What is the relationship between energy consumption in a country and its economic growth?

Author: Florine Romijn
University of Twente
P.O. Box 217, 7500AE Enschede
The Netherlands

ABSTRACT,
The thesis presents an analysis of the relationship between energy consumption and economic growth with time-series data of 108 countries worldwide. From 2000 until 2014, annual data is used. The conclusion of this research is that an unidirectional causality is found from energy consumption to economic growth, found by using a one-step and two-step system generalized method of moments (GMM). From the four views discussed, e.g. growth-energy view, the energy-growth view, the neutrality view and the bidirectional view, these results are consistent with the energy-growth view.

Graduation Committee members:
Prof. Dr. M.R. Kabir
Dr. X. Huang

Keywords
Energy consumption, economic growth, energy-growth nexus, growth-energy nexus, system GMM

1. INTRODUCTION

Based on the World Bank report of 2015 primary energy consumption causes 60% of the global CO_2 emissions. This is the reason why it is important to understand the relationship between energy consumption and economic growth in order to reduce global warming and eventually reduce the impact on the environment(Maji & Sulaiman, 2019).

Energy consumption is an essentiality for modern economies these days, as this is an important resource for production. Therefore, the discussion is still heated in the energy economics literature, since it is seen that economies with higher production and energy consumption have higher incomes per capita (Owusu & Asumadu-sarkodie, 2016). This subject is also part of the climate change dilemma. Since most of the energy generation still comes from non-renewable energy sources, this results in emissions that have an arguably negative impact on the environment.

The motive for this research is to find out whether it is reasonable to discuss if energy consumption and economic growth can be seen apart from each other or to see economic growth and energy consumption as a coupled entity.

Energy can be divided into two categories: renewable energy and non-renewable energy. The need to reduce greenhouse gas in the environment can lead to an increase in renewable energy, in order to let the use of fossil energy decline. Another issue is that to maintain sustainable growth, the need for so-called 'green' energy is higher than for lower growth countries (Maji & Sulaiman, 2019).

Decoupling energy consumption from economic growth is necessary to increase energy efficiency (Moreau & Vuille, 2018). By doing so, the relationship of energy use on growth needs to attenuate. Decreasing energy consumption is one part of the necessary plan to reduce emissions and reducing our impact on climate change (Friedlander, 2009). However, Shahbaz et al. (2017) conclude from previous research that one causal relationship between economic growth and energy consumption has not been defined.

There have been researchers that support the hypothesis that energy consumption induces economic growth.[1] And there are some that support the hypothesis that economic growth leads to energy consumption.[2] Others support the feedback hypothesis: there is a bidirectional relationship between energy consumption and economic growth.[3]

A causal relationship between energy consumption and economic growth could be a driver to see whether economic growth could be decoupled from energy use and the emissions that go with it. In addition, the scarcity of energy is a motivator to change the effects of energy use on economic growth or the implementation of renewable energy to stimulate growth.

The use of energy can be divided into two categories: renewable energy and non-renewable energy, of which the latter is the most harmful at the moment, while renewable energy is not a threat to the environment since the sources can be infinite. In the long-run, a bidirectional causal relationship is discovered between renewable energy usage and economic growth (Saad & Taleb, 2018).

The aim of this research is to discover a causal and bidirectional relationship between the use of energy and economic growth, where higher energy use causes a higher economic growth, so we can be aware of the result: economic growth and start thinking of stimulating this without increasing the usage of non-renewable energy (Abid, 2016). If there is a bidirectional causal relationship, a thing to discover is a way to separate economic growth from energy use (Shahbaz et al., 2017).

The research question for this study would be: What is the relationship between energy consumption in a country and its economic growth? To examine this, multiple countries will be examined in both energy usage and economic growth measured in real growth of the Gross Domestic Product (GDP), the value of production in a country.

2. CONCEPTUAL FRAMEWORK

2.1 Theory and evidence

The Keynesian model discusses that the effective demand or an increase in aggregated demand should contribute to economic growth. Based on economic values like consumption, national income, investments and savings, Keynes developed a theory that could explain the changes in the level of economic activity (Sharipov, 2015). For this research, the relationship between the energy use and economic growth would be important. According to Keynes, if the effective demand increases, the production increases, which increases the energy usage, and the economic growth. This could mean that the effective demand has a relationship with energy usage and economic growth but does not mean that energy usage has an relationship with economic growth or the other way around.

