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THE ENERGY-GROWTH NEXUS: FURTHER EVIDENCE FROM DISAGGREGATE RENEWABLE ENERGY SOURCES

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Dissertation submitted as partial requirement for the conferral of

Master in Economics

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August 2015

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Abstract

The importance of renewable energy sources has grown substantially over the last ten years, mainly because they are seen as an important tool in mitigating climate change problems. Besides the environmental benefits, renewables have also been argued to contribute to economic activity and development. This study explores the relationship between economic growth and disaggregate renewable energy sources (hydropower, biomass, wind, and solar energies) in twenty OECD countries over the period 1993-2012. Applying recently developed panel time series techniques our analysis controls for unobserved heterogeneity and cross-section dependence between countries. The empirical findings suggest that there is no long-run relationship between economic growth and the different types of renewable energy. However, the results of short-run estimation reveal that electricity generation from biomass contributes to economic growth, while wind energy generation might have a negative impact on economic activity. The remaining two renewable energy categories (hydropower and solar energy) don't appear to affect economic growth in the short run. The evidence of no interrelationship between the analyzed renewable energy sources and economic activity might be explained by their relatively low share in total energy production. Overall, our findings show that different renewables have diverse impacts on economic growth, therefore the energy-growth nexus line of research should look deeper at the disaggregated level in future investigations.

Keywords: renewable energy, economic growth, panel time series, cross-sectional dependence.
JEL classification: C33, Q43

Acknowledgements

It is difficult to overstate my gratitude to Professor Henrique Monteiro for patient guidance, inspiration, and advices. I was lucky to have such a supervisor who cared about student's work like it would have been a project carried on his own. I am thankful to Professor Henrique Monteiro for being responsive whenever I had a question about my research or writing.

I would like also to express my gratefulness to Professor Tomasz Zylicz for all support and valuable suggestions, which were highly important for the accomplishment of presented thesis.

Last, but not the least I want to thank my mother for anytime support and encouragement, as well as my friends for their patience throughout the time of working on this research.

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List of abbreviations

ADF: Augmented Dickey-Fuller test

ARDL: Autoregressive distributed lag

BP: British Petroleum

CARICOM: Caribbean Community

CSD: Cross-section dependence

CSP: Concentrated solar power

EEA: European Environmental Agency

EIA: Energy Information Administration

EU: European Union

GDP: Gross domestic product

GHG: Greenhouse gas

GMM: Generalized method of moments

GNP: Gross national product

HDI: Human development index

IEA: International Energy Agency

IHA: International Hydropower Association

IPS: Im, Pesaran and Shin test

IRENA: International Renewable Energy Agency

LCOE: Levelized cost of energy

MG: Mean group

NREL: National Renewable Energy Laboratory

OECD: Organization for Economic Co-operation and Development

OPEC: Organization of the Petroleum Exporting Countries

PMG: Pooled mean group

REN21: Renewable Energy Policy Network for the 21st Century

TFEC: Total final energy consumption

US: United States

VAR: Vector autoregressive

VEC: Vector error correction

UNEP: United Nations Environment Programme

Introduction

Back in 1977 Denis Hayes, a coordinator of the first Earth Day, told that "By the year 2000, renewable energy sources could provide 40 percent of global energy budget..." The main argument behind Hayes's statement was related to the climate change threats, which would afterwards cause carbon emission reduction targets to have a priority role in countries' policies across the world. However, due to the direct link between economic activity and energy use (and so CO2 emission) such policy could reduce economic growth. Given the concerns about the impact of global warming accompanied with fossil energy resources depletion[1] a number of countries focused on the renewable energy sources (hydroelectricity; wind; solar and geothermal power; biomass) as a solution to two problems - pollution reduction and energy supply security.

Nowadays renewables are the fastest growing world energy source (BP 2015). Even though the level of 40% share stated by Hayes hasn't been reached, renewable energy is getting an important place in energy mix worldwide. According to Renewables Global Status Report by 2013 renewables supplied approximately 19.1% of world's final energy consumption (REN21 2015). Over the past decade the share of primary energy consumption from renewable power sources increased from 0.5% to 4.2%[2]. Renewables have already proven to be an effective element of climate change mitigation policy. Despite rising energy use, the level of carbon emission related to energy consumption in 2014 remained stable, which partially had been attributed to the increase renewable energy exploitation (REN21 2015).

