THE ENERGY-GDP NEXUS IN EU COUNTRIES

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ABSTRACT

The neutrality hypothesis between the energy consumption and the economic activity is examined for the panel of EU-27 countries and selected sub-panels. The causality runs from the energy consumption to the GDP for the EU-27, but the causality from the GDP to the energy consumption cannot be confirmed. The evidence therefore speaks for the rejection of the neutrality hypothesis in favor of the growth hypothesis. These results differ between the original (EU-15) and the new EU member countries (EU-12). In the original member countries, there is a tendency to increase the economic growth with the energy consumption savings. In the new member countries a negative impact of the energy consumption savings on the economic growth is found. Examining the sectoral energy consumption, the main drivers of the causality in the relationship are identified as the residential sector, industry and services. The residential energy consumption savings appear to increase the economic growth in both original and new member countries. But the role of the energy consumption savings in the industrial and services sectors differs across the groups. For the industrial sector, the energy consumption savings increase economic growth in the original member countries. In the new member countries, energy conservation might hinder the economic growth. In services, the energy consumption does not seem to have an impact in the original member countries, while in the new member countries the savings in energy consumption seem to degrade the economic growth. The energy conservation policies might be beneficial for the more developed countries of EU-15, but not for the less developed countries of EU-12.

Keywords
GDP, Energy use, EU-27, Energy-GDP nexus

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1. INTRODUCTION

In 2007 the European energy policy has been introduced as a response to several issues. The main objectives of the policy are often abbreviated as 20-20-20 goals. These goals should be achieved by the year 2020, and are typically of the 20% magnitude. Specifically, the goals are: i) reduction in the EU's domestic greenhouse gas emissions at least to 20% below 1990 levels, ii) 20% share of renewables on the final energy consumption, accompanied with 10% share of bio-fuels on the total gasoline and diesel consumption, and iii) 20% reduction of the primary energy consumption (by improving energy efficiency).

The main reason behind the introduction of the policy is the commitment of European Union countries to reduce the emission of greenhouse gases, mainly the carbon dioxide, by the Kyoto protocol.

The link of such a commitment to the policies targeted on the energy conservation can be shown with the so-called Kaya identity. The Kaya identity can be written as $C \equiv N \cdot \frac{GDP}{N} \cdot \frac{E}{GDP} \cdot \frac{C}{E}$, where C stands for the carbon emissions, N for population, $\frac{GDP}{N}$ represents the economic level (GDP per capita), $\frac{E}{GDP}$ the primary energy intensity, and $\frac{C}{E}$ the carbon emission factor (the carbon intensity of energy) (Hoffert and Caldeira, 2004).

The population growth is rarely regulated (but on the other hand, in many countries it might be seen as relatively stable). Hardly any policy maker would propose the economic stagnation (or regress) in order to stabilize (or curb) the emissions. Therefore we can assume that there will be an economic progress. Then to achieve the reduction in emissions, it would need to be offset by the last two terms in the equation, i.e. the energy intensity and the carbon emission factor.

The energy conservation plans, such as the EU 20-20-20, typically aim to influence both of them.

However, given the prevalence of fossil fuels as the energy sources in basically all countries in the world, the compliance to the commitment of reduction of the carbon dioxide emissions typically implies the necessity of the reduction in the amount of energy consumed (de Nooij et al., 2003). As the emission trading introduces the total emission caps (necessary condition to establish a pricing scheme for emissions). If the large-scale technology shift is difficult, these emission caps can be viewed as the indirect energy consumption caps.

However, despite the principle of subsidiarity in the implementation of European policies, there is a standing question whether the impacts of the implementation will influence all the countries in the same manner.

The typical characteristics of the new member countries are their higher energy intensity, accompanied by somewhat lower economic level than in the original member countries. The apparent ambition for the convergence in the efficiency of energy usage might be appealing. However, the question is if the increased energy efficiency (or reduced energy use), will go hand in hand with the economic efficiency. In other words, if all the countries follow this common policy, will they all experience the same effects? Is the common policy more beneficial for one of the country groups, while being inexpedient for the other?

The aim of the article is to investigate the so-called energy-economy nexus in the EU countries on the disaggregated level. The main research questions are:

Of the four major hypotheses - the neutrality hypothesis, the feedback hypothesis, the conservation hypothesis or the growth hypothesis – which best describes the situation in the European Union?

Is there an observable difference between the two dichotomous groups of the original member countries and the new member countries?

Unlike most of the studies that investigate the energy-economy nexus, the estimations are done both on the aggregate and sectoral level. This distinction is strongly advocated e.g. by Gross (2012). Unlike the previous studies in the field, this paper uses panel framework with multiple groups and investigates both aggregate and sectoral level. The sign of the causality is also considered.

The identification of the appropriate hypotheses will serve as the basis for the policy recommendation regarding the energy conservation schemes. The text starts with the general theory and methodology. The literature review regarding the topic follows. In the subsequent part the data description and the estimation results can be found.

2. The Energy-Economy Nexus

This section provides the introduction to the energy-economy nexus investigation, along with the basic classification. The next subsection presents the literature review of the subject.

2.1 The Energy-Economy Nexus Description

First of all, what is the energy-economy nexus? Basically, it is an investigation of the causality between the energy consumption and the economic performance.

The main object of interest is whether we can observe either the existence of a stable long-run relationship or the Granger causality between the variables. The existence of the long-run equilibrium is examined by cointegration testing. The Granger causality tests examine if the changes in one variable affect the future development of the other variable.

The genesis of the topic is closely linked to the oil shocks in the 1970s and 1980s, which contributed to the development of the energy economics as a specialized branch of research (Bhattacharyya, 2011). The disruption in the supply has raised both public and academic awareness regarding the importance of energy in the economic development of countries. The basic dilemma of the investigation is whether the reduction in the energy consumption will not cause a second round penalty in terms of lower economic growth. This question remains in the spotlight even today, even though for different reasons. In the 1970s and 1980s, the reduction in the energy consumption was unavoidable result of the supply shock. Today the main cause of the reductions in the energy consumption is the international struggle to reduce the emissions of the greenhouse gases.

