previous empirical reasoning, affect economic growth in the OECD in a heavily negative fashion. The main reason for including this point in our policy discussion is to suggest that energy policy to maintain or increase economic growth might make as big of a difference outside the borders of the country implementing it as it does inside. This subject of course warrants vast further research and attention, but is potentially of great importance.

5.2 Summary and Conclusion

This paper has attempted to investigate the role of energy use patterns in the economic growth trajectory of countries in the OECD. An introduction to the subject was followed by a substantial analysis of earlier research highlighting important historical aspects of energy use, the pivotal role of technological growth, empirical observations on causality between income and emission trends, as well as aspects to be taken into account while discussing energy policy. In order to make further predictions with accuracy, a theoretical section consisting of a Solow model was presented. The model was modified to take into account the finite stock of nonrenewable energy resources available to an economy and how both current use and depletion affects economic growth in the present and future.

The groundwork was thus complete for us to construct an empirical study estimating the effect of the renewable energy share of primary energy supply on the GDP per capita growth rate within the OECD. After extensive data collection, statistical testing and interpretation of results, the output of the study widely confirmed the empirical observations of earlier research, as well as the predictions of the modified version of the Solow model.

A discussion then followed connecting the content of all previous sections. The aforementioned bidirectional causal relationship between renewable energy and economic growth was treated, as was its interpretations with regard to the OECD member states and other countries which have not yet reached the same degree of economic and societal development. The importance of offsetting the depletion effect, as well as the economic losses associated with continued use of nonrenewable energy resources, with new technology and development within the sector of renewable energy, was also highlighted. Considerations for the economic and political future of the OECD were treated to conclude the discussion.

The main conclusion of this thesis is thus that there does exist a positive relationship between renewable energy supply and economic growth, at least when observing more developed countries such as the OECD member states. Further, this relationship and it's characteristic to vary depending of which stage of economic development a country is in, lead the discussion to review how to best make use of this notion with regard to enabling both the environment and economies around the world to thrive, while still securing the best possible prospect of economic growth within the OECD. One aspect presented is the ability for developed countries to minimise the negative environmental impact needed for less developed countries to reach higher levels of economic growth through technological diffusion. The minimised environmental impact is predicted to also minimise the prospect of future growth limitations within the OECD.

It is clear that further research on the subject of energy policy is required in order to construct policies successfully dealing with both global emissions as well as environmentally friendly technology diffusion. An interesting subject might be to research the impact of robust intellectual and physical property rights on technology transfer toward less wealthy regions of the world. Another, whether the kinds of policy treated in the discussion requires political unions with legislative powers or whether countries can be expected to implement them on their own. This paper has been incredibly interesting to write and it will be exciting to witness the fashion in which the future eventually plays out.

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7. Appendices

7.1 Appendix A

Below follows a complete derivation of the production function of the modified Solow model.

The first step toward finding the steady state GDP per capita growth rate is to express GDP in its per capita form (y):

$$Y = BK^{\alpha}E^{\gamma}L^{1-\alpha-\gamma}$$

$$y = \frac{Y}{L} = \frac{BK^{\alpha}E^{\gamma}L^{1-\alpha-\gamma}}{L^{\alpha}L^{1-\alpha}} = Bk^{\alpha}E^{\gamma}L^{-\gamma}$$

To express the production function in terms of the growth rates of its components, the natural logarithm is taken:

$$ln\, y = ln\, B + \alpha \cdot ln\, k + \gamma \cdot ln\, E - \gamma \cdot ln\, L$$

Then the first difference with respect to time:

$$\frac{d\, ln\, y}{d\, t} = \frac{d\, ln\, B}{d\, t} + \alpha \frac{d\, ln\, k}{d\, t} + \gamma \frac{d\, ln\, E}{d\, t} - \gamma \frac{d\, ln\, L}{d\, t}$$

$$g_y = g_B + \alpha \cdot g_k + \gamma \cdot g_E - \gamma \cdot n$$

Two steps remain before completion. The first is a specification of g_E[1]:

$$g_E = \frac{\dot{E}}{E} = \frac{\dot{E}}{S_E \cdot R} = \frac{S_E \cdot \check{R}}{S_E \cdot R} = \frac{\check{R}}{R} = \; -S_E$$

[1] Please note that both dots and arrows above a variable implies the change within said variable. The reason for not being able to uniformly utilize one of these symbols is software limitations with regard to equations.