Apart from environmental issues renewable energy sources also contribute to employment and energy access. Additionally, due to their relative abundance and possibility to be replenished in a short period of time, these energy sources can significantly improve resilience of countries' energy system and decrease their vulnerability to volatile oil price. Despite the intermittent nature, their economic benefits increase interest in renewables and make them an important development policy element.

With the growing importance of sustainable development and the role of energy in it the question arises on the relationship between renewable energy sources and economic growth. The significance of energy for the process of economic development is well known fact that has been

[1]According to EIA report we have enough oil to last for 25 years (EIA 2014b).
[2] With an exception for biomass, that in 2014 grew to 10% comparatively to 1% in 2004. (REN21, 2015)

proven in a number of empirical studies (Soytas & Sari, 2003; Apergis & Payne, 2009; Ozturk, 2010; Drege et al., 2010). However, the literature related to the renewable energy and economic growth nexus is quit recent (Salim et al., 2014; Apergis & Payne, 2014; Ohler & Fetters, 2014). Even though the conclusions on the nature of dynamics between renewable energy and economic growth are still contentious, researchers have agreed that tapping into renewable energy sources contributes to a country's economy.

Although, most of the studies focused on aggregate energy consumption/production, there is a reason to believe that the relationship between renewables and Gross Domestic Product (GDP) production might be energy type specific. Analyzing the relationship between GDP and several traditional energy sources (mainly coal, natural gas, and electricity) Yang (2000) argues that the use of aggregate energy data doesn't show the extent to which countries depend on different energy sources. We suspect therefore that, conclusions drawn from the analysis based on aggregate energy data may mask diverse impacts of various renewable energy types.

Renewable energy expansion is a crucial element of different policies (environmental, energy, economic). For example, the Renewable Energy Directive (2009/28/EC) requires that renewable energy sources must have a 20% share in the European Union's gross final consumption of energy in 2020 (European Parliament 2009). Therefore, a deep understanding of the way different renewables affect economic growth is called for. Moreover, it is important to note that further renewable energy deployment still requires governmental support. In order to develop the most effective policy instrument that will also suit countries' economic conditions, the relationship between each renewable energy types and economic activity should be identified first.

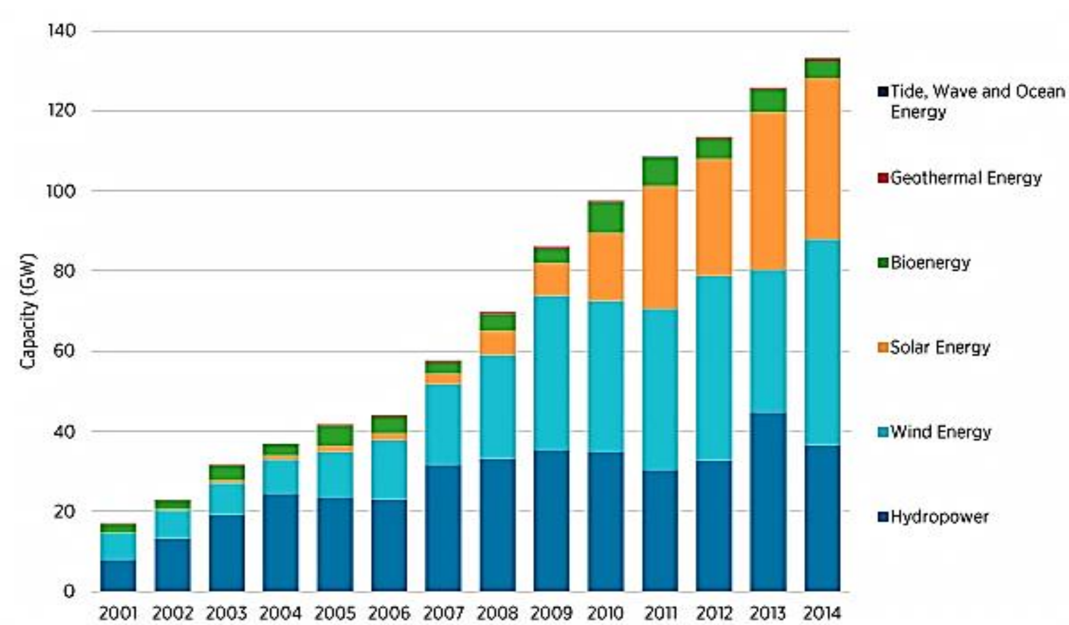
In this study we investigate the long- and short-run linkage between economic growth AND disaggregate renewable energy sources. To our knowledge the majority of previous studies, which consider relationship between GDP and different renewables, are country specific. Ohler & Fetters (2014) is the only study that focused both on a set of countries (from Organization for Economic Co-operation and Development (OECD)) and disaggregates renewable energy sources. We use a more recent sample of OECD countries and apply recently developed panel time series methodological approach that can significantly increase the power of the employed statistical tests. Therefore, this study is aimed to contribute to existing literature on economic growth- energy nexus and provide more insights on relative impact of each renewable energy type on the economy.