The recent energy policy debates also raised a significant attention both by the public and the politicians. Among the most distinct of such public debates are the environmental concerns and consequent "pro-green"[1] measures. Sometimes, the agreements to extend the scope and quantity of such policies are labeled as the post-Kyoto protocol negotiations. . These primarily focus on the energy conservation measures and regulations. Among other things, the political response to natural events and disasters also come into play. An example may be the shutdown of nuclear power plants (NPP) in Germany following the Fukushima NPP incident, considerably reducing the electricity generation supply.

It is however unclear whether the policy makers proposing the lower consumption are aware of all the possible effects on the economy. This article intends to provide such an insight regarding the effects of the changes in the energy consumption on the economy growth (measured by real GDP per capita).

The investigation of the relationship between the energy consumption and the economic activity is the classical topic of the energy economy. As the literature reviews suggest (see e.g. Bohi and Zimmerman (1984), Dahl (1994), Keppler et al. (2007), Mahadevan and Asafu-Adjaye (2007), Sari and Soytas (2007) or Ozturk (2010)) it remains a lively topic even decades after the seminal work of Kraft and Kraft (1978). Even today it is still considered a topic of fundamental importance (Chontanawat et al., 2008).

2.2 The Basic Classification

As summarized e.g. in Ozturk (2010), the literature suggests four different hypotheses, describing the directions of causality between the energy consumption and economic growth. Each of the basic hypotheses has vastly different policy implications. These four hypotheses are: the neutrality hypothesis, the feedback hypothesis, the growth hypothesis and the conservation hypothesis. The direction of causality described by these hypotheses is shown in Table 1.

Table 1: The basic types of energy-economy relationships

Designation	Description
The neutrality hypothesis	No causality between *E* and *GDP*
The conservation hypothesis	Uni-directional causality: E←GDP
The growth hypothesis	Uni-directional causality: E→GDP
The feedback hypothesis	Bi-directional causality: E↔GDP

[1] E.g. well known case of the ban of incandescent light bulbs in the European market (by Commission Regulation (EC) No 244/2009), forcing a switch of the consumer's choice towards discharge lamps. Despite the wording of the document, labeling itself as "setting the ecodesign requirements" (for its aim to reduce the energy consumption and consequently some of the related carbon dioxide emissions), it should be noted the presence of toxic materials in the discharge lamps (most commonly mercury vapor, metal halides, phosphor, beryllium, cadmium, or thallium), represents a significant environmental concern and goes directly against the appeal of the United Nations Environment Programme (2009).

It is noteworthy this regulation was indeed only one of the first measures in the regulation of availability of technologies that are deemed "inefficient".

Interested reader can find additional plans in the document of the European Commission COM(2006) 545: Communication from the Commission - Action Plan for Energy Efficiency: Realising the Potential.

The neutrality hypothesis:

The first of the four basic types is the neutrality hypothesis, expecting no causality between the economic growth and energy consumption. This implies neither the energy conservation nor expansion policies will affect the economic growth, and vice versa. It naturally serves as the null hypothesis in the investigation.

One of the basic arguments for the validity of the neutrality hypothesis is that the energy expenditures represent only a rather small fraction of the GDP. Therefore it is not likely that even the significant changes in the consumption will have very distinct effects on the GDP,[2] or that these effects will be effectively overshadowed by other factors.

A somewhat different scope of arguments is focusing on the structure of the economy.

It is expected that with time (and higher levels of development), the production structure will be shifting towards the service sector (that is typically less energy intensive). Such a structural change, typically evidenced by significant energy intensity changes, may lead to what is often labeled as decoupling of the energy use and GDP, and would speak for the absence of evidence for the causality (especially if considered only on the aggregate levels).

The last type of arguments favoring this hypothesis focuses on the absence of the actual physical link between the variables. It points out to the limited possibility to store the energy consumed in previous periods (especially valid with the use of relatively low-frequency data, such as the typical annual panels). Then the volumes of the past energy consumption cannot have a reasonable physical linkage to the current output. This type of argument, however, is not reasonably applicable to all types of the hypotheses, and focuses only on the Granger causality tests.

Bi-directional hypothesis:

The opposite point of view represents the "feedback hypothesis", expressed as the mutual interdependence of the energy consumption and economic growth, their joint determination and bi-directional causality.

In such case, the policy implications need to take into the account the expected behavior of the economy given the specific form the relationship both for the design and for the effects of the proposed energy policy. Unlike other types of hypotheses, this usually requires additional policy investigation (ideally it would be based on even more detailed information datasets), or the policy design that needs to specify the hierarchy of the targets.

Uni-directional hypotheses:

The remaining two hypotheses represent uni-directional causalities. From the viewpoint of energy conservation policies, they are probably the most interesting ones.

The uni-directional hypothesis may be found either from the economic growth to the energy consumption (the "conservation hypothesis") or from the energy consumption to the economic growth (the "growth hypothesis").

[2] For instance, Rotemberg and Woodford (1996) estimate the value of oil inputs in the US economy to be less than 4% of the total value added.

The conservation hypothesis implies the energy conservation plans may be implemented without the impacts on the economic growth. Typically, if the evidence for this hypothesis is found, the policy recommendation advocates the implementation of the energy conservation policies. This type of hypothesis is usually favored by economists, who consider the energy primarily as the intermediate product. Therefore, with the increasing level of output there will be an increasing demand for goods and services, including the derived demand for energy.

On the contrary, the growth hypothesis considers the energy as a necessary production factor. It is typically favored by the engineers and the applied physicists (Beaudreau, 2010) and it implies the reduction in the energy consumption (or energy supply) will affect the economic growth. This type of hypothesis would also advocate the inclusion of energy in the macroeconomic production function.

2.2.1 The sign of the causality

In the construction of the hypotheses, it is tacitly assumed the sign of the causality is positive. Then, in the case of the growth hypothesis, the reduction in consumption will negatively affect the economic growth or the energy supply expansion may speed up the growth. In case of conservation hypothesis, we would expect that with the increasing economic development, there will be an increase in the energy consumption.