However, the relationship between economic growth and energy consumption is proven to be complex, since there are lots of different results and conclusions to be found in previous research. This means that there is not yet a conclusive result in this subject, hence this paper will be an addition to previous research and can be extension to the current view on economic growth and energy consumption.

In another case, Hardt et al. (2018) researched whether the energy reduction in the UK a result is of energy efficiency or offshoring of the production. The UK has successfully decoupled the energy consumption from the economic growth over the past 15 years. This could mean that it is possible to maintain growth and decrease the amount of energy used to produce this growth. In the UK, the GDP grew, even during the financial crisis of 2008, while the overall energy use decreased. This could mean that with current globalization, the energy usage of a country does not affect the growth of this country, since energy-intensive production can be offshored to countries with less wealth (Hardt et al., 2018).

Nayan et al. (2014) describe four views that explain the relationship between energy consumption and economic

[1] e.g. Apergis and Payne, 2009; Ozturk et al., 2010; Ouedraogo, 2013; Aslan et al., 2014b

[2] e.g. Huang and Hwang, 2008; Narayan et al., 2010; Kasman and Duman, 2015

[3] e.g. Constantini and Martini, 2010; Belke et al., 2011; Coers and Sanders, 2013

growth. One view they describes is that economic development and growth affect energy use rather than the other way around. Another view they argue, is the importance of considering energy as an essential factor of production in addition to labor, materials and capital. Therefore, energy is necessary for growth. The third view they discuss is that economic growth and energy consumption cause each other. Their last view discusses that there is no relationship between economic growth and energy consumption. This would mean that there are four hypotheses to be conducted for this research, based on this study.

For the first view, the growth-energy view, evidence in different researches showed that economic growth has an impact on real GDP and not the other way around. This is first supported by Akarca & Long (1979) and later by others as well. This indicates that there ought to be a plan for the increasing demand in energy due to the globalization (Saidi & Hammami, 2015). As well as the effects on current global ecosystem, when financial growth results in higher energy consumption. This should lead to more focus on production technologies that lead to less pollution (Asafu-Adjaye, 2000).

The second view, the energy-growth view, discussed empirical evidence that energy consumption has a unidirectional causal relationship with real growth. Like Sari, Ewing, & Soytas (2008) there have been researches that found the evidence of the energy-growth view. If this view is proven to be true, the focus on renewable energy could be another way to enable growth. The decoupling of energy consumption and economic growth becomes more important when reasoning from this view (Moreau & Vuille, 2018).

The third view, the bidirectional view, stresses the researches that confirms a bidirectional causal relationship between energy consumption and economic growth. This view is widely supported, in addition to the first two views. Coers & Sanders's (2013) research supports this view, as well as Kahouli (2019). This view indicates that the economic growth and energy consumption are cointegrated with each other. This gives other issues, since economic and energy policies need to be implemented cooperatively (Kahouli, 2019).

The fourth view, the neutrality view, discusses the evidence that does not lead to any confirmation of the first three views. This is a view that is supported by other researches, like Abid (2016). This view does not have certain developments after confirming the relationship, since it does not indicate a causal relationship between economic growth and energy consumption. Also Wang, et al. (2019) found no evidence to support a uni- or bi-directional relationship between economic growth and energy consumption in all cases. This research has looked at the lower, upper and middle income groups within a sample size of 187 countries around the world.

Muhammad (2019) also discuss three of these views without the neutrality nexus. This shows that there are generally four views to look at the research question. Muhammad (2019) elaborates the economic growth and pollution nexus, the use of energy output and the nexus that these views are approached jointly.

This research adds information to support the decoupling method. This method is a concept to disconnect economic growth from environmental damage, as a result from energy consumption. (Wang, Jiang, & Zhan, 2019) The decoupling method could lead to a solution to the environmental pollution problem. This could eventually lead to successful countrywide and global policies to reduce environmental damage and pollution. The decoupling of energy consumption and economic growth can only take place when the relationship between those two variables can be described without any inconsistencies. However, a limitation of this theory can be that energy will be outsourced in the current globalization and worldwide supply chains(Kan, Chen, & Chen, 2019).

Only few of these researches focus on multiple countries and periods. Therefore, this research focusses on multiple countries all over the world and not only developing or OECD countries. This is an addition to previous research since most elaborate on one country or cooperating countries like the G7.

In addition, there is some criticism from Zheng & Walsh (2019) about the temporal causality testing instead of time series analysis and the conclusions not being robust nor convincing. Therefore, this study focusses on multiple countries and over a period of time, further discussed in chapter 3.