The thesis is structured in the following way. Chapter II provides an overview of global renewable energy sector together with a discussion of its latest trends. The main theoretical hypotheses on the economy- energy nexus as well as a literature review are presented in chapter III. Chapter IV and V present a detailed description of the data and methodological techniques used in this study. The results along with their discussion are given in the chapter VI, while chapter VII concludes.

2. Overview of the renewable energy market

Over the last two decades, an increasing usage of renewable energy sources has become a global trend. During 2004-2014 overall growth of primary energy supply from renewables reached 30%. According to REN21 report, by the end of 2013 renewable energy sources provided approximately 19% of the worldwide final energy consumption that was enough to supply approximately 22.8% of global electricity (REN21 2014a). In 2014 renewables accounted for 59% of net additions to global power capacity (REN21 2015). Though the largest share of renewables still belongs to hydro power sources its share in the renewable total went from 93% in 2000 to 64% in 2014. Although installed hydropower production capacity has increased in this period, for other renewables it grew faster, increasing their share. A recent publication by International Renewable Energy Agency (IRENA) reports that in 2014 solar and wind power constituted almost 40% of newly installed capacity worldwide (IRENA 2015b).

Figure 1. Installed renewable energy capacity – net additions.



Source: (IRENA 2015b)

Looking across countries China is not only the country that that produce the largest amount of electricity from renewable energy sources (26% of total installed capacity), but it is also responsible for around 40% of world expansion and 60% of non-OECD countries growth. USA (leading in biomass energy production), Germany (leader in solar photovoltaic (PV) power capacity), Brazil (second and third place in bioenergy and hydro power generation respectively), and Canada (fourth in hydropower capacity installed) follow China in the absolute level of electricity production from renewables.[3] Other countries with a large renewable energy capacity are Norway, Japan, Italy, and Spain. Worth noticing that according to the US Energy Information Agency Iceland electricity supply relies 100% on hydropower and geothermal energy sources, while generating capacity in Norway is over 90% green (EIA 2014a).

One of the main factors that contributes to such an expansion of renewable energy usage is the decreasing cost trend. According to the IRENA cost analysis renewable energy sources are becoming more and more competitive with fossil fuel fired electricity generation sources (IRENA 2015c).