The possible negative sign of the causality might render the typical policy recommendation moot as the implications of the negative sign of causality are largely reversed. For instance, instead of the usual recommendation of the growth hypothesis - i.e. against the energy conservation implementation - it would advocate the reductions in energy consumption. Why might this hold? There is a complex linkage between the interaction of the energy in the production process. One of the possible explanations is there is a diverse structure of the actual energy consumption. If the production processes, for instance in the industrial sector, move away from the energy-intensive activities, while maintaining the output, the innovation potential of such a change will be exhibited as the negative causality. This innovation might be influenced by the efficiency incentives in the existing production, but also by the motivation of the intra-industry structural change.

The case of negative conservation hypothesis would probably be motivated with a different consumption motivations associated with the higher income levels. In other words, as the individual income rises, the consumers might prefer the more efficient ("green") consumption, even if it is not strictly more expedient. We can observe this pattern with increasing consumption of organic foods, and in general, there is a higher level of environmental awareness in the high income countries than in the low income countries.

The importance of the sign of the causality is often neglected in the literature. Typically, it is *assumed* the sign of causality is positive (Narayan and Popp, 2012). Among the scarce exceptions, recognizing the importance of the sign are Gross (2012), Narayan and Popp (2012), Bowden and Payne (2009) or Sari and Soytas (2007).

2.3 The Controversy of the Topic

The energy-economy nexus investigation is also often considered controversial. There are two main reasons for the controversy. The first one is methodological, the second one rather practical.

Regarding the methodology, (Beaudreau, 2010) points out that the energy-economy nexus investigation is essentially exploratory in nature and does not have solid theoretical grounding. This is largely true. Despite the effort by Ghali and El-Sakka (2004) to link the topic to the neoclassical production function, it eventually boils down to the description of the dynamic interactions between a set of variables. Due to the "relaxed" position of the theory, the studies often differ in their model setup, which renders the comparability of their results rather difficult. However, the energy conservation policies themselves are also often applied without solid theoretic reasoning. The exploratory nature of the topic then serves well to investigate the applicability of the policy.

The practical reason to criticize the approach is the empirical dichotomy of the results. While the classification is simple, the evidence for the energy-economy relationships is mixed.

This holds even for the very beginning of the topic. The conclusions of the studies regarding the USA data were switching from the evidence for conservation hypothesis in Kraft and Kraft (1978), to the neutrality hypothesis in Akarca and Long (1980). Yu and Hwang (1984) then confirmed the absence of causality using the sample 1947-1979 in the annual frequency, but identified unidirectional causality using the sample 1973-1981 in quarterly frequency. Later on, Yu and Choi (1985) and Erol and Yu (1987) concluded with the neutrality hypothesis.

The "neutrality hypothesis" for the USA was also found in the subsequent articles by Yu and Choi (1985) and Erol and Yu (1987). Abosedra and Baghestani (1991) however supported the results in Kraft and Kraft (1978), despite using different type of tests (direct Granger instead of the Sims procedure).

Due to the absence of prevailing conclusion, there is a dispute whether the results are spurious. Given the lack of the theoretical basis, it is hard to justify the general validity of the results. The mainstream production theory does not help in the explanation for the role of energy, and there is not even a consensus on the substitutability with the other production factors. The econometric estimates carried out on the industry level come to different conclusions even in the question whether capital and energy are complements or substitutes (Stern, 2004).

The evidence for the energy-economy relationships is mixed even if comparing the studies regarding the "similar" countries or even the different time samples of the same country. On the other hand, the differences in the results can be attributed to the differences in the methodology applied, the selection of the data (it is sensible to assume some heterogeneity in the behavior in different sectors in the economy, and of course possible development or changes in the relationship in time) or the different dynamics (lag structure) employed (Masih and Masih, 1997).

Nevertheless, even when accounting for the variety of possible explanatory variables as well as measures of growth, the topic is still worth attention for the policy makers. If for nothing else, even the seemingly non-uniform answer of different aspects of the economy examined provides the reasoning for the different attention to different sectors (and different policy making for different countries).

For the obvious reasons, the closest attention should be paid to the framework most closely resembling the proposed policy.

The data availability is also an issue, especially in Europe, where the era of centrally planned economies (CPE) affected the development of many states.[3] The reasonable assumption on information capability of the past for the current development simply does not hold for but the very recent period in case of post-communist countries. This range may be approximately 20 years, or possibly less due to necessary post-transformation adjustments. Given the limited availability of high frequency data, it is often problematic to set up more complex estimation schemes. Annual data also often lead to the inclusion of rather limited number of lags.

Even with the efforts of international bodies like OECD, World Bank or Eurostat office, the data are also rarely available both in sufficient sectoral and time detail. This limits the operating field of a researcher, and is also a reason this paper works only with the annual data for the EU-27 countries in the period of 1995-2010[4], even though the more detailed data in higher frequency probably might be able to provide details that might remain unanswered in this analysis. The adoption of the detailed sectoral investigation of energy consumption patterns would probably be highly beneficial for the topic.

Nevertheless, given the challenge of achieving the common policy goals of the European Union in the energy sectors of individual countries, it is the aim of this article to examine whether there is the same type of energy-economy relationship in the individual countries. Consequently, the question is whether there may be some unexpected concerns regarding the implications of achieving this common goal.

The main hypothesis of the article is to test what type of hypothesis holds for the European Union countries as a whole and in the two dichotomous groups of the original and the new member countries. The purpose of the identification is to find out if the objective of the energy consumption reduction will or will not affect the economic growth.

This paper contributes to the literature by fulfilling the typical shortage found in many of the articles, i.e. examining only the causality per se, but not the sign of the causality. Furthermore, along with the aggregate data, it employs sectoral analysis and identifies the type of the energy-economy nexus relationship in the different groups.