In multiple researches, a difference is made between energy demand and the aggregate production function (Zheng & Walsh, 2019). To be clear about this research, an aggregate production function will be used. This is a more objective method than estimating the demand function of energy, since this will be an estimation and the aggregate production function will be a factual matter.

To conclude, the different views are supported by several researches. The growth-energy view confirmation can lead to a different policy, namely the innovation of technologies to reduce pollution, whilst the energy-growth view results in more focus on using different energy sources with less pollution. The bidirectional view requires a tight collaboration between economic and energy policy development. The neutrality view does not necessarily need certain developments.

Previous research shows conflicting results, which leads to all the different views being supported by multiple researches.

2.2 Hypotheses

Since previous research does not have a definite outcome to be proven true, multiple hypotheses need to be conducted and tested.

For the energy-growth view, the prediction would be that energy levels are positively related to economic growth. This would be so, since the economic growth increases when the energy levels increase because economic growth goes together with increase in production according to the Keynesian model. For this reason, the hypothesis for the energy-growth view will be:

Hypothesis 1 There is a positive impact of the energy consumption of a country on the real growth in GDP.

For the growth-energy view , the prediction would be that economic growth is positively related to energy consumption. This would mean that with higher economic growth, there will be higher energy consumption. This can be the case because of the increase in production leads to an increase in energy consumption. This would lead to a second hypothesis:

Hypothesis 2 There is a positive impact of real growth of GDP on energy consumption of a country.

The neutrality view would lead to the null hypothesis: no impact of real growth of GDP on energy consumption or the other way around.

Since there is also empirical evidence of previous research that implies a bidirectional causality between the two variables this can also be proven by combining the two hypotheses (Kahouli, 2019).

3. METHODOLOGY

3.1 Statistical tests

3.1.1 Testing hypotheses 1 and 2

Kahouli (2019) tested both the static and dynamic relationship between economic growth and energy consumption, with panel data of 34 OECD countries. He conducts Pooled OLS and GLS estimator as tests for static relationships. He conducts one-step Generalized Method of Moments (GMM), as data test.

The difference between OLS, GLS and a GMM estimation is the dynamic or static regression results. Since we test a panel with different time series and countries, the static regression will not be as accurate as the dynamic regression. Therefore, in this study, a dynamic regression will be conducted.

To test the energy-growth and the growth-energy hypothesis Nayan et al., (2014) uses a system GMM estimation to estimate an energy consumption and real GDP model as with equation A and equation B for the two dynamic variables, energy consumption and economic growth. The system GMM is a dynamic regression, which is sufficient for this research and is also used by Kahouli (2019).

Equation A: The energy consumption model

$$EC_t = \alpha EC_{t-1} + \beta_1 GDP_t + POP_t + INFL_t + \nu_t + \varepsilon_t$$

Equation B: The economic growth model

$$GDP_t = \alpha GDP_{t-1} + \beta_1 EC_t + POP_t + INFL_t + \nu_t + \varepsilon_t$$

Where,

GDP = real Gross Domestic Product per capita in US dollars($), based on the inflation and GDP per capital for 2014 per country.

EC = energy consumption measured in kilograms (kg) of oil and oil equivalent of energy use per capita per country.

POP = population per country in number of people

INFL = inflation in a country in percentages (%)

The system GMM was developed by Arellano & Bover (1995). This method is considered more advanced than the difference GMM. The GMM combines the relevant regressions in a system by expressing this in first-differences and in levels. First differences are checking for unobserved heterogeneity and overlooked variable bias as well as for time-constant components of measurement error. It also can correct the internality bias, by orchestrating the explanatory variables.

Estimating two equations reduces the possible bias and increases the lesser precision correlated with the "simple first difference GMM" (Nayan et al., 2014).

According to Kahouli (2019) and Nayan et al. (2014), the GMM estimator method is the most common method to use with panel data. In these researches they also use a Hansen test to test for validity of the instruments. The Sargan/Hansen of over-identifying restriction and tests for validity of the instruments with all the instruments as a group being exogenous as null hypothesis. This null hypothesis should not be rejected. If the Hansen's J test p-value is above 0.6, the null hypothesis should be rejected. If it is above 0.4, the hypothesis should be skeptically looked at.

The GMM results show either a significance or insignificance for each dependent variable on the independent variable. This will be showed in a z value. The output of a GMM estimation takes in account the timeframe.

This all will be tested in Stata, since Stata is the only program that can do a system GMM estimation.