Entering this into the g_y function gives us:

$$g_y = g_B + \alpha \cdot g_k - \gamma(S_E + n)$$

The final step is a specification of g_k:

$$g_K = \frac{\check{K}}{K} = S\frac{Y}{K} - \delta$$

Since g_K needs to be constant in the steady state, Y and K need to grow at the same rate. This also implies that y and k need to fulfill the same condition. Thus:

$$g_Y = g_K \leftrightarrow g_y = g_k$$

Taking this into account we are able to complete our calculations:

$$g_y = g_B + \alpha \cdot g_k - \gamma(S_E + n)$$

$$(1 - \alpha)g_y = g_B - \gamma(S_E + n)$$

<u>The final result is the following expression:</u>

$$g_y = (\frac{1}{1-\alpha})g_B - (\frac{\gamma}{1-\alpha})(S_E + n)$$

7.2 Appendix B

List of variables					
Description	**Code**	**Type**	**Source**	**Calculations**	**Limitations**
GDP per capita growth	GDPPCG	Dependent	Penn World Tables	$\left(\frac{\frac{GDP}{Population}_{1994}}{\frac{GDP}{Population}_{1990}}\right)^{1/5} - 1$	None
Percentage of total primary energy supply that is renewable	SRE	Independent (Main)	OECD Data	None	None
Population growth	PopG	Independent (Control)	Penn World Tables	Example for time period 1990-1994: $\left(\frac{Pop_{1994}}{Pop_{1990}}\right)^{1/5} - 1$	None
Average years of schooling for population age 15 and above.	AvgEdu	Independent (Control)	Barro R. & J.W. Lee	None	Raw data given in 5 year averages already.
Investment in the form of: Annual growth rate of gross fixed capital formation	InvG	Independent (Control)	OECD Data	None	Missing data for first time period.*

*Countries missing data from first time period (1990-1994): Lithuania and Luxembourg

Notes:
- Averages were made of all data (except for AvgEdu) in 5 year periods. (1990-1994, … , 2010-2014)
- Missing data from period one does not affect our study due to GDPPC and PopG being lagged one period.
- Partially missing data has been regulated by doing an average only on the data available. This is when the majority of the time period is covered by data.
- Estimations are treated as legitimate data due to the source being reliable.

List of countries*			
Main regression	Balanced regression**	Without outliers***	Only EU members
Australia	Australia	Australia	Austria
Austria	Austria	Austria	Belgium
Belgium	Belgium	Belgium	Czech Republic
Canada	Canada	Canada	Denmark
Chile	Chile	Chile	Estonia
Czech Republic	Czech Republic	Czech Republic	Finland
Denmark	Denmark	Denmark	France
Estonia	Estonia	Estonia	Germany
Finland	Finland	France	Greece
France	France	Germany	Hungary
Germany	Germany	Hungary	Ireland
Greece	Greece	Ireland	Italy
Hungary	Hungary	Italy	Latvia
Iceland	Latvia	Japan	Lithuania
Ireland	Iceland	Latvia	Luxembourg
Italy	Ireland	Luxembourg	Netherlands
Japan	Italy	Mexico	Poland
Latvia	Japan	Netherlands	Portugal
Lithuania	Mexico	New Zealand	Slovakia
Luxembourg	Netherlands	Poland	Slovenia
Mexico	New Zealand	Portugal	Spain
Netherlands	Norway	Slovakia	Sweden
New Zealand	Poland	Slovenia	United Kingdom
Norway	Portugal	South Korea	
Poland	Republic of Korea	Spain	
Portugal	Slovakia	Sweden	
Republic of Korea	Slovenia	Switzerland	
Slovakia	Spain	United Kingdom	
Slovenia	Sweden	United States	
Spain	Switzerland		
Sweden	United Kingdom		
Switzerland	United States		
United Kingdom			
United States			

* Israel and Turkey were removed from all regressions due to insufficient data.

** Removed due to unbalanced data: Lithuania and Luxembourg (missing investment data).

*** Outliers: Finland (low investment growth), Greece (low investment growth), Iceland (high share of renewable energy), Lithuania (high investment growth) and Norway (both high GDP per capita and TFP).