Bachelor Thesis

Renewable energy and economic growth in the European Union

A study into the relationship between renewable energy, labor, capital and economic growth

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1. Introduction

While large oil producing countries are suffering from declining fossil fuel prices, renewable energy production is booming. In 2015, total new investments in renewable energy reached a new record of 285.9 billion US dollars. The global investments in new renewable power capacity in the same year were, with a total of 265.8 billion dollars, more than twice as high as the investments in new fossil fuel capacity (REN21, 2016). As a consequence of the increasing investments in renewable energy, the costs are decreasing rapidly.

One of the causes of the increasing investments in renewable energy is environmental concerns. The global issue of climate change has put pressure on countries to transition from fossil fuels to energy that is produced in a more sustainable way. This incentivized countries from all over the world to organize several climate summits, in which the nations agreed that more effort is needed to combat climate change. Stimulating investments in renewable energy production is one way in which countries try to limit climate change.

Another important contributing factor to the increasing consumption of renewable energy is the wish to decrease dependence on energy import for political reasons. The European Union (EU), concerned about the dependency on oil and gas imports from Russia, formulated the wish to further deploy renewable energy (European Commission). This policy is part of the European Security Strategy, and partially explains increasing investments over the last ten years.

The growing popularity of renewable energy and the development of policies aimed at energy transition motivated several economists to focus their research on the matter. More specifically, they investigate the relationship between renewable energy consumption and economic growth. The transition to renewable energy might be important for the fight against climate change and for geopolitical reasons, but are there also economic benefits attached to the transition to renewable energy? This question is interesting not only for economists but also for policy makers whose decisions are constrained by tight budgets.

Of course, economists would not be investigating the relationship between renewable energy and economic growth if there were no indications of such a correlation. Domac et al (2005) explained that renewable energy could have an impact on employment and business expansion and thus increase a country's GDP. Chien and Hu (2007) show that renewable energy might increase the macroeconomic efficiency of countries. If this is true in reality, policy makers should also stimulate renewable energy production for economic reasons.

This thesis aims to give a clear picture of the existing theoretical and empirical knowledge concerning the relationship between renewable energy consumption and GDP. In addition to this an empirical research of 27 countries from the European Union will be conducted.

The central question of this thesis is:

What is the (causal) relationship between renewable energy consumption and economic growth in the European Union?

The paper has the following structure. First, the existing theoretical literature about the production function, energy and renewable energy will be reviewed. Then, the empirical literature of this subject will be reviewed, after which the contribution of this paper to the existing literature will be explained. The literature review will be followed by statistical analysis of a panel of 27 countries from the EU. First the data and methodology will be discussed, after which the results will be shown. The paper ends with a conclusion and a discussion.

2. Literature review

In this section, the theoretical and empirical literature related to the production function, energy as an input factor and renewable energy as a separate input factor will be reviewed. Furthermore, the contribution of this research to the existing literature will be pointed out.

2.1 Theory

Neo-classical production function

Neo-classical economists assume that households, being individuals or firms, maximize their utility given some constraints. These constraints consist of the scarce resources that are needed in order to produce goods and receive utility. One of the key concepts of neo-classical economists is the production function. The production function links a set of inputs to the production of output. A commonly used production function is the Cobb-Douglas production function. The Cobb-Douglas function treats labor and capital as separate inputs that can be used for the production process. After adaptions by several economists, the Cobb-Douglas function that still remains the framework for many economic papers has the form of:

$Q = AL^{\beta}K^{\alpha}$ where Q=total output, L=labor, K=capital and A, β and α are measures for technological development.

Naturally, in reality labor and capital are not the only inputs that are used in the production of goods. The reason that mainstream economists focus on these inputs is the division that they make between primary factors of production and intermediate inputs (Stern, 2004). Primary factors of production are inputs that are not directly used up in production. Labor, capital and land are considered to be primary factors of production. The employees that a firm uses for its current production, for example, can still work for the firm in the future. Intermediate inputs, on the other hand, are input factors that are used up during one production process. These factors of production cannot be used for future production. For this reason, these inputs are given less importance than the primary factors of production that can be used repeatedly.

Energy as an input factor

Because mainstream economists treat energy as an intermediate input factor, energy has received much less attention as an input factor than labor and capital. According to Stern (2004), energy should receive more attention as an input factor in the production function, for the following reasons. Most of the energy sources are non-reproducible, while labor and capital are reproducible in the long run. This is why natural scientists and ecological economists stress the importance of energy and the availability of energy for the production process. In fact, labor and capital need energy in order to produce output. Limited availability of energy thus limits the growth of output. Therefore, energy should be included in the production function (Stern, 2004).

Renewable and non-renewable energy
In the empirical literature, there are several economists who divide energy in two categories, namely renewable and non-renewable energy. This division is motivated by the different characteristics of renewable and non-renewable energy. In environmental economics, resources are usually divided in two categories, namely stock resources and flow resources. The current use of flow resources has no effect on future availability (Perman, 2003). Examples are wind and solar energy. Stock resources have the characteristic that current use does affect future availability. Stock resources can be further divided into renewable and non-renewable resources. Renewable resources have the ability to reproduce themselves and grow in size, as long as the harvest rate is not too high. Examples are biotic and plant populations. Non-renewable resources cannot reproduce themselves and are therefore exhaustible. Examples are natural oil and gas (Perman, 2003).

In most empirical literature and in statistical databases, the term renewable energy does not only cover renewable stock resources, like biomass energy, but also flow resources like solar energy. Thus, the term renewable energy is used to describe all energy sources that are not exhaustible given that a sustainable rate of extraction is used. Energy resources that are not renewable will be called 'traditional' or 'non-renewable' sources, of which the most important ones are coals, natural oil and gas. In most papers, including this one, nuclear energy also falls into this 'traditional' category, even though in reality it has different specifics than all of the above.