3.1.2 One-step GMM and Two-step GMM

There are two system GMM estimators. The two estimators are: the one-step and two-step GMM. These estimators are different. The two-step GMM is based on a weighted matrix. And although both GMM estimators are asymptotically normal, the two-step estimator's asymptotic variance is smaller. In addition, the two-step GMM is also asymptotically more powerful than the one-step GMM (Hwang & Sun, 2015). However, for this study, both estimators will be carried out to be able to check and compare the results.

3.2 Variables

3.2.1 Variables hypothesis 1

The real GDP per year is the dependent variable for hypothesis 1, the energy consumption is the independent variable. For the real GDP calculation, the *Equation 1* is used.

Equation 1: The calculation of real GDP

Real GDP per capita for year y per country *j* ($RGDP_{yj}$) = Nominal GDP of year *y* per county *j* ($NGDPy_j$)/ GDP deflator for year *y* per country *j* (DEF_{yj})

The energy consumption per year *y* per country *j* (EC*yj*) is taken directly from the World Bank for each country per year.

3.2.2 Variables hypothesis 2

For hypothesis 2, the energy consumption is the dependent variable and the real growth in GDP is the independent variable.

3.2.3 Control variable

As a control variable, the real economic growth in percentages (%) will be used. This variable will be conducted by taking the percentual difference between the inflation for each year and the previous year.

3.2.4 Explanatory variable

As explanatory variables the inflation per year will be used as well as population size, to explain either real GDP or energy consumption.

In *Table 1*, a summary of the statistical data can be found. This shows the number of observations, the mean and the standard deviation for all the variables. The results of this table will be discussed in section 3.3.1.

3.3 Data

3.3.1 Data collection

For my research I composed the real GDP per year by taking the nominal growth of GDP for 15 years, correcting it for inflation for all the respective years with all data collected at the World Bank. The number of countries that have all data listed including inflation rates, the GDP and energy consumption in oil equivalents are 108 countries between 1999 and 2014. The real GDP in US dollar per capita per year per country will be calculated by using *Equation 1*.

The energy consumption per capita data is directly retrieved from the World Bank data base.

The variable real growth will be conducted from the difference in real GDP per year and making a percentual difference by dividing it by the old value.

The countries that will be used for this research are listed in *Table 7,* Appendix 1.

3.3.2 Descriptive statistics

The descriptive statistics are presented in *Table 1*. The number of observations, mean and standard deviation as well as the minimum and maximum values can be found there. The number of observations for each variable is 1605. The mean of real GDP is 12,489.68 and the standard deviation is 17,174.11 and is measured in US$. The minimum real GDP per capita is 14.85$. The maximum is 111,730.30$ per capita. The minimum value seems low, but it is data of the Republic of Congo in 2010, a country that has had a tremendous amount of growth since then and during the 15 years used in this research.

For real GDP, the mean is 2503.78 kg of oil or oil equivalent. The standard deviation is 3024.55 kg. The minimum 113.42 kg and the maximum is 21959.44 kg. This variable is measured per capita, but there can be big differences in the use of energy between countries that have great availability of energy and countries where the availability of energy is somehow compromised. The political state could also have an impact on this variable.

The population has a big standard deviation, since this depends on the size of the country, as well as the economic and political state. The minima and maxima of respectively 281,205 people and 31.8 million people are thus plausible.

The inflation has a mean of 8.87% with a standard deviation of 67.28%. Since the inflation is prone to economic and political influences, this variable can have a wide spread. The minimum is -27.63, which indicates a deflation and the maximum is 2630.12.

Table 1 Descriptive statistics of data.

Variable	obs	mean	std. dev.	min	max
rgdp	1605	12489.68	17174.11	14.85	111730.30
ec	1605	2503.78	3024.55	113.42	21959.44
pop	1605	27700000.00	44200000.00	281205	318000000.00
infl	1605	8.87	67.28	-27.63265	2630.12

4. Results

4.1 Correlations between variables

In *Table 2* the correlation matrix is displayed. The correlation between economic growth and energy consumption is positive. The relation between economic growth and population size is also positive. The correlation between economic growth and inflation indicates a negative relationship. Energy consumption and population has a negative correlation, and energy consumption with inflation has a negative correlation as well. Between population size and inflation, a positive relation exists. However, the positive and negative relations are to be neglected in this study, since the results in the correlation matrix are all near zero. These are thus not significant, since a strong correlation is supposed to be close to 1.

Compared to other studies in this field, e.g. Wang, Su, et al. (2019), Kahouli (2019), Shahbaz et al.(2017), and Saidi & Hammami (2015), these correlations are low. The correlations in all of those studies are closer to the range of 0.5 to 1. This is a possibility, since the data is not the same and this study differs from others in the way that multiple countries have been used for the panel over a period of 15 year. Other studies use different kind of time series data and/or countries.

Table 2 Correlation Matrix

Variables	*RGDP*	*EC*	*Pop*	*Infl*
Real GDP per capita (RGDP)	1.000			
Economic consumption (EC)	0.2213	1.000		
Population (Pop)	0.0277	-0.0052	1.000	
Inflation(Infl)	-0.0559	-0.0283	0.012	1.000

4.2 Main results and discussion

The main results are displayed in *Table 3* and *Table 4*. The tables display the results of the one-step GMM and the two-step GMM for each model.

The number of observations, N, F-statistic and Hansen and Sargan tests, are also shown in the tables for all of the models.

For all models, the Hansen's J-test for validity of instruments give a 'robust but weakened by many instruments result'. This means that there is some evidence of misspecification at conventional significance levels. This indicates that the dynamic panels of real GDP and energy consumption are doubtful. Still, the p-value is above 0.05, which gives no indication to reject the null hypothesis. They are uncorrelated with the error term and therefore the over-identifying restriction is valid.

The Sargan test for over-identification of instruments gives a p-value lower than 0.05, which indicates a rejection of the null hypothesis. This rejection indicates that the models used are possibly misspecified. This could lead to a rejection of the results of the GMM estimation with the used instruments.

4.2.1 Real GDP as dependent variable
The results for real GDP as dependent variable are shown in Table 3. All models mentioned, e.g. model 1, 2, and 3, are displayed in Table 3.

Model 1 shows that a regression is found for the complete model, with a significance of 10%. The one-step GMM, as well as the two-step GMM give a coefficient of 0.07, which is low. Population has no significant coefficients. Inflation has a significant GMM estimator of -20.13 and a z-value of -2.45 which has a 5% significance.

These coefficients mean that for a 1% increase in energy consumption, the Real GDP grows with 0.07%. and for a 1% in inflation increase, the Real GDP decreases with 20.13 percent.

Model 2 shows the model of energy consumption as a sole influence on Real GDP. This model shows that there is not a difference in coefficient, 0.07 with the first complete model, but there is a slight difference in z-value. This still does not make a difference in the significance of 10%. The rest of the values are also not significantly different from the complete model.

Model 3 displays the results of energy consumption and population on real GDP. These results match the previous results, the coefficient of the two-step GMM for energy consumption on real GDP is slightly higher, 0,08, but this is a small difference. The significance found for both the one-step and two-step GMM is 10%. The coefficient found for the one-step GMM is 0.04, which is lower than the previous coefficients found. To conclude, this model does not show a relationship between population and real GDP, however, it adjusts the results for the other variable. The other values found in this model are in close range to the previously found. When the energy consumption grows with 1%, the coefficients for the one-step GMM and the two-step GMM respectively give a 0.04% and 0.08% increase in real GDP.

The evidence gives us a reason to reject the null hypothesis and thus to accept hypothesis 1, with an increase of 0.07% overall, at an increase in energy consumption of 1%.

This result is consistent with the result of Paul & Bhattacharya (2004), since they find a significant relationship from energy consumption to real GDP.

Table 3 Results for energy consumption, population and inflation on real GDP per capita in 3 models.

	Model 1		Model 2		Model 3	
Dependent variable: Real GDP	One- Step GMM	Two-Step GMM	One- Step GMM	Two-Step GMM	One- Step GMM	Two-Step GMM
Energy consumption	0.07(1.90)***	0.07(1.89)***	0.07(1.88)***	0.07(1.87)***	0.04(1.88)***	0.08(1.88)**
Population	0.00(0.07)	0.00(0.08)			0.00(0.01)	0.00(0.02)
Inflation	-20.13(-2.45)**	-20.14(-2.45)**				
N	1497	1497	1497	1497	1497	1497
F-Statistic	10489.98	10354.25	11179.38	11149.91	10919.99	10846.84
Hansen	106.45	106.45	106.84	106.84	106.74	106.74
Sargan	1092.97	1092.97	1091.49	1091.49	1092	1092.86

Notes: Values in brackets are the z-values.

* indicate significance at 1%

** indicate significance at 5%

*** indicate significance at 10%

4.2.2 Energy consumption as dependent variable
Table 4 displays the results of the three models with energy consumption as a dependent variable.

Model 1 shows the panel results for the complete model with energy consumption as the dependent variable, real GDP as independent variable and population and inflation as explanatory variables. These results do not show any significance and the coefficients are all near zero or zero. This means that no evidence is found to reject the null hypothesis and therefore to accept hypothesis 2.

Model 2 displays the results of the model where just real GDP as an independent variable is taken into account. The negative 0.00 is displayed since this is a rounded value and the unrounded value is slightly negative. However, these values are not significant and very close to zero. So for both one-step and two-step GMM the -0.00% does not have a significance of 10%, which leads to the rejection of the null hypothesis.

Model 3 displays the results of the panel for real GDP and population on the energy consumption. These results do not differ from the previous results.

So, the null hypothesis is not rejected for energy consumption as dependent variable for all developed models. There is thus no reason to accept hypothesis 2.

These findings are also consistent with the findings of Saidi & Hammami (2015), but are inconsistent in the way that the coefficient values are not as big as in the study of Saidi & Hammami (2015) and therefore the impact of energy consumption per capita on the real GDP is not as strong .

4.2.3 Hypotheses conclusions
Hypothesis 1: There is a positive impact of the energy consumption of a country on the real growth in GDP. This hypothesis is approved, since the null hypothesis is rejected by a significance of 10%. This gives an increase in real GDP of 0.07% at an increase of 1% energy consumption in the complete model with explanatory variables.

Hypothesis 2: There is a positive impact of real growth of GDP on energy consumption of a country. For this hypothesis, there is no evidence to reject the null hypothesis, which does not give an indication to assume an impact of real GDP to energy consumption.

The GMM estimators indicate an unidirectional relationship from energy consumption to economic growth. These findings are consistent with Asafu-Adjaye (2000) and Paul & Bhattacharya (2004). However, these results are found when differentiating long-run from short run results.

However, these results are not consistent with the study of Saidi & Hammami (2015), since in that study there is a bidirectional significant relationship found between energy consumption and real GDP.

Table 4 Results of the panel for real GDP, population and inflation on energy consumption displayed in 3 models.

	Model 1		Model 2		Model 3	
Dependent variable: Energy consumption	One- Step GMM	Two-Step GMM	One- Step GMM	Two-Step GMM	One- Step GMM	Two-Step GMM
Energy consumption	0.00(-1.18)	0.00(-1.11)	-0.00(-1.18)	-0.00(-1.16)	-0.00(-1.18)	-0.00(-1.18)
Population	0.00(-0.81)	0.00(-0.84)			-0.00(-0.81)	-0.00(-0.81)
Inflation	0.17(-0.03)	0.03(-0.06)				
N	1497	1497	1497	1497	1497	1497
F-Statistic	21828.65	21623.53	23899.51	23891.28	23077.87	22634.79
Hansen	106.13	106.13	106.28	106.84	106.49	105.98
Sargan	854.06	854.06	854.84	854.28	853.35	854.04

Notes: Values in brackets are the z-values.

* indicate significance at 1%

** indicate significance at 5%

*** indicate significance at 10%

4.2.4 Control variable

The control variable for this study is economic growth per year in percentages. *Table 5* gives the results for real growth as independent variable and energy consumption as dependent variable. The one-step and two-step GMM estimations are very high compared to the estimations of real GDP on energy consumption, but still not significant. This means that taking real growth in percentages as an independent variable, also does not give an indication to reject the null hypothesis and there is no evidence found to accept hypothesis 1.

The F-statistic, Hansen and Sargan tests do not give a different result from the first models with real GDP as variable. The values are comparable.

Table 5 Results of the panel for real growth on energy consumption.

Dependent variable: Energy consumption	One-Step GMM	Two-Step GMM
Real growth	11.61(0.55)	11.85(0.08)
N	1497	1497.858)
F-Statistic	23077.87	3250000
Hansen	106.49	106.49
Sargan	853.35	853.35

Notes: Values in brackets are the z-values.

In *Table 6*, the results of the panel for real growth in percentages as dependent variable are given.

The results of these GMM estimations are not significant, and the coefficients are very close to zero. This gives no reason to reject the null hypothesis or to accept hypothesis 2. The Hansen and Sargan test results differ from previous models, but the conclusions form these values are the same: the Hansen's J-test implies that the instruments are 'robust but weakened by many instruments' and the Sargan test gives a 'not robust but not weakened by many instruments'. So it has the same implications as described in *section 4.3*.

The control variable thus has no significant or surprising impact on economic growth. And since the growth per year can fluctuate every year for every country, finding a concrete impact either way can be troublesome.

Table 6 Results of the panel for energy consumption on real growth.

Dependent variable: Real GDP	One-Step GMM	Two-Step GMM
Energy consumption	-0.00(-0.73)	-0.00(-0.72)
N	1497	1497
F-Statistic	41.34	39.21
Hansen	161.21	105.14
Sargan	105.14	161.21

Notes: Values in brackets are the z-values.

5.Conclusions

Looking at the results of the analysis of this data, by performing a system GMM estimation, a unidirectional causality is found running from energy consumption to economic growth. This is consistent with the widely supported energy-growth view, the second view discussed in the theoretic framework.

These results are in agreement with the results of Asafu-Adjaye (2000) and Paul & Bhattacharya (2004).

However, since other researches show conflicting results, no concrete conclusion can be drawn. The next conclusion is based on the fact that this research found support of the energy-growth view.

A solution for the greenhouse gas pollution would be focusing on renewable energy, in order to be able to keep stimulating economic growth. Renewable energy, instead of fossil fuels could reduce the emissions of greenhouse gas and at the same time enable economic growth.

6. Limitations

The biggest limitation of this study is that the Sargan test does indicate a rejection of the null hypothesis. This gives indication that the models used are possibly misspecified. This, however, does not give certainty that the models are misspecified, and since the Hansen's J-test does not give an indication that the instruments are not valid, this is negligible.

In addition, there are some limitations to the method and the data. First, the data used is annually, since most data banks do not provide them quarterly for most countries. Expanding the data to quarterly would mean a more accurate result.

Secondly, the energy consumption in kilograms of oil equivalent are combined energy data from different sources. They are neither categorized nor specified. This limits the research since there cannot be tested for results of different categories or specifications.

Third and lastly, there may be some explanatory variables that are not found. This could influence the results of the study.

References

1.Abid, M. (2016). Energy Consumption-Informal Economic Growth Analysis: What Policy Options Do We Have? *Journal of the Knowledge Economy*, *7*(1), 207–218. https://doi.org/10.1007/s13132-014-0211-x

2.Akarca, A. T., & Long, T. V. (1979). Energy and Employment. *Resources and Energy*, *2*, 151–162.

3.Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, *68*(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-D

4.Asafu-Adjaye, J. (2000). The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. *Energy Economics*, *22*(6), 615–625. https://doi.org/10.1016/S0140-9883(00)00050-5

5.Coers, R., & Sanders, M. (2013). The energy – GDP nexus ; addressing an old question with new methods. *Energy Economics*, *36*, 708–715. https://doi.org/10.1016/j.eneco.2012.11.015

6.Friedlander, G. D. (2009). Energy: Crisis and challenge. *IEEE Spectrum*, *10*(5), 18–27. https://doi.org/10.1109/mspec.1973.5217018

7.Hardt, L., Owen, A., Brockway, P., Heun, M. K., Barrett, J., Taylor, P. G., & Foxon, T. J. (2018). Untangling the drivers of energy reduction in the UK productive sectors: Efficiency or offshoring? *Applied Energy*, *223*(March), 124–133. https://doi.org/10.1016/j.apenergy.2018.03.127

8.Hwang, J., & Sun, Y. (2015). Should We Go One Step Further ? An Accurate Comparison of One-step and Two-step Procedures in a Generalized Method of Moments Framework.

9.Kahouli, B. (2019). Does static and dynamic relationship between economic growth and energy consumption exist in OECD countries ? *Energy Reports*, *5*, 104–116. https://doi.org/10.1016/j.egyr.2018.12.006

10.Kan, S., Chen, B., & Chen, G. (2019). Worldwide energy use across global supply chains: Decoupled from economic growth? *Applied Energy*, *250*(February), 1235–1245. https://doi.org/10.1016/j.apenergy.2019.05.104

11.Maji, I. K., & Sulaiman, C. (2019). Renewable energy consumption and economic growth nexus: A fresh evidence from West Africa. *Energy Reports*, *5*, 384–392. https://doi.org/10.1016/j.egyr.2019.03.005

12.Moreau, V., & Vuille, F. (2018). Decoupling energy use and economic growth: Counter evidence from structural effects and embodied energy in trade. *Applied Energy*, *215*(February), 54–62. https://doi.org/10.1016/j.apenergy.2018.01.044

13.Muhammad, B. (2019). Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries. *Energy*, *179*, 232–245. https://doi.org/10.1016/j.energy.2019.03.126

14.Nayan, S., Kadir, N., Ahmad, M., & Abdullah, M. S. (2014). Revisiting Energy Consumption and GDP: Evidence from Dynamic Panel Data Analysis. *Procedia Economics and Finance*, *7*(Icebr), 42–47. https://doi.org/10.1016/s2212-5671(13)00216-5

15.Owusu, P. A., & Asumadu-sarkodie, S. (2016). Civil & Environmental Engineering | Review Article. A review of renewable energy sources , sustainability issues and climate change mitigation. *Cogent Engineering*, *15*(1), 1–14. https://doi.org/10.1080/23311916.2016.1167990

16.Paul, S., & Bhattacharya, R. N. (2004). Causality between energy consumption and economic growth in India: A note on conflicting results. *Energy Economics*, *26*(6), 977–983. https://doi.org/10.1016/j.eneco.2004.07.002

17.Saad, W., & Taleb, A. (2018). The causal relationship between renewable energy consumption and economic growth: evidence from Europe. *Clean Technologies and Environmental Policy*, *20*(1), 127–136. https://doi.org/10.1007/s10098-017-1463-5

18.Saidi, K., & Hammami, S. (2015). The impact of CO 2 emissions and economic growth on energy consumption in 58 countries. *Energy Reports*, *1*, 62–70. https://doi.org/10.1016/j.egyr.2015.01.003

19.Sari, R., Ewing, B. T., & Soytas, U. (2008). The relationship between disaggregate energy consumption and industrial production in the United States : An ARDL approach, *30*, 2302–2313. https://doi.org/10.1016/j.eneco.2007.10.002

20.Shahbaz, M., Hong, T., Hoang, V., Kumar, M., & Roubaud, D. (2017). Energy consumption , fi nancial development and economic growth in India : New evidence from a nonlinear and asymmetric analysis. *Energy Economics*, *63*, 199–212. https://doi.org/10.1016/j.eneco.2017.01.023

21.Sharipov, I. (2015). Contemporary economic growth models and theories: A literature review. *Centre for European Studies*, *VII*(3), 759–773.

22.Wang, Q., Jiang, R., & Zhan, L. (2019). Is decoupling economic growth from fuel consumption possible in developing countries? – A comparison of China and India. *Journal of Cleaner Production*, *229*, 806–817. https://doi.org/10.1016/j.jclepro.2019.04.403

23.Wang, Q., Su, M., Li, R., & Ponce, P. (2019). The effects of energy prices, urbanization and economic growth on energy consumption per capita in 186 countries. *Journal of Cleaner Production*, *225*, 1017–1032. https://doi.org/10.1016/j.jclepro.2019.04.008

24.Zheng, W., & Walsh, P. P. (2019). Economic growth, urbanization and energy consumption — A provincial level analysis of China. *Energy Economics*, *80*, 153–162. https://doi.org/10.1016/j.eneco.2019.01.004

Appendix 1

Table 7 List of countries in panel

Countries				
Albania	Czech Rep.	Kosovo	Philippines	United States
Algeria	Ecuador	Kuwait	Poland	Uruguay
Angola	Egypt, Arab Rep.	Kyrgyz Rep.	Qatar	
Argentina	El Salvador	Latvia	Romania	
Armenia	Estonia	Lebanon	Russian Fed.	
Australia	Ethiopia	Libya	Saudi Arabia	
Austria	Finland	Lithuania	Senegal	
Azerbaijan	France	Luxembourg	Serbia	
Bahrein	Gabon	Malta	Singapore	
Bangladesh	Georgia	Mauritius	Slovenia	
Belarus	Germany	Mexico	South Africa	
Belgium	Ghana	Moldova	Spain	
Benin	Greece	Morocco	Sri Lanka	
Bosnia and Herzegovina	Guatemala	Myanmar	Sudan	
Botswana	Haiti	Nepal	Sweden	
Brunei Darussalam	Honduras	New Zealand	Tajikistan	
Bulgaria	Hong Kong SAR, China	Nicaragua	Tanzania	
Cambodia	Hungary	Niger	Thailand	
Cameroon	Iceland	Nigeria	Togo	
Chile	Israel	North Macedonia	Trinidad and Tobago	
Congo, Dem. Rep.	Jamaica	Norway	Tunesia	
Costa Rica	Japan	Oman	Turkey	
Cote d'Ivoire	Jordan	Pakistan	Turkmenistan	
Croatia	Kazachstan	Panama	Ukrain	
Cuba	Kenya	Paraguay	United Arab Emirates	
Cyprus	Korea, Rep.	Peru	United Kingdom	