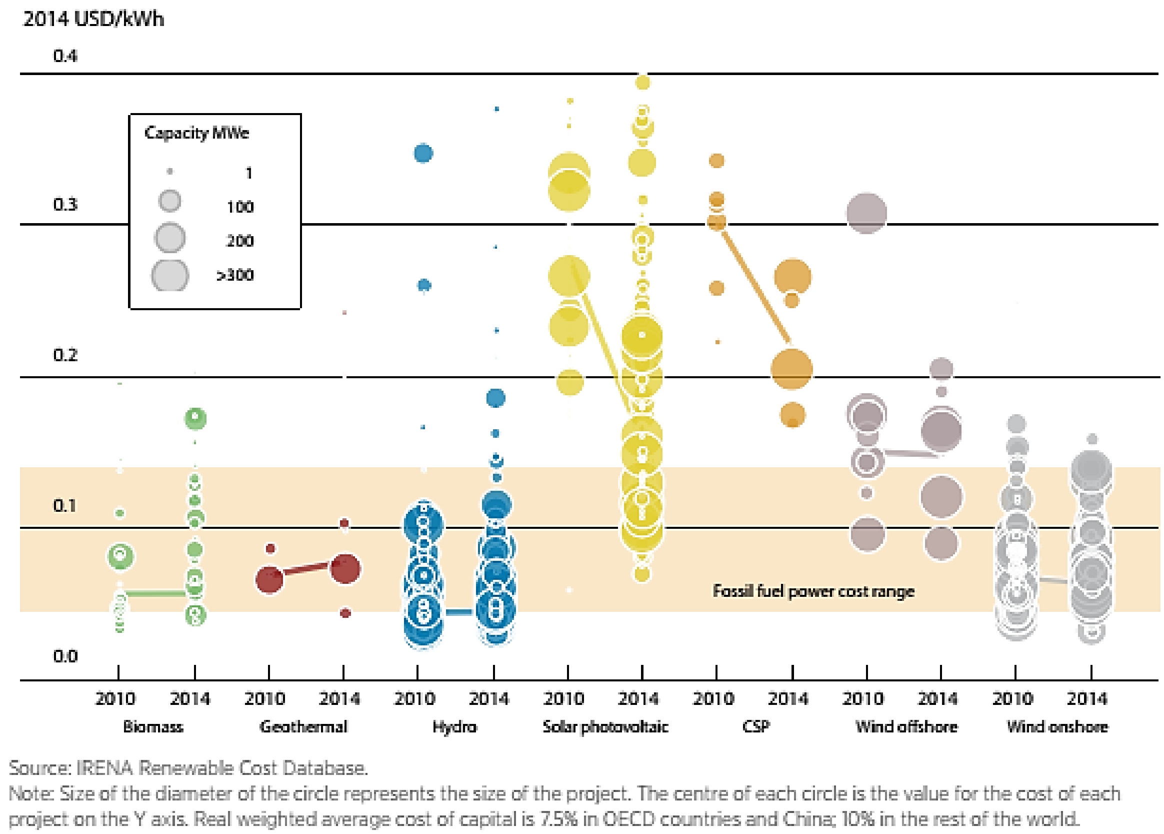
The leader in the electricity cost declining is solar energy. According to estimates provided by IRENA the prices of solar PV module in 2014 were around 75% lower than its level in 2009. While in the end of 2014 costs of energy generated via fossil fuel power plants ranged between USD 0.045 and USD 0.14/kWh, the latest solar PV technologies reached electricity price level of USD 0.08 per kWh. On average, though, the solar power generation costs vary from USD 0.12/kWh in North America to over USD 0.30/kWh in Central America (**Erro! A origem da referência não foi encontrada.**). One of the REN21reports highlights that in 2013, the cost of electricity generated with rooftop solar panels was below retail electricity prices in several countries, including Australia, Brazil, Denmark, Germany, and Italy (REN21 2015). At the same time solar PV is considered to be competitive without subsidies in around 19 markets over several countries in Latin America, Europe, Asia, and some US states.

The costs of onshore wind energy also continue to fall, though slower than for solar technology. Due to the fact that wind technologies are more capital intensive(64% to 84% of total installed costs belong to wind turbines) such trend can be related to rising commodity and raw materials prices (NREL 2012). However, some countries keep decreasing trend in the capital cost of wind energy (over 2008-2010 costs in the US declined by 15%, and by more than 20% in Denmark) (IRENA, 2012b; NREL, 2012). With a base year of 2010 IRENA projects that by 2030 the LCOE

[3] The information provided is based on the IRENA report as on the end of 2014.

from onshore wind power sources will have declined by 9%-22%, while cost reduction for offshore wind technology is expected to be higher – 18%-30% (IRENA 2012b).

Figure 2.The levelized[4] cost of electricity (LCOE) from renewable technologies, 2010-2014



Source: (IRENA 2015c).

The costs of electricity produced from hydropower sources remain the lowest among all renewables. In the regions with abundant economic resources (Brazil, China, India) the average hydropower LCOE is about USD 0.05/kWh. However, for Europe and North America this number is higher – USD 0.09/kWh to USD 0.16/kWh. Regarding small hydropower projects we can see that they are becoming a competitive option for developing countries to trigger small off-grid electrification schemes in rural areas. Another mature renewables power sources – biomass and geothermal - show relatively stable level of energy cost (IRENA 2015c).