Renewable energy as a factor of production

The theoretical literature about the relationship between renewable energy and GDP is limited to a paper of Domac et al. (2005). This paper suggests that renewable energy increases the macroeconomic efficiency by two means: 1) The business expansion and new employment that renewable energy brings results in economic growth and 2) The import substitution effect of energy has direct and indirect effects on expanding the GDP and trade balance (Domac, Richards, & Risovic, 2005)

The second process seems counterintuitive. If countries have limited energy sources, the natural consequence is that consuming more energy use leads to more import and not less. But for renewable energy, there is a possible import substitution effect. As Scholten and Bosman (2016) describe, due to the growing demand for oil and gas and limited availability of these resources, consumer countries are overwhelmingly dependent on the supply of the few producer countries. This gives the producer countries an oligopolistic position and a lot of market power. High import prices negatively affect the trade balance and GDP. Regarding renewable energy, countries can make the choice to either import or produce (Scholten & Bosman, 2016). Due to the different techniques that are available for diverse climates, renewable energy production is not limited to certain regions. Producing and consuming renewable energy at home allows countries to reduce their energy import, so that the import substitution effect occurs and the GDP increases.

2.2 Empirical literature

Energy as an input factor: bivariate framework

The first well-known empirical study that focuses on the relationship between energy and GDP is published by Kraft and Kraft (1978). This study examines the existence of a Granger causal relationship between energy and GDP for the United States. The result shows a Granger causal relationship from GDP to Energy consumption. This proves that increasing or decreasing the GDP has an effect on energy consumption but expanding the energy consumption does not necessarily affect the GDP. This research is contradicted by Akarca and Long (1980) who find, by applying a Sim's technique to data from the USA, that there is no causal relationship between energy and GDP. This new result gave reason for many other researches to examine the correlation. Many of these researches use a bivariate framework that only looks at energy and real GDP, for instance Nachane et al. (1988) and Lee (2005). An extensive overview of all the empirical studies is given by Ozturk (2009) and Payne (2010). The main conclusion that can be drawn from the overviews is that both methods used as well as the results obtained in different papers vary.

Energy as an input factor: multivariate framework.

The problem with using energy as the only input factor in the production function is that it is likely to lead to an omitted variable bias. Omitted variable bias occurs when some variables that are determinants of the dependent variable – here GDP - and correlate with the independent variable of interest - here energy – but are excluded from the analysis. Lee et al. (2008) underline this thought by their observation that "neglecting the impact of the capital stock on income tends to overestimate the effect of energy consumption" (Lee, Chang, & Chen, 2008). Furthermore, Stern (1993) and Stern (2000) argue that using a bivariate framework with energy consumption as the only input factor might wrongfully lead to the conclusion that there is no causal relationship, because of substitution effects between energy and other inputs in the production function. This substitution effect means that a decrease (increase) in energy consumption might result in an increase (decrease) of the other input factors. Without including these other input factors, one might mistakenly conclude that energy consumption has no causal effect on economic growth. Both papers suggest to include capital and labor as inputs.

To limit these problems, a multivariate framework that includes other important variables is used in multiple studies. Lee and Chang (2008) include labor and capital in their study of 16 Asian countries. Their result shows a short term causal relationship between GDP and energy consumption and no long term causality. Ghali and El-Sakka (2004) also use a neo-classical production function with total employment, capital stock and energy consumption in Canada as input factors and GDP growth as output. They employ a Vector error-correction model to test whether there is cointegration and Granger-causality. Testing for cointegration is useful because in the case that the time-series of the variables (say X and Y) are non-stationary and cointegrated, the results of the standard Granger-causality or Sims causality tests are invalid, as Payne (2010) explains.

Even though this second category of researches uses multiple variables to limit the omitted variable bias, there are still issues with the results. As Ozturk (2009) shows quite well by comparing a large group of papers on this subject, there are many contradicting outcomes. For the same countries, there are papers that show a causal relationship between energy and GDP and other papers that found no causality at all. This holds for the bivariate framework as well as the multivariate frameworks.

The different findings can be summarized by four hypotheses, as Payne (2010) suggests. The first is the "growth" hypothesis. The line of thought is that energy consumption plays an important role in economic growth both directly and as a complement to capital and labor in the production process. The growth hypothesis is supported if an increase in energy consumption causes a surge in real GDP. If the causal relationship is positive, consuming more energy might lead to economic growth. Limits to the availability of energy could then negatively affect economic growth. The policy implication is to increase the availability of energy. If the causal relationship is negative, the implications are different. It might be that the negative effect of energy on GDP is due to excessive energy consumption in sectors that are unproductive (Payne, 2010). In that case, production should be reallocated to more productive sectors.

Secondly, Payne (2010) mentions the "conservation" hypothesis. This hypothesis is supported if an increase in real GDP leads to growth in energy consumption. In this case, energy conservation policies – for example increasing energy efficiency - do not affect real GDP (Payne, 2010).

The third is the "neutrality" hypothesis. This hypothesis asserts that energy consumption is only a small part of GDP and that an increase or decrease in energy consumption does not have a significant effect on GDP. At the same time, GDP should not cause energy consumption. This hypothesis is supported if there is no evidence for causality between energy consumption and GDP. Again, in this case energy conservation policies do not impact real GDP (Payne, 2010). .

Finally, there is the "feedback" hypothesis. This one proposes that there is interdependency between energy consumption and GDP and that they may be regarded as complements. This hypothesis is supported if there is proof of bi-directional causality (Payne, 2010).

Renewable energy as a separate input factor

The varying results that are found by economists who investigate the relationship between energy and GDP might be due to the diverse methods they employ, the numerous countries they include or the different time periods. Another possible explanation is that the papers wrongly group all sorts of energy consumption as one input factor. In reality there are different sources of energy that are produced in various ways with dissimilar cost functions. Therefore, some recent studies focus on the relationship between renewable energy and GDP.