2.4 Literature review

For instance Narayan and Popp (2012) classify the literature into two strands. The first of them examines the energy-economy nexus for single countries and the second strand examines Granger causality for panels of countries. In both strands, the energy-economy nexus is usually examined on the aggregate level. This means

[3] As the results in Hajko (2012) indicate, in the analysis concerning the energy consumption development in the EU countries, the attention should be paid to the significant differences between the countries of EU-15 (original EU members) and the new member countries.

[4] With this data range I assume that by the beginning of the examined period the transformation processes (including post-transformation recessions) in the formerly centrally planned economies were more or less finished. Also, the real GDP values are not available for all the countries in the sample for periods before 1995.

the focus of the investigation is on the link between the aggregate economic output and the total energy consumption.

This implies two different types of aggregation. The first one is the aggregation of countries into the panel groups, and the second one is the aggregation of the various activities within a country. While the former is apparently done for the estimation purposes, the latter is more concerned with the methodological background.

The aggregation of the energy consumption is characterized by the ability to encompass any energy mix, without any possible distortions based on naturally diverse historical preference of a certain energy source, national resource availability, consumption restrictions (as would typically be the case of nuclear energy), economy structure or physical necessities of certain production processes.

However, the aggregated approach has also been subjected to criticism.

For instance, Cleveland et al. (2000) argue that the different types of aggregation may lead to different analytical results regarding not only the significance but also the direction of the causality. They argue the different quality of the energy should be taken into account. Assuming the prices of energy reflect the marginal productivities (and the differences in the appropriate uses of various different energy sources), the different quality of energy seems to be evidenced by the different prices for the same unit of thermal equivalent of energy using different energy sources.

Cleveland et al. (2000) therefore recommend constructing the Divisia index of energy consumption. This approach however requires the availability of the data on the cost shares of a given fuel to employ in the construction of the aggregate index, which is often unavailable.

Ayres et al. (1996) argue for the use of the thermodynamic concept of exergy.[5] Further elaboration on the subject of exergy is provided e.g. by Ayres et al. (2003), who use yet another exergy-related term ''useful work'.[6] The exergy approach however is very complex, requiring detailed transformation processes data, and the empirical examples are scarce. (see e.g. Warr and Ayres, 2010).

Nevertheless, the aggregation is not without its merits. The establishing point of the aggregate studies lies mainly in their general applicability. Furthermore the overall targets of conservation policies are also formulated with the use of aggregate energy consumption.

The approach based on the "aggregate-aggregate" link can still be found in most of the studies - see for instance Narayan and Popp (2012), Narayan et al. (2010), Chontanawat et al. (2008), Narayan and Smyth (2008), Mahadevan and Asafu-Adjaye (2007), Sari and Soytas (2007), Lee (2006), Sari and Soytas (2006), Lee (2005), Ghali and El-Sakka (2004), Sari and Soytas (2003) or Asafu-Adjaye (2000). Mainly due to the dissatisfaction with the dichotomous results of the aggregate studies, there have been several attempts to improve the investigation of the energy-economy link.

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[5] Exergy is a measure of distance from the thermodynamic equilibrium. In other words is the maximum amount of work that can be recovered from a system as it approaches reversible equilibrium with its environment.

[6] The 'useful work' is exergy multiplied by an estimated conversion efficiency. It is therefore less than the theoretical maximum available work (exergy). See the article for the details of 'useful work' construction.

Sometimes, the studies employ additional variables (usually production factors of capital/labor or consumer price index) in the estimations. Some authors point out that one unit of energy consumed does not produce the same outcome, if it is used in various forms. This leads to the so-called disaggregated analysis, typically focusing on certain specific types of energy - electricity seems to be one of the favored choices. In a more data-demanding approach, some authors even adjust for various qualities of different forms of energy based on the costs.

Some studies have considered a different type of disaggregation – instead of the selection of fuel type, the energy consumption is classified by the economic sector. The proponents of this approach argue that not all of the energy consumption can be attributed to the GDP generation processes (as would be expected in the energy-economy nexus). Furthermore, the impacts from the distinct energy consumptions can be differentiated enough to cancel each other out in aggregation (e.g. Gross (2012) labels this situation as the "Simpsons' Paradox", i.e. a situation when the results estimated on the sub-populations are more informative than those estimated on whole populations).

2.4.1 Disaggregated studies using the fuel type selection

The estimation of the disaggregated relationship is less frequent than the studies employing aggregate approach. The typical reason for the selection of a specific type of energy is based on the assumption of the closer link of the specific energy consumption in the energy-economy nexus.

The fuel specific studies are found in two variants. The first of them selects only one specific fuel type, typically electricity, nuclear energy or renewables. The second variant uses multiple fuels in the estimations.

Among the examples of the fuel-specific studies focused on the nuclear energy can be included Nazlioglu et al. (2011), Apergis and Payne (2010), Yoo and Ku (2009). Acaravci and Ozturk (2010), Narayan and Prasad (2008) and Yoo (2006) employed the electricity as their choice of energy variable. Menegaki (2011) examined the energy-economy link using renewables and Apergis et al. (2010) study nuclear energy and renewables.

In more exhaustive fashion, Sari and Soytas (2004), Wolde-Rufael (2004), and Yang (2000) choose several distinct fuel types in their analysis. In all three cases the authors found that not all fuel types exhibit the same influence in the energy-economy nexus in the examined countries/areas (Turkey, Shanghai and Taiwan, respectively).

However, a rather strong argument against the use of distinct fuel sources in analysis is the rather small share of a given fuel on the total consumption and the diversity of fuel usage across the sectors. The focus on solitary source could possibly lead to incorrect conclusions if not factored for the other explanatory variables.

Another argument against specific fuel type selection is that the energy sources are subject to substitution over time - in such a case, the changes in the consumption of a energy source *A* can be balanced out by the opposite changes in the consumption of energy source *B*. This would naturally distort the results if only one of them was included in the analysis (typically this might be a problem for long samples). Furthermore, a consumption of a single fuel type can be more prone to external fluctuations and bubbles (especially given the largely opened commodity market). Unless the analysis includes all the fuel types that constitute the majority of the energy consumption, there is a doubt if the substitution effects do not influence the results.

2.4.2 Disaggregated studies using sectoral selection

Even less frequent than specific fuel type studies are the sectoral disaggregated studies. Examples of the disaggregated sectoral studies are Gross (2012), Bowden and Payne (2009), Zachariadis (2007) or Hondroyiannis et al. (2002). All these studies used the thermal aggregates as the energy variable (i.e. the final energy consumption). Of these studies, only Zachariadis (2007) examined the disaggregated relationship in the panel settings. Two remaining studies examined USA and Hondroyiannis et al. (2002) studied the energy-economy nexus in Greece.

Gross (2012) examined the aggregate and sectoral level (namely industry, commerce and transport) in the United States. Unlike the usual settings, he employed sectoral value added instead of the GDP measure. He finds evidence for the growth hypothesis in the commercial sector and the feedback hypothesis in the transport sector. On the other hand Bowden and Payne (2009), Zachariadis (2007) or Hondroyiannis et al. (2002) all used the aggregate value of the GDP in pair with sectoral energy consumptions. Bowden and Payne (2009) examined USA data and found evidence for the growth hypothesis in the industrial sector and feedback hypothesis in the commercial and residential sectors. Zachariadis (2007) finds neutrality hypothesis in the USA, and mixed evidence in the remaining G-7 countries. Hondroyiannis et al. (2002) concluded with the evidence for the growth hypothesis.

The sectoral analysis combining pairs of aggregate GDP and sectoral energy consumption is employed in this article, in the settings similar to the approach in Zachariadis (2007), with the methodological approach similar to those in Bowden and Payne (2009).

However, it should be noted there is another type of disaggregated analysis. Unlike the aggregation of the energy consumption based on the thermal equivalent of individual fuels, this disaggregation is based on the specific types of fuel.

3. THE MODEL FRAMEWORK

This section provides the description of the data and model employed in the estimation.

3.1 The Data

The sources of the data were Eurostat and World Bank statistics[7]. All data are in annual frequency.

[7] Tables Final energy consumption, by sector [tsdpc320], Real GDP per capita, growth rate and totals [tsdec100] and World Bank indicator NY.GDP.MKTP.KD.

The data in levels were transformed to natural logarithms. The ADF tests[8] of the stationarity of the data were employed. In case of non-stationarity,[9] the data were transformed to growth rates (by taking the first differences of the natural logarithms). Due to a large number of estimation results, only the most important estimations will be shown.

3.2 The Model Setup

The principal methodology that will be applied in this paper follows the usual approach in the literature. In other words it applies the cointegration testing combined with the Granger causality to establish the direction of the causality. The objective of the cointegration testing is to examine whether there is a stable long run relationship between the variables in question. If no cointegration is found, the causality testing is performed in the VAR in differences.

The necessary first step is to find out the order of integration of the variables, i.e. how many differences of the variable we have to perform in order to get stationary series. The purpose of this is two-fold. First, the cointegration is defined as the property of $I(1)$ variables. Second, if there is no cointegration, the estimations performed with non-stationary variables might lead to spurious correlation. The estimations then need to be carried out with stationarized variables.

To test the cointegration between the variables in a panel framework the suitable tests were proposed by Pedroni (2000, 2004). If no cointegration relationship can be found, the data are stationarized (usually by taking the first differences and re-testing if the differenced data are stationary) and the analysis focuses on the so-called Granger causality in the VAR framework.

This type of causality is employed to establish what remains unclear in the common regression analysis, i.e. the direction of the causality. If we observe the significance of the relation between the explained and the explanatory variables, we are unable to tell whether the causal effect runs from the explanatory variable to the explained variable or vice versa. The Granger causality is based on the assumption that events of the future cannot cause the events in the past. If the explanatory variables represent the events in the past, the aforementioned assumption explains the logic behind the conclusion that past events caused the current events.

To test the hypotheses of the Granger causality, the following equations are estimated:

[8] ADF test relies (in the well-known form of $\Delta y_t = \beta_0 + \gamma_t + (\phi - 1) y_{t-1} + \rho_1 (\Delta y_{t-1}) + \ldots + \rho_{p-1} (\Delta y_{t-p+1}) + \varepsilon_t$ (i.e. with up to p lags) on observing whether the coefficient of y_{t-1} is significantly different from zero. In this case the lagged structure was obtained by sequential elimination of insignificant lags (starting from high number of lags) in order to avoid the problems with possible autocorrelation of the error term in the ADF test equation.

[9] It is noteworthy that in several cases, the more work should be done to deal with possible structural breaks (leading to signs of non-stationarity), namely in case of Greece, Portugal and Romania in case of the GDP variable, and Finland, Greece, Portugal and Spain in case of the energy consumption variable.

$$\Delta y_t = \alpha + \sum_{i=1}^{m} \beta_i \Delta y_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta e_{t-j} + \tau time + \delta_1 D1 + \delta_2 EU8 + \sum_{j=1}^{n} EU8 \cdot \lambda_j \Delta e_{t-j} + u_t \quad (1)$$

$$\Delta e_t = \alpha + \sum_{i=1}^{m} \beta_i \Delta y_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta e_{t-j} + \tau time + \delta_1 D1 + \delta_2 EU8 + \sum_{i=1}^{m} EU8 \cdot \lambda_i \Delta y_{t-i} + u_t \quad (2)$$

where Δy_t represents the growth rate of real GDP per capita, Δe_{t-j} represents the growth rate of the final energy consumption, *time* represents the time trend (in case of trend stationary variables) and $D1$ represents a dummy variable (in order to accommodate the possibility of a structural break following the global financial turmoil and starting the period of crisis) with value of 1 for years 2008-2010 and 0 otherwise,[10] $EU8$ represents a dummy variable separating the groups of the original and new member countries, and the u_t represents the error term.

Due to the limited number of time observations for each cross-sectional unit and relatively low annual frequency, the lag structure is only modest in the estimations. The lag order was based on the Akaike information criterion, and the most appropriate form seems to be with 1 lag in most cases. This also allows rather easy interpretation of the signs in the suspect relationship. However, if higher lag order is desirable, the computation of the cumulative effect should be performed. The computation can be based either on the sum of the lagged coefficients, or by the impulse response function.

The estimations were done for several panels of the countries, using dynamic panel method with the "system estimator" (Blundell and Bond, 1998).

The procedure undertaken therefore consists of the following steps: ADF test for the data in levels and in growth rates, cointegration testing and causality testing.

Estimations were done for the "full" groups of EU-27 (all European Union countries), EU-15 (original member countries) and EU-12 (new member countries).

Several countries have shown possible problems with the order of integration higher than 1. In order to avoid possible negative impact of this undesirable behavior, the estimations were carried out both for the original groups and the groups where such countries were excluded (see Table 2 for the overview).

This exclusion was done for the purpose of more robust results, unhindered by the possible spurious effects of non-stationarity. The modified groups are:

EU-15 → EU-11, based on the group of the original member countries (EU-15), with the exclusion of Greece, Portugal, Spain and Finland,

EU-12 → EU-8, based on the group of the new member countries (EU-12), with the exclusion of Cyprus, Malta, Slovenia and Romania,

EU-27 → EU-19, created as the union of the groups of EU-11 and EU-8.

[10] While we may argue for the different choice of periods for the structural change, the individual models did not respond significantly different with the inclusion of multiple dummy variables; furthermore, the problem with the matrix invertibility occurred with too many dummy variables.

Table 2: Overview of the Country Groups

Country name	*Country code*	*EU-27*	*EU-15*	*EU-12*	*EU-19*	*EU-11*	*EU-8*
Austria	AT	✓	✓		✓	✓	
Belgium	BE	✓	✓		✓	✓	
Bulgaria	BG	✓		✓	✓		✓
Cyprus	CY	✓		✓			
Czech Republic	CZ	✓		✓	✓		✓
Denmark	DK	✓	✓		✓	✓	
Estonia	EE	✓		✓	✓		✓
Finland	FR	✓	✓				
France	GR	✓	✓		✓	✓	
Germany	DE	✓	✓		✓	✓	
Greece	ES	✓	✓				
Hungary	HU	✓		✓	✓		✓
Ireland	IE	✓	✓		✓	✓	
Italy	IT	✓	✓		✓	✓	
Latvia	LV	✓		✓	✓		✓
Lithuania	LT	✓		✓	✓		✓
Luxembourg	LU	✓	✓		✓	✓	
Malta	MT	✓		✓			
Netherlands	NL	✓	✓		✓	✓	
Poland	PL	✓		✓	✓		✓
Portugal	PT	✓	✓				
Romania	RO	✓		✓			
Slovakia	SK	✓		✓	✓		✓
Slovenia	SI	✓		✓			
Spain	FI	✓	✓				
Sweden	SE	✓	✓		✓	✓	
United Kingdom	UK	✓	✓		✓	✓	

In order to examine the significance of the relationship on the disaggregated level, the estimations are also done for the individual sectors, as advocated in Zachariadis (2007) or Bowden and Payne (2009).

The results based on the limited and non-limited groups do not deviate much from each other. For the sake of brevity, I present the sectoral estimations only on the limited, but arguably more robust panel of EU-19.

4. Estimation Results

There are significant differences between the development between the original and the new member countries (see Table 3). The GDP has been growing nearly at double of the rate of the original member countries. The energy consumption practically has not changed in the new member countries, while it has gone up by about 10% in the original member countries. There were also major structural changes in the pattern of consumption. In the new member countries, the previous champions of the centrally planned economies, i.e. the industrial and agricultural sector, have experienced major reductions. While the energy consumption patterns are becoming more similar in the end of the estimation sample, the industrial sector still is more prominent in the new member countries. On the other hand, both transportation and services have experienced an increasing consumption in both country groups. Furthermore, both groups experienced significant energy intensity improvements (but notice it is still more than double in the absolute value in the new member countries). This fits well with the expectation of the dematerialization of the economy.

Table 3: Overview of the Changes

	EU-15				EU-12			
	1995	2010	Avg Annual Growth rate (%)	Relative change (%)	1995	2010	Avg Annual Growth rate (%)	Relative change (%)
GDP (billions)	10166	13430	1.41	32.11	589	986	3.5	67.48
GDP per capita	21360	27887	1.79	30.56	4880	8264	3.57	69.34
Total energy consumption	899581	982523	0.59	9.22	171072	170776	-0.01	-0.17
Energy cons. in services	99474	130150	1.81	30.84	14574	22268	2.87	52.79
Energy cons. in industry	258743	246949	-0.31	-4.56	69441	44637	-2.9	-35.72
Residential energy cons.	230367	255566	0.69	10.94	51380	51759	0.05	0.74
Energy cons. in transport	278116	319735	0.93	14.96	24557	45483	4.19	85.21
Energy cons. in agriculture	22215	19042	-1.02	-14.28	8769	6004	-2.49	-31.53
Energy intensity	0.09	0.07	-1.26	-17.32	0.29	0.17	-3.39	-40.39

Table 4: Panel Estimations with Energy Explaining GDP

	EU-27	*EU-19*	*EU-15*	*EU-11*	*EU-12*	*EU-8*
GDP(-1)	0.0938***	-0.0133	0.0598	0.0166	0.2801*	0.1308
	(0.000)	(0.802)	(0.309)	(0.828)	(0.060)	(0.483)
const	0.0374***	0.0317***	0.0614***	0.0494***	0.0279**	0.0071
	(0.000)	(0.000)	(0.000)	(0.000)	(0.025)	(0.750)
D1	-0.0455***	-0.0543***	-0.0211***	-0.0312***	-0.0424***	-0.0637***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)
time	-0.0011***	-0.0003	-0.0029***	-0.0018***	-0.0001	0.0026**
	(0.000)	(0.324)	(0.000)	(0.000)	(0.873)	(0.015)
energy(-1)	-0.0908***	-0.2121***	-0.1027***	-0.1471***	-0.1013	-0.051
	(0.000)	(0.000)	(0.000)	(0.000)	(0.130)	(0.540)
EU8*(energy(-1))	0.1519***	0.3051***				
	(0.000)	(0.000)				
EU8	0.0233***	0.0227***				
	(0.000)	(0.000)				

Coefficient values. P-values are in the parentheses.

Table 5: Panel Estimations with GDP Explaining Energy

	EU-27	*EU-19*	*EU-15*	*EU-11*	*EU-12*	*EU-8*
energy(-1)	-0.0041	-0.1959	-1.0528***	-0.6616***	0.0185	-0.4216
	(0.957)	(0.217)	(0.000)	(0.005)	(0.941)	(0.371)
const	0.0061	-0.0162	0.0872***	0.0397***	-0.0374	-0.0869**
	(0.571)	(0.298)	(0.000)	(0.004)	(0.124)	(0.013)
D1	-0.0071	-0.0204***	0.002	-0.0034	-0.0227*	-0.0483**
	(0.126)	(0.000)	(0.734)	(0.663)	(0.080)	(0.016)
time	0.000	0.0018**	-0.0052***	-0.0023***	0.0032**	0.0066***
	(0.968)	(0.053)	(0.000)	(0.014)	(0.024)	(0.002)
GDP(-1)	0.0624	-0.0042	0.023	-0.0968	-0.0741	0.0086
	(0.632)	(0.986)	(0.885)	(0.556)	(0.669)	(0.961)
EU8*(GDP(-1))	-0.1728	0.0383				
	(0.393)	(0.906)				
EU8	-0.0006	-0.0074				
	(0.936)	(0.426)				

Coefficient values. P-values are in the parentheses.

Table 6: Panel Estimations with Sectoral Energy Consumption Explaining GDP, EU-19

	Coefficient	*P-value*
GDP(-1)	-0.2509	0.339
const	0.0345***	0.006
EU8	0.027***	0.000
D1	-0.0476***	0.000
time	-0.0005	0.382
E_services(-1)	-0.0256	0.105
E_industry(-1)	-0.1039***	0.009
E_residential(-1)	-0.0382**	0.049
E_transport(-1)	0.0426	0.606
E_agricul(-1)	0.0052	0.735
EU8*E_industry(-1)	0.1874***	0.000
EU8*E_services(-1)	0.0629***	0.001
EU8*E_residential(-1)	-0.1136	0.181
EU8*E_transport(-1)	0.0886	0.437
EU8*E_agricul(-1)	0.0115	0.799

Table 7: Panel Estimations with GDP Explaining Sectoral Energy Consumption, EU-19

	Industry	*Services*	*Residential*	*Transport*	*Agriculture*
energy(-1)	-0.2114	-0.1317***	-0.2784***	-0.1041	-0.1659***
	(0.364)	(0.006)	(0.000)	(0.208)	(0.000)
const	-0.0399	0.0149	-0.0167	0.033***	-0.0688
	(0.126)	(0.752)	(0.348)	(0.001)	(0.128)
D1	0.0034**	-0.0002	0.001	-0.0009	0.0039
	(0.024)	(0.925)	(0.312)	(0.217)	(0.129)
time	-0.0714***	0.0205*	0.031***	-0.0372***	-0.0049
	(0.000)	(0.062)	(0.000)	(0.000)	(0.767)
GDP(-1)	-0.0049	0.0166	-0.0129	0.0184***	-0.0141
	(0.839)	(0.420)	(0.389)	(0.000)	(0.538)
EU8*(GDP(-1))	-0.1801	0.0339	-0.1038	-0.0527	0.2593
	(0.776)	(0.973)	(0.817)	(0.659)	(0.720)
EU8	-0.2204	-0.1907	0.1845	0.2831	-0.3416
	(0.768)	(0.860)	(0.753)	(0.132)	(0.714)

Coefficient values. P-values are in the parentheses.

As explained in the previous section, the first step of the estimation is to test for the cointegration. In this estimation sample, no evidence for the cointegration has been found at the usual level of significance. Therefore the main attention is paid to the Granger causality tests. The results for the aggregate levels are summarized in Table 4 ($E \rightarrow GDP$ causality) and Table 5 ($GDP \rightarrow E$ causality). The results for the sectoral level are in Table 6 ($E \rightarrow GDP$ causality) and Table 7 ($GDP \rightarrow E$ causality).

The results significantly differ between the original and the new member countries, regardless if we use the non-limited or limited groups of the countries.

For the panel of the countries of the whole European Union, the causality seems to be from the energy consumption to the GDP, but not vice versa (this is similar to the results e.g. in Lee (2005), Lee (2006), Chontanawat et al. (2008), Narayan and Smyth (2008) or Narayan and Popp (2012)). The evidence speaks for the rejection of the neutrality hypothesis in favor of the growth hypothesis. However the causality effect seems to be more prominent in the original member countries.[11] This is in line e.g. with the results of Chontanawat et al. (2008) who found that such a relationship may be observed with a greater proportion in OECD/developed countries than in the non-OECD/developing countries.

However, it should be noted that the original and the new member countries show differences in the sign of the effect of the change in energy consumption.[12] The negative sign of the original member countries (i.e. a similar result as in Narayan and Popp (2012) for G-6 countries) indicates that the policies aiming at the reduction of the energy consumption, such as the 20-20-20 plan, would not hinder economic growth. The negative sign implies they may, in fact, even prove to be beneficial in terms of faster economic growth. Such an observation in these, arguably "more developed/advanced", countries of the European Union probably lies in the higher innovation power in these countries, as opposed to the room for extensive source allocation in the countries where the lower costs of operations may be expected.

The inverse effect can be observed in the new member countries. Along with nearly double energy intensity (see **Error! Reference source not found.**), this indicates the process of dematerialization is still far from that in the new member countries. This is evident from the structure of the economy in the EU-12, with generally higher share of industrial sector contributing to the creation of the value added. Such a negative effect is also found e.g. in Lee (2005), who argues that the possibility of economic growth slowdown due to energy conservation is the case for the developing countries regardless of whether they are transitory or permanent.

Even though not all of the new member countries can be considered "developing countries" by the OECD definition, their characteristics in energy consumption economic output, and necessarily in energy intensity, might be considered much closer to those of "developing" countries than to characteristics of the original EU countries.

Recall the estimation sample ranges back to 1995, i.e. before the enlargement of the EU. The EU-12 countries relied more on attracting the more energy and labor intensive industries in order to increase their growth potential. The possibility of reallocation of the production into these countries may be the differentiating factor

[11] The causality effect is either slightly positive or not-significant in the new member countries, depending on the size of the sample and sectoral consumption.

[12] It is noteworthy to mention that while the Narayan and Smyth (2008) found the positive sign of such a relationship, implying the negative impact of energy consumption reduction in G7 countries, Narayan and Popp (2012) found for the group of G6 countries a negative sign, implying the energy conservation policies would not hamper (or it may even enhance) economic growth.

in the aforementioned energy-economy relationship. One of the major driving force of companies' restructuring was to lower the costs of operation. This goal can be achieved by multiple ways, for instance with innovations of the technology, with the special training programmes aimed at the increasing of the productivity per input factor unit. However, it may be also achieved with relocation to a country with lower input factor costs. This is typically the case for the foreign investments in the emerging markets of "less developed" countries. Such relocation drives the input factor consumption higher. Therefore restricting the input factor availability would cause the hindered economic growth.

If we take a look at the sectoral energy consumption estimations, we can find some major differences contributing to such a behavior. In the original member countries, only the industrial and residential energy consumption seems to be significant in the energy-economy nexus. In the new member countries, apart from these groups, the services are influential. Unlike the industrial sector in the original member countries (negative sign), both the services and industrial energy consumption exhibits positive sign in the new member countries. This means that energy conservation policies would prove beneficial in the original member countries, being not limiting and possibly even beneficial for the economic growth (though it is questionable whether the consumption restriction would induce more innovations). In the new member countries, the story is reversed. Energy conservation policies that will cause reduction in the energy consumption in services or industrial sectors will hinder the economic growth.

Energy consumption in the residential sector exhibits negative sign in both groups. This corresponds to the much less-diversified pattern in the household behavior than the behavior of the firms. It can be expected that the behavior of the firms in services or industries will be more dynamic. The firms are generally more willing to relocate or to change their structure of production. It is also rather easy to affect the residential sector on the EU-wide level. This was already evidenced e.g. by the household appliances design restrictions. Even though such policies inherently limit the consumers' free will and probably limit the consumer's satisfaction, the evidence suggests the energy conservation policies aimed on the residential sector would not hinder economic growth and may even prove beneficial in terms of faster growth.

5. CONCLUSION

The energy conservation policies are one of the main tools to fulfill the supranational agreements in the struggle against the global warming. The energy-economy nexus examines the impacts of these energy conservation policies. In response to the EU 20-20-20, the goal of this paper therefore was to examine the energy-economy nexus in the countries of the European Union. Acknowledging the dichotomous characteristics of the energy consumption between the original and the new member countries, the objective was to find out if the energy conservation will have the same impacts across the different groups of the European Union countries. As recommended by Gross (2012), the estimations are done not only on the aggregate level, but also on the sectoral level. Unlike most of the previous disaggregated studies, the estimation is done in the panel framework and the sign of the causality is also taken into the account.

For the panel of EU countries, the growth hypothesis seems to hold. Therefore the changes in the growth rate of energy consumption Granger cause changes in the economic growth rate. This corresponds well to results that can be found in the literature so far (see Lee (2005), Lee (2006), Chontanawat et al. (2008) and Narayan and Smyth (2008)). Unlike most of the previous studies, this paper pays attention to the sign of the coefficients in the energy-economy nexus. As such, it seems that this established growth hypothesis is quite different for the "more developed countries" of the EU-15 group and the "less developed countries" of the EU-12 group, even on the aggregate level of analysis.

In the "more developed" countries the energy conservation policies do not hinder economic growth and may in fact prove beneficial to faster economic growth. In the "less developed" countries the opposite applies and the energy conservation policies would probably hinder the economic growth. The conclusion for "more developed countries" of the EU-15 seems to correspond rather well to the results of Narayan and Popp (2012), who examined the energy-economy nexus for the G-6 countries. The results for the "less developed countries" are similar to the results of Lee (2005) or Lee (2006), who worked with the samples of the developing countries. Using the disaggregated levels of energy consumption it has been shown that the results differ across the country groups and across the sectors. One solitary exception of this behavior is the residential sector. But not all the sectors are significant in the energy-economy relationship.

The residential sector is significant in both original and new member countries. It also shows the negative sign in both groups. The energy savings in residential sector may be even beneficial.

The other significant areas are the services and industrial sector. Their role in the nexus is however quite different between the groups. In the new member countries, the energy conservation in both services and the industrial sector probably restricts the economic growth.

In the original member countries, the industrial sector is influential, but services are not. Furthermore, the estimated sign of the industrial energy consumption is the opposite to that in new member countries. The energy savings in the EU-15 industrial sector may even increase economic growth.

The disaggregated results indicate the total energy consumption should be applied as an explanatory factor with some caution. Considering the richer results in sectoral division, it seems as a good practice not to focus on the aggregate values (or at least not only) and instead to consider the different behavior of different sectors in both energy consumption analyses and in the energy conservation policy design. As such, the unified energy conservation policies do not seem to be the best recipe for all the countries involved in them.

Even though there may be political will to construct the common goals and objectives, different policy design for each of the groups should probably be considered. Care should be taken especially with the energy conservation policy implementations in the new member countries, especially regarding the influential sectors of services and industry. It is true that the energy intensity is still higher in the new member countries. But if we examine the energy-economy nexus, it will be irresponsible to forcibly reduce the energy consumption. Furthermore, energy conservation plans and regulations should probably be constructed separately for the production areas of the economy and for the residential energy sector.

Even though the evidence for the energy-economy relationship remains mixed in the literature, given the comparison of the results with some of the previous studies, similar patterns can be found. Namely that the energy conservation policies might be a reasonable policy for the developed countries, but not so much for the less developed countries.

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