Comparing LCEO in the US it is clear that renewables can no longer been considered as a too expensive source of energy. At the same time comparison between renewable and non-

[4] LCOE reflects the per-kilowatt hour cost of building and operating a generating plant over an assumed financial life and duty cycle. Note: LCOE don't include all subsidies and support mechanisms.

renewable energy cost doesn't account for the hidden cost of latter[5]. Naturally, the costs of renewable energy production vary from country to country. But in the areas, where geographical and climate conditions are relatively similar, technological progress might lead to price convergence making renewables to become dominant in countries' energy mix.

Table 1. US average LCOE, 2014

Energy source	Cost, USD/kWh
Coal	0.09-0.14
Natural gas	0.07-0.13
Nuclear	0.10
Wind	0.08-0.20
Solar PV	0.13
Solar thermal	0.24
Hydro	0.09
Geothermal	0.05
Biomass	0.10

Source: (EIA 2015)

A significant growth of the renewable energy market is also driven by government support. As a response to the global warming problem renewable energy emerged as a one of the mechanisms that could eventually reduce greenhouse gas (GHG) emissions without harming economic development. Since the adoption of the Kyoto Protocol (UNFCCC 1998), which established a 10 - years target of GHG emission reduction "…by an average of 5.2% below the 1990 levels by 2008-2012" (World Nuclear Association 2015), both developed and developing countries have given a strong priority to renewable energy deployment. On the early stages, when conventional energy costs were significantly lower than renewable ones, clean energy couldn't be competitive without state support. In the early 2000's 48 countries implemented different policy options (fiscal incentives, public financing) to encourage renewable energy deployment (IRENA 2012a). Supporting clean energy penetration and investment in renewable technologies development had a huge impact on the significant cost reduction discussed before. Such performance and costs

[5] The cost of electricity generated from fossil fuel increases to between USD 0.07 and USD 0.19/kWh if a number of health and environmental factors are taken into consideration. (IRENA, 2014)

improvements paved the way for the adoption of renewable energy support policies in a number of countries. By 2015 the number of countries that promote renewable energy through support schemes in their energy policy is now 148. Since mid-2005, when the majority of countries enacting such policies were OECD - member states (69% of all supporting initiatives), more low- and middle-income countries started to consider renewable energy deployment as an important part of their energy policies. [6] **Erro! A origem da referência não foi encontrada.** presents renewable energy targets for key member states of G-20. Among other regulatory policy tools (feed-in tariffs, net metering/billing, renewable portfolio standards, and quotas) feed-in-tariffs is the second most widely used mechanism to support renewables deployment. REN21 report concludes that "Globally, renewable energy targets and feed-in tariffs policies had have the biggest influence on renewable energy market introduction" (REN21 2014b).

Table 2. Renewable energy sources' targets

Country	Renewable target for electricity share in 2020 (unless specified),%	Share of RE in electricity generation, 2012, %
Australia	About 28 as legislated	15 (as for 2013)
Brazil	Tech-specific targets. No certain energy target set, but it is adjusted to the pollution reduction targets.	82
Canada	Province-level targets (average projected national share: 70)	66
China	Tech-specific targets. 9.5 in final energy production by 2015.	20
France	27	15
Germany	35(2020); 40-45 (2040)	23
India	Double RE capacity from 2012 till 2017	16
South Korea	11 (target RE share in total energy production)[7]	3 in total energy production
Japan	On-going discussions on target for 2030 (expected to be 30)	12
Mexico	35 (2024)	9
UK	31	11
US	Binding targets in 29 states (projected national share: 14)	12

[6] According to (REN21 2014b) emerging economies account for 95 of the countries with support policies, up from 15 in 2005.
[7] Breakdown for capacity in the energy sector is not provided.

EU-28	33	25.4

Source: (IRENA 2014a).

At the same time strategies to facilitate renewable energy progress have been adopted at the regional level. For instance, after the approval of the Arab Renewable Energy Framework by the Arab League in September 2014, the 22 member states[8] joined the European Union (EU) and the Caribbean Community (CARICOM) in developing a regional framework to strengthen renewable energy sector (REN21 2015).

Apart from governmental institutions international organizations also encourage governments to enact regulatory tools that would provide further deployment of clean energy. For example, the UN Secretary General's Sustainable Energy for All initiative (launched in 2012) gives a number of incentives for countries, which have enforced its principles as policy priority, to commit to the growth of renewables.