The previous section of this thesis discussed the theoretical motivation for this approach. The empirical literature on the subject is more extensive. An important paper is that of Chien & Hu (2007), who use a data envelopment analysis (DEA) model to estimate the technical efficiency (TE) for 45 economics in the years 2001-2002. They find that renewable energy increases the technical efficiency of countries, while traditional energy decreases the technical efficiency. They also indicate that technical efficiency is higher in developed countries compared to developing countries. With technical efficiency they mean the amount of energy, labor and capital stock that is necessary to produce the economic output. So if it is said that renewable energy improves the technical efficiency this means that with the same level of inputs more output can be produced (Chien & Hu, 2007). This provides a motivation for looking at the effect of renewable energy on GDP separately from traditional energy.

After this research into the effect of renewable energy on technical efficiency, papers that investigate the causal relationship between renewable energy and GDP followed. Chien & Hu (2008) explore whether renewable energy indirectly affects GDP through import and through capital formation. 116 economies are included in the panel and Structural Equation Modelling is used. The model uses capital formation, trade balance, total energy imports, renewable energy consumption and GDP as independent variables. Their outcome shows that renewable energy has a positive effect on GDP through the path of capital formation, and not through the trade balance. It is important to note that only data from the year 2003 is used in the paper. The disadvantage of limiting the data to one year is that the presence of shocks might lead to wrong conclusions about the causal relationship and the magnitude of the coefficient.

Sadorsky (2009) uses a panel cointegration model to investigate the relationship between per capita renewable energy consumption and per capita income in 18 emerging economies. The natural logarithms of the variables were used to induce linearity. The result is that "increases in real per capita income have a positive and statistically significant impact on per capita renewable energy consumption" (Sadorsky, 2009). This is in line with the conservation hypothesis mentioned above.

Payne & Apergis (2010) perform both a heterogeneous panel cointegration test and a panel error correction model on a panel of 20 OECD countries. The heterogeneous panel cointegration test is used to allow for interdependence in the cross-section (panel cointegration) and different individual effects (heterogeneity). The variables that were included are real GDP, renewable energy consumption, real gross fixed capital formation and the labor force. All these variables are transformed to natural logarithms. The heterogeneous panel cointegration test shows a long-run equilibrium relationship between real GDP and all the other variables, with statistically significant and positive coefficients. The results show that a 1% increase in renewable energy consumption increases real GDP by 0.76%. At the same time, the panel error correction model indicates bidirectional causality between renewable energy consumption and GDP growth both in the long and the short term. The first result supports the growth hypothesis while the second supports the feedback hypothesis. Similar results were found after using the same methods on a panel of 6 Asian countries (Apergis & Payne, 2011) and a panel of 13 Eurasian countries (Apergis & Payne, 2010).

Furthermore, Tugcu et al. (2012) investigate the long-run causal relationship between renewable energy and non-renewable energy and economic growth, using data from the G7 countries. They use a classical and an augmented production function and apply an Autoregressive Distributed Lag (ARDL) to cointegration approach. The classical production function that they apply is the Cobb-Douglas production function to which they add the renewable and non-renewable energy consumption variables. The augmented production function includes measures for human capital and R&D. Their first result is that there is bidirectional causality between renewable and non-renewable energy and GDP for all countries when the classical production function is used, which supports the feedback hypothesis. When using the augmented production function, the causality between renewable energy and GDP differs per country. The feedback hypothesis is supported for 2 countries and the conservation policy for 1 country, for the other countries there is no proof of causality. On the contrary, there is no evidence for any causality between non-renewable energy and GDP when the augmented production function is used (Tugcu & Ozturk, 2012)

2.3 Contribution to existing literature

The empirical literature that treats renewable energy as a separate input factor and also includes the labor force and capital formation is very limited. Of these limited papers, there are, to the author's knowledge, no papers that include data after 2008. While at the same time, the investments in renewable energy have increased exponentially in the last decade. In 2013, global investment in renewable energy was 442.8% higher than in 2004 (REN21, 2014). In this research, data up to the year 2014 will be used, so that these late developments are also included. This might give different results than using data from earlier time periods, when the share of renewable energy was much lower than it is today. When the amount of renewable energy consumption is too low, it is not likely that it will have an impact on GDP, simply because the share is too small.

Furthermore, a different panel will be used than in previous research, namely 27 countries from the European Union. The first advantage of using countries which are from the same continent and are politically integrated is the likelihood of increased homogeneity, since all countries are more or less in the same stage of development. This increases the internal validity and reliability of the research. Secondly, given political integration, research that focusses on the EU might give useful policy implications. The EU is working towards a union with more collaboration in the field of energy and energy security, which they call the Energy Union (European Commission, 2016). This Energy Union has its own investment plan, which includes funding renewable energy projects. The conclusion from this research on whether increasing renewable energy consumption is good for economic growth, could therefore give policy implications for this Energy Union.

Therefore, this thesis makes a contribution to the existing literature by including recent data and the use of data from a new, politically integrated panel.

3 Empirical Research

3.1 Data

For this study 27 countries within the European Union were selected, for which annual time-series data over the period 1990-2014 was collected. This leads to an unbalanced panel with a total of 647 observations. Focusing solely on countries from the EU, which are more or less in the same state of development, has the advantage of increased validity and reliability of the results for the selected countries and all other countries that have the same stage of development. The disadvantage is that the results might have a low external validity for countries that have different characteristics than the European countries, for example developing countries. The variables used in the analysis are the following:

- Gross domestic product in constant 2005 US dollars. This is the most commonly used indicator for economic growth. Taking constant US dollars ensures that increases in prices do not influence our analysis. Data is collected from the World Bank Development indicators.
- Gross fixed capital formation in constant 2005 US dollars. Data is obtained from the World Bank development indicators.
- Labor force. Data is obtained from the International Labour Organization
- Renewable energy consumption in thousands of tonnes of oil equivalent (TOE). The source of this data is Eurostat. The renewable energy sources include wind, solar, hydroelectric and tidal power, geothermal energy, biomass and the renewable part of waste (Eurostat, 2015)
- Non-renewable and total energy consumption in thousands of TOE. Data is provided by Eurostat.