Significant policy support along with fast technological progress create all necessary conditions for renewable energy sources to become cost - competitive with conventional power. For the global policy landscape renewable energy is not restricted to be only an efficient tool in dealing with environmental problems. Being a technically and economically feasible power solution, renewable energy sources might play a vital role for the countries' economies. There are three main channels through which renewables development might have en economic impact: job creation, energy security/trade balance, and economic growth.

Implementation of long-term renewable energy deployment policies and further clean energy expansion can lead to sustainable job creation for all stages of the renewable energy life cycle (IRENA 2011). In light of the high rate of unemployment in a large amount of countries (especially in EU) the possibility of job creation associated with renewables expansion has been getting the attention of policy makers. Renewables job classification includes direct (employees of renewable energy sector itself), indirect (jobs in supporting industries, such as steel or software), and induced (jobs in all other sectors that benefit from any of the various macroeconomic feedbacks (IRENA 2014b). Evaluating a direct employment effect from wind energy in EU countries, Blanco &

[8] The League of Arab States includes Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, the Palestinian Territories, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, United Arab Emirates, and Yemen.

Rodrigues (2009) argues that wind turbine manufacturers provide a lion's share of the jobs. A comparison of different energy supply sources for US concludes that renewable energy and low carbon sources generate more jobs than the fossil fuel sector per unit of produced energy (Wei et al., 2010). One of the OECD reports also suggested that green energy investment had a considerable influence on employment creation (OECD 2011).

In 2014 the number of renewable energy jobs (excluding large hydropower stations) reached 7.7 million (IRENA 2015a). This level is 18% higher than the one reported for 2013, and up 35% over the last two years. Solar PV sector is estimated to be the biggest employer providing jobs to almost one third of the total number of employees of the renewable energy industry. Biofuels and wind sectors follow solar with an employment level of 1.8 million and 1 million respectively. The employment estimates may rise by 50% to 100% if we consider both indirect and direct jobs (Rutovitz and Harris 2012). Geographically, employment in renewable energy sector is growing across different countries but the bulk of employment is concentrated in major renewable energy producers - US, China, EU (especially Germany), Brazil, and India (REN21 2014a).

It should be noted that energy technologies differ from each other, and so the number of jobs created varies across renewable energy sources (**Erro! A origem da referência não foi encontrada.**). Thus, the strength of labor market expansion depends a lot on the type of renewables that a given region/country exploits the most. Other relevant factors for jobs creation include industrial and labor policies, success of renewables deployment, and the multiplier effect of this process on the rest of economy (IRENA 2011).

Table 3. Employment requirements by technology

Energy source	Construction time, years	Construction and installation, jobs year/MW	Manufacturing, Jobs year/MW	Operation and maintenance, jobs/MW
Hydro	2	6.0	1.5	0.1
Wind offshore	2	2.5	6.1	0.2
Wind onshore	4	7.1	10.7	0.2
Solar PV	1	9.0	11.0	0.2
Solar thermal	2	5.3	4.0	0.4
Ocean	2	9.0	1.0	0.3

Biomass	2	14.0	2.9	1.5
Geothermal		6.8	3.9	0.4

Source: (REN21 2014a)

It is important to mention that the claim on renewables leading to job gains not without its critics. The controversies related to the fact that expansion of employment in renewable energy sector may bring greater loses in other energy systems (the so called crowding out effect). Additionally, the final impact of growing electricity prices may, in turn, lower labor demand in other sectors of economy restraining the number of employees (or cutting off new recruitment) and cutting down households' expenditures. Therefore, care needs to be taken while drawing a general conclusion regarding net impact of renewable energy deployment on the employment level.

Energy security is another factor that drives renewable energy penetration. For countries highly dependent on energy imports, a stable and cost-effective power supply is crucial for their economies. For example, more than half of EU final energy consumption came from imported sources (Eurostat 2014). Moreover, economic progress, growing population and rising energy demand have raised doubts that conventional energy sources would be enough to satisfy worldwide energy needs since the publication of Meadows ey al. (1972). For instance Saudi Arabia that accounts for 22.1% of OPEC oil reserves[9] "…could become a net importer of oil by 2038 if domestic consumption continued to increase in the same rate" (REN21 2014a). All threats related to energy import (oil price volatility, political instability, economic crisis) highlight an advantage of renewables being a viable solution to decrease energy insecurity risk. In one of the reports IRENA claimed that including different renewable energy sources into countries' energy portfolio and establishing decentralized energy system could improve energy security (Ölz et