All the variables are transformed into percentage growth rates (per year) using natural logarithms, to ensure stationarity and to directly measure the changes in economic growth. This also ensures that differences in the unit of measurement do not influence the results, since all growth rates are in percentages.

Due to lack of reliable and complete data, Malta is excluded from the analysis. Since Malta is a relatively small country with about 400.000 inhabitants and a 0.06% share in total GDP, leaving out Malta should not negatively affect the validity and reliability of the results. Furthermore, for Estonia, Latvia, Lithuania and Croatia some data was missing before 1995. These countries are still included in the panel so that our panel is unbalanced. It is unlikely that this has a large impact on the validity of the results, given the large number of observations.

The 27 countries from the EU that are included in our sample are:

Austria	France	Netherlands
Belgium	Germany	Poland
Bulgaria	Greece	Portugal
Croatia	Hungary	Romania
Cyprus	Ireland	Slovakia
Czech Republic	Italy	Slovenia
Denmark	Latvia	Spain
Estonia	Lithuania	Sweden
Finland	Luxembourg	United Kingdom

3.2 Methodology

Following previous studies (Ghali et al. (2004), Yuan (2008) and Shafiei (2013) among others) a neo-classical production function will be used in this research. Traditionally, capital and labor are used as the inputs in this production function. In our analysis, renewable and non-renewable energy consumption will be included. This gives the following equation:

$$Y_{t,i}= f\,(K_{t,i},\ L_{t,i},\ R_{t,i},\ N_{t,i})$$

Where Y= real GDP, K= gross fixed capital formation, R= renewable energy and N= non-renewable energy. The subscripts t and i represent the time period and country.

In Cobb-Douglas form, the production function is defined by:

$$Y_{t,i}= AK_{t,i}^{a}\ L_{t,i}^{b}\ R_{t,i}^{c}\ N_{t,i}^{\ d}$$

This study examines the effect on economic growth, so that it is more useful to use differences in logarithms:

$$\Delta \ln\left(Y_{t,i}\right) = a\Delta\ln(K_{t,i}) + \ b\Delta\ln(L_{t,i}) + c\Delta\ln(R_{t,i}) + \ d\Delta\ln(N_{t,i})$$

Multiplying by 100 gives the percentage growth rate. This function forms the basis for the structural model that will be used to test our hypotheses.

The goal of this research is to investigate which of the four hypotheses proposed by Payne (2010) holds. The four hypotheses, as mentioned in the literature review, are:

1. The growth hypothesis

This hypothesis is supported if renewable energy growth causes GDP growth and not vice versa.

2. The conservation hypothesis

This hypothesis is supported if GDP growth causes renewable energy growth and not vice versa.

3. The neutrality hypothesis

This hypothesis is supported if there is no causal relationship between renewable energy growth and GDP growth.

4. The feedback hypothesis.

This hypothesis holds if there is causality in both directions.

The relationship between the variables will be estimated using a Panel Least Squares method. Specifically, a panel least squares with cross section fixed effect regression will be used to estimate the sign, magnitude and significance of the variables. A cross section fixed effect regression allows for within-group variation over time. This is useful because even though countries within the EU have many similarities, the growth of renewable energy might follow a different path in each country. Denmark and Sweden for example have a long tradition of using renewable energy, while other countries only recently started to shift to renewable energy. The cross section fixed effects option controls for these differences.

The structural model that will be used to test the four hypotheses has the form:

$$GDP\_GROWTH_{i,t} = C + \beta 1 * R\_GROWTH_{i,t} + \beta 2 * N\_GROWTH_{i,t} + \beta 3 * CAP\_GROWTH_{i,t} + \beta 4 * LF\_GROWTH_{i,t} + \mu_i + \varepsilon_{i,t}$$

Where

$GDP\_GROWTH_{i,t}$:	annual real GDP growth in percentages (computed using natural logarithms) in country i in period t
C:	A constant term
$R\_GROWTH_{i,t}$:	annual renewable energy growth in percentages, the independent variable of interest in country i in period t
$N\_GROWTH_{i,t}$:	the control variable annual non-renewable energy growth in percentages in country i in period t
$CAP\_GROWTH_{i,t}$:	the control variable annual percentage change in fixed capital formation in country i in period t
$LF\_GROWTH_{i,t}$:	the control variable annual percentage change in the labor force in country i in period t
μ_i	country fixed effects
$\varepsilon_{i,t}$:	the error term

First, fixed effect panel least squares will be used to investigate whether there is correlation between renewable energy and GDP and whether this correlation is significant. The next step is to introduce instrumental variables in order to check whether renewable energy causes GDP or vice versa. If renewable energy is significant in the first panel least squares results and is still significant in our model with instrumental variables, either the “growth” hypothesis or the “feedback” hypothesis should be supported. Then, the conclusion is that with some certainty renewable energy causes economic growth, but it is possible that GDP also causes renewable energy growth. Furthermore, the “conservation” hypothesis will be supported if renewable energy is only significant in the first model. In that case, the conclusion is that with some certainty GDP causes renewable energy and not vice versa. Finally, the neutrality hypothesis will be supported if there is no causality in any of the tests.

In order to control for heteroscedasticity, White standard errors will be used. As N= 27 and T= 24, N>T. This means that the best suitable option is White period standard errors.

3.3 Results

The focus of this research is the relationship between renewable energy and GDP. Still, it is useful to first look at total energy, so that later it is possible to compare the results.

Table 1 Correlation

	GDP_GROWTH	E_GROWTH	CAP_GROWTH	LF_GROWTH
GDP_GROWTH	1.000000	0.452564	0.733770	0.112734
E_GROWTH	**0.452564**	1.000000	0.286857	0.128299
CAP_GROWTH	0.733770	**0.286857**	1.000000	0.040762
LF_GROWTH	0.112734	**0.128299**	0.040762	1.000000

The table shows that capital growth strongly correlates with GDP growth, followed by energy growth. Furthermore, the correlation between energy growth and the control variables is not very strong. The following figure shows the panel least squares with cross-section fixed effects.

Figure 1 Fixed effect regression with total energy

Dependent Variable: GDP_GROWTH
Method: Panel Least Squares
Date: 06/08/16 Time: 12:10
Sample (adjusted): 1991 2014
Periods included: 24
Cross-sections included: 27
Total panel (unbalanced) observations: 620
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.709743	0.090782	18.83350	0.0000
E_GROWTH	0.208868	0.052148	4.005310	0.0001
CAP_GROWTH	0.210800	0.039821	5.293718	0.0000
LF_GROWTH	0.071690	0.062881	1.140088	0.2547

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.648915	Mean dependent var	2.246200
Adjusted R-squared	0.631659	S.D. dependent var	3.600835
S.E. of regression	2.185388	Akaike info criterion	4.448641
Sum squared resid	2817.793	Schwarz criterion	4.662982
Log likelihood	-1349.079	Hannan-Quinn criter.	4.531957
F-statistic	37.60367	Durbin-Watson stat	1.947620
Prob(F-statistic)	0.000000		

Using a confidence interval of 95%, the results indicate that there is a significant relationship between energy growth and economic growth. Since the number of time periods is smaller than the number of countries, Eviews gives a warning for reduced rank. This means in practice that some tests, like the Wald test, could lead to errors and should therefore be treated carefully, but it should not influence the results of the panel least squares since the total number of observations is high.

Now, the first structural model will be used, in which renewable and non-renewable energy are treated as separate inputs.

Table 2 Correlation

	GDP_GROWTH	CAP_GROWTH	LF_GROWTH	R_GROWTH	N_GROWTH
GDP_GROWTH	1.000000	0.719096	0.124270	0.022675	0.460332
CAP_GROWTH	0.719096	1.000000	0.064114	**-0.053565**	0.301074
LF_GROWTH	0.124270	0.064114	1.000000	**0.024714**	0.133043
R_GROWTH	**0.022675**	-0.053565	0.024714	1.000000	-0.115725
N_GROWTH	0.460332	0.301074	0.133043	**-0.115725**	1.000000

The table shows that Capital growth is strongly correlated with GDP growth, as well as non-renewable energy growth and GDP growth. Renewable energy growth on the contrary is very weakly correlated with GDP growth. It is also important to note that none of the independent variables are strongly correlated with renewable energy growth. The following figure shows the panel least squares with cross-section fixed effects.

Figure 2 Fixed effect regression with renewable and non-renewable energy

Dependent Variable: GDP_GROWTH
Method: Panel Least Squares
Date: 06/14/16 Time: 10:44
Sample (adjusted): 1991 2014
Periods included: 24
Cross-sections included: 27
Total panel (unbalanced) observations: 620
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.662312	0.093875	17.70779	0.0000
R_GROWTH	0.022274	0.009718	2.292167	0.0222
N_GROWTH	0.185280	0.045496	4.072457	0.0001
CAP_GROWTH	0.211156	0.039441	5.353749	0.0000
LF_GROWTH	0.076345	0.065616	1.163519	0.2451

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.652405	Mean dependent var	2.246200
Adjusted R-squared	0.634700	S.D. dependent var	3.600835
S.E. of regression	2.176346	Akaike info criterion	4.441878
Sum squared resid	2789.787	Schwarz criterion	4.663364
Log likelihood	-1345.982	Hannan-Quinn criter.	4.527971
F-statistic	36.84998	Durbin-Watson stat	1.935273
Prob(F-statistic)	0.000000		

The variable renewable energy growth is significant, so that there is a significant correlation between renewable energy growth and economic growth. However, these results do not tell us whether renewable energy growth causes economic growth. It is possible that renewable energy growth causes GDP growth, but also the other way around. And it is still possible that the effect goes both ways. The only hypothesis that could be rejected at this moment is the neutrality hypothesis.

In order to check which variable causes the other, Instrumental Variables will be used. It is difficult to argue that GDP growth in year t will affect any of the other variables in year t-1. Therefore, lags of the independent variables and the dependent variable could be used as instruments. Using 4 lags of each variable gives us a total of 20 instruments.

Figure 3 Two stage least squares with instrumental variables

Dependent Variable: GDP_GROWTH
Method: Panel Two-Stage Least Squares
Date: 07/04/16 Time: 12:35
Sample (adjusted): 1995 2014
Periods included: 20
Cross-sections included: 27
Total panel (unbalanced) observations: 512
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank
Instrument specification: C GDP_GROWTH(-1) GDP_GROWTH(-2) GDP_GROWTH(-3) GDP_GROWTH(-4) R_GROWTH(-1) R_GROWTH(-2) R_GROWTH(-3) R_GROWTH(-4) N_GROWTH(-1) N_GROWTH(-2) N_GROWTH(-3) N_GROWTH(-4) CAP_GROWTH(-1) CAP_GROWTH(-2) CAP_GROWTH(-3) CAP_GROWTH(-4) LF_GROWTH(-1) LF_GROWTH(-2) LF_GROWTH(-3) LF_GROWTH(-4)
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.969590	0.387210	2.504045	0.0126
R_GROWTH	0.094631	0.059531	1.589611	0.1126
N_GROWTH	0.213966	0.116952	1.829517	0.0679
CAP_GROWTH	0.260295	0.044274	5.879208	0.0000
LF_GROWTH	0.513855	0.443222	1.159363	0.2469

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.507395	Mean dependent var	2.375813
Adjusted R-squared	0.476672	S.D. dependent var	3.501833
S.E. of regression	2.533277	Sum squared resid	3086.813
F-statistic	8.009616	Durbin-Watson stat	1.951789
Prob(F-statistic)	0.000000	Second-Stage SSR	4178.765
Instrument rank	47	Prob(J-statistic)	0.306121

In the model with instrumental variables, renewable energy growth is no longer significant. This means that renewable energy growth does not cause economic growth. But figure 2 showed that renewable energy growth was significant, meaning that **economic growth** results in renewable energy growth, which supports the Conservation hypothesis. With this model, it is not possible to show what the magnitude of the effect from GDP growth on renewable energy growth is, since a different model needs to be employed to estimate the coefficient of GDP growth. This new model should include other variables that have a causal effect on renewable energy growth, to avoid the omitted variable problem.

For comparison, a model with total energy growth and instrumental variables gives the following result.

Figure 4 Two stage least squares with energy and instrumental variables

Dependent Variable: GDP_GROWTH
Method: Panel Two-Stage Least Squares
Date: 07/04/16 Time: 13:15
Sample (adjusted): 1995 2014
Periods included: 20
Cross-sections included: 27
Total panel (unbalanced) observations: 512
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank
Instrument specification: C GDP_GROWTH(-1) GDP_GROWTH(-2)
GDP_GROWTH(-3) GDP_GROWTH(-4) E_GROWTH(-1) E_GROWTH(
-2) E_GROWTH(-3) E_GROWTH(-4) CAP_GROWTH(-1)
CAP_GROWTH(-2) CAP_GROWTH(-3) CAP_GROWTH(-4)
LF_GROWTH(-1) LF_GROWTH(-2) LF_GROWTH(-3) LF_GROWTH(-4)
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.974069	0.195562	4.980870	0.0000
E_GROWTH	0.052695	0.134561	0.391606	0.6955
CAP_GROWTH	0.230939	0.059759	3.864492	0.0001
LF_GROWTH	1.292028	0.428023	3.018595	0.0027

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.020305	Mean dependent var	2.375813
Adjusted R-squared	-0.038639	S.D. dependent var	3.501833
S.E. of regression	3.568846	Sum squared resid	6139.072
F-statistic	8.016835	Durbin-Watson stat	1.563168
Prob(F-statistic)	0.000000	Second-Stage SSR	4227.308
Instrument rank	43	Prob(J-statistic)	0.911424

The results are similar to the results of the model with instrumental variables and renewable energy. In the model with instrumental variables, energy growth is not significant. This means that it is possible to conclude with some certainty that economic growth has a causal effect on energy growth and not vice versa. Again, with this model it is not possible to observe the magnitude of the effect that economic growth has on energy growth, since there might be other variables that also cause energy growth.

3.4 Robustness checks

In every empirical research, it is important to check whether the results are robust for changes in the methods and variables that are used. The first check is to test whether the results change when the model controls for time fixed effects complementary to the cross section fixed effects. Time fixed effects exist when there is a certain period in which all countries are affected by a shock, or when they all move along the same cycle. One example is the economic crisis, which affected all European countries.

Figure 5 Fixed effect regression with period fixed effects

Dependent Variable: GDP_GROWTH
Method: Panel Least Squares
Date: 06/13/16 Time: 09:43
Sample (adjusted): 1991 2014
Periods included: 24
Cross-sections included: 27
Total panel (unbalanced) observations: 620
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.791990	0.093456	19.17463	0.0000
R_GROWTH	0.021778	0.007296	2.985082	0.0030
N_GROWTH	0.151803	0.034052	4.457955	0.0000
CAP_GROWTH	0.157021	0.039994	3.926097	0.0001
LF_GROWTH	0.051061	0.061309	0.832846	0.4053

Effects Specification

Cross-section fixed (dummy variables)
Period fixed (dummy variables)

R-squared	0.738143	Mean dependent var	2.246200
Adjusted R-squared	0.713623	S.D. dependent var	3.600835
S.E. of regression	1.926959	Akaike info criterion	4.232832
Sum squared resid	2101.655	Schwarz criterion	4.618646
Log likelihood	-1258.178	Hannan-Quinn criter.	4.382800
F-statistic	30.10348	Durbin-Watson stat	1.691914
Prob(F-statistic)	0.000000		

If figure 5 is compared to figure 2, there are a couple of things that need attention. The variable renewable energy becomes more significant, and the standard error is smaller in figure 5. The coefficient of renewable energy growth barely changes.

Another robustness check is to control for period fixed effects in the model with Instrumental Variables. This leads to the following figure.

Figure 6 Instrumental Variables with period fixed effects

Dependent Variable: GDP_GROWTH
Method: Panel Two-Stage Least Squares
Date: 07/04/16 Time: 13:52
Sample (adjusted): 1995 2014
Periods included: 20
Cross-sections included: 27
Total panel (unbalanced) observations: 512
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank
Instrument specification: C GDP_GROWTH(-1) GDP_GROWTH(-2) GDP_GROWTH(-3) GDP_GROWTH(-4) R_GROWTH(-1) R_GROWTH(-2) R_GROWTH(-3) R_GROWTH(-4) N_GROWTH(-1) N_GROWTH(-2) N_GROWTH(-3) N_GROWTH(-4) CAP_GROWTH(-1) CAP_GROWTH(-2) CAP_GROWTH(-3) CAP_GROWTH(-4) LF_GROWTH(-1) LF_GROWTH(-2) LF_GROWTH(-3) LF_GROWTH(-4)
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.960685	0.449859	2.135527	0.0332
R_GROWTH	0.099656	0.077663	1.283182	0.2001
N_GROWTH	0.202371	0.102553	1.973339	0.0491
CAP_GROWTH	0.241464	0.067254	3.590333	0.0004
LF_GROWTH	0.549452	0.400808	1.370861	0.1711

Effects Specification

Cross-section fixed (dummy variables)
Period fixed (dummy variables)

R-squared	0.559678	Mean dependent var	2.375813
Adjusted R-squared	0.512978	S.D. dependent var	3.501833
S.E. of regression	2.443824	Sum squared resid	2759.192
F-statistic	22.68538	Durbin-Watson stat	1.878979
Prob(F-statistic)	0.000000	Second-Stage SSR	1839.772
Instrument rank	66	Prob(J-statistic)	0.224413

Renewable energy growth is still insignificant, but more insignificant than in figure 3. The coefficient of renewable energy changes only slightly. Thus, the model with instrumental variables is quite robust for period fixed effects.

It is also useful to check whether the results change when the number of observations is limited. If the last ten years of the sample are left out, it is certain that the economic crisis of 2008 does not affect the results. Limiting the sample to the period 1991-2004 gives the following result.

Figure 7 Period 1991-2004 panel least squares

Dependent Variable: GDP_GROWTH
Method: Panel Least Squares
Date: 06/27/16 Time: 15:16
Sample (adjusted): 1991 2004
Periods included: 14
Cross-sections included: 27
Total panel (unbalanced) observations: 350
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.088436	0.130543	15.99805	0.0000
R_GROWTH	0.024992	0.009460	2.641775	0.0087
N_GROWTH	0.164440	0.065314	2.517671	0.0123
LF_GROWTH	0.041896	0.054820	0.764254	0.4453
CAP_GROWTH	0.138350	0.047286	2.925797	0.0037

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.531451	Mean dependent var	2.917053
Adjusted R-squared	0.487387	S.D. dependent var	3.056127
S.E. of regression	2.188095	Akaike info criterion	4.488341
Sum squared resid	1527.296	Schwarz criterion	4.830044
Log likelihood	-754.4596	Hannan-Quinn criter.	4.624351
F-statistic	12.06085	Durbin-Watson stat	1.723603
Prob(F-statistic)	0.000000		

Renewable energy growth is still significant, and the sign of the coefficient remains positive. The magnitude of the coefficient changes slightly.

The same test could be repeated using the period 2004-2014.

Figure 8 Period 2004-2014

Dependent Variable: GDP_GROWTH
Method: Panel Least Squares
Date: 07/04/16 Time: 14:09
Sample: 2004 2014
Periods included: 11
Cross-sections included: 27
Total panel (balanced) observations: 297
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.454701	0.112002	12.98816	0.0000
R_GROWTH	0.021024	0.016696	1.259218	0.2091
N_GROWTH	0.145431	0.025301	5.748003	0.0000
CAP_GROWTH	0.278017	0.023401	11.88047	0.0000
LF_GROWTH	0.177370	0.101288	1.751142	0.0811

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.811970	Mean dependent var	1.630294
Adjusted R-squared	0.790763	S.D. dependent var	3.975923
S.E. of regression	1.818683	Akaike info criterion	4.132621
Sum squared resid	879.8238	Schwarz criterion	4.518162
Log likelihood	-582.6942	Hannan-Quinn criter.	4.286967
F-statistic	38.28883	Durbin-Watson stat	2.054657
Prob(F-statistic)	0.000000		

The results show that if the panel is limited to the last ten years of the data, renewable energy growth is clearly insignificant. There is a large difference between this result and the results in figure 7 and 2. One possible explanation is that the economic crisis negatively affects the results in this sample.

Figure 9 Period 1991-2004 instrumental variables

Dependent Variable: GDP_GROWTH
Method: Panel Two-Stage Least Squares
Date: 07/04/16 Time: 14:54
Sample (adjusted): 1995 2004
Periods included: 10
Cross-sections included: 27
Total panel (unbalanced) observations: 242
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank
Instrument specification: C GDP_GROWTH(-1) GDP_GROWTH(-2)
GDP_GROWTH(-3) GDP_GROWTH(-4) R_GROWTH(-1) R_GROWTH(-2) R_GROWTH(-3) R_GROWTH(-4) N_GROWTH(-1) N_GROWTH(-2) N_GROWTH(-3) N_GROWTH(-4) CAP_GROWTH(-1) CAP_GROWTH(-2) CAP_GROWTH(-3) CAP_GROWTH(-4) LF_GROWTH(-1) LF_GROWTH(-2) LF_GROWTH(-3) LF_GROWTH(-4)
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.891569	0.508243	3.721777	0.0003
R_GROWTH	0.089184	0.050283	1.773636	0.0776
N_GROWTH	0.129551	0.102008	1.270012	0.2055
CAP_GROWTH	0.120470	0.087520	1.376490	0.1701
LF_GROWTH	0.456782	0.435804	1.048136	0.2958

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.055894	Mean dependent var	3.490663
Adjusted R-squared	-0.078339	S.D. dependent var	2.314764
S.E. of regression	2.403722	Sum squared resid	1219.133
F-statistic	8.575415	Durbin-Watson stat	1.601288
Prob(F-statistic)	0.000000	Second-Stage SSR	581.8667
Instrument rank	47	Prob(J-statistic)	0.224101

Renewable energy growth was insignificant in the results section and is also insignificant if the panel is to the first 14 years.

Figure 10 Period 2004-2014 instrumental variables

Dependent Variable: GDP_GROWTH
Method: Panel Two-Stage Least Squares
Date: 07/04/16 Time: 14:55
Sample: 2004 2014
Periods included: 11
Cross-sections included: 27
Total panel (balanced) observations: 297
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank
Instrument specification: C GDP_GROWTH(-1) GDP_GROWTH(-2) GDP_GROWTH(-3) GDP_GROWTH(-4) R_GROWTH(-1) R_GROWTH(-2) R_GROWTH(-3) R_GROWTH(-4) N_GROWTH(-1) N_GROWTH(-2) N_GROWTH(-3) N_GROWTH(-4) CAP_GROWTH(-1) CAP_GROWTH(-2) CAP_GROWTH(-3) CAP_GROWTH(-4) LF_GROWTH(-1) LF_GROWTH(-2) LF_GROWTH(-3) LF_GROWTH(-4)
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.145076	0.309673	3.697698	0.0003
R_GROWTH	0.072206	0.046421	1.555480	0.1210
N_GROWTH	0.170266	0.047724	3.567733	0.0004
CAP_GROWTH	0.283780	0.023866	11.89039	0.0000
LF_GROWTH	0.231688	0.355708	0.651343	0.5154

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.800225	Mean dependent var	1.630294
Adjusted R-squared	0.777694	S.D. dependent var	3.975923
S.E. of regression	1.874619	Sum squared resid	934.7764
F-statistic	4.641503	Durbin-Watson stat	2.095731
Prob(F-statistic)	0.000000	Second-Stage SSR	3071.365
Instrument rank	47	Prob(J-statistic)	0.002853

If the panel is limited to the last 10 years, renewable energy remains insignificant. The coefficient is slightly different than in figure 10, as well as the probability. But in general, the model with instrumental variables is quite robust for changes in the period.

The last robustness check is changing the number of lags that are used in the models with instrumental variables. In the results section, 4 lags of each variable were used. The next figure shows whether the results change if the number of lags is limited to 2 lags of each variable.

Figure 11 Instrumental Variables with Two lags

Dependent Variable: GDP_GROWTH
Method: Panel Two-Stage Least Squares
Date: 07/04/16 Time: 15:02
Sample: 2004 2014
Periods included: 11
Cross-sections included: 27
Total panel (balanced) observations: 297
White period standard errors & covariance (d.f. corrected)
WARNING: estimated coefficient covariance matrix is of reduced rank
Instrument specification: C GDP_GROWTH(-1) GDP_GROWTH(-2)
R_GROWTH(-1) R_GROWTH(-2) N_GROWTH(-1) N_GROWTH(-2)
CAP_GROWTH(-1) CAP_GROWTH(-2) LF_GROWTH(-1)
LF_GROWTH(-2)
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.309095	0.329600	3.971767	0.0001
R_GROWTH	-0.029129	0.071776	-0.405832	0.6852
N_GROWTH	0.003014	0.096752	0.031148	0.9752
CAP_GROWTH	0.248942	0.028376	8.773011	0.0000
LF_GROWTH	0.697729	0.353127	1.975860	0.0492

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.746245	Mean dependent var	1.630294
Adjusted R-squared	0.717626	S.D. dependent var	3.975923
S.E. of regression	2.112759	Sum squared resid	1187.358
F-statistic	3.160357	Durbin-Watson stat	2.050167
Prob(F-statistic)	0.000000	Second-Stage SSR	3449.608
Instrument rank	37	Prob(J-statistic)	0.024643

The results in figure 11 are quite different from the results in figure 3. The coefficient of renewable energy growth that was positive in figure 3, is now negative**.** Furthermore, it is now even clearer that renewable energy growth is insignificant.

5. Conclusion and discussion

In the beginning of the results section, it was shown that both energy and renewable energy correlate with GDP growth. The results of the panel least squares regression with cross section fixed effects showed that the relationship between energy and GDP growth in the first figure and between renewable energy and GDP growth in the second figure was significant. This means that the "neutrality" hypothesis should be rejected. After introducing instrumental variables, renewable energy growth was no longer significant. The same results were found in the model with total energy growth. This means that renewable energy growth does not cause economic growth, but economic growth does have an effect on renewable energy growth. Therefore, the "conservation" hypothesis cannot be rejected. Unfortunately, the results do not show how large the effect from economic growth on renewable energy growth is. For the magnitude of the effect a different model with renewable energy as the dependent variable should be employed. Other variables that possibly have a causal effect on renewable energy should be included in this model, to avoid the omitted variable problem. One possible example of a variable that should be included in the analysis is the level of CO_2 emissions in a country, as this might influence policy makers to stimulate investments in renewable energy.

What do the results mean in reality? If economic growth causes renewable energy growth, it means that it is not possible to influence economic growth in a significant way by increasing renewable energy consumption. Important to note is that renewable energy consumption might still play a role in economic growth, but not a significant one. As the figures show, the input factor capital formation has a much larger impact on economic growth. The policy implication is that energy conservation policies, for example increasing the energy efficiency of countries so that less energy is used, do not affect GDP. Conservation policies are one of the ways in which the European Union is currently trying to decrease its energy dependence (European Commission) and could also be helpful in limiting climate change.

The results also imply that countries start to consume more renewable energy in a period of economic growth. This means that by focusing on policies that increase economic growth, renewable energy growth should follow. The question is whether economic growth leads to enough renewable energy growth to effectively limit climate change, or whether the percentage is rather small. Studying the effect of economic growth on renewable energy growth could help policy makers to make the right decisions for this matter.

Of course, this study has some limitations. The most important limitation is the method used to conduct the empirical research. The method that should be used to measure the relationship between renewable energy and economic growth is one of the key topics in the current research. The most recently published papers use advanced methods with panel cointegration and error correction models. It is possible that a panel cointegration and error correction model would give different results and are more reliable. Furthermore, as mentioned before, this study focusses on a panel of countries that are all from the EU, which decreases the external validity. The result is that it is not possible to give a conclusion that will represent the whole world. In development countries, the relationship between renewable energy and GDP could be different. To formulate conclusions that are valid in all parts of the world, more research is needed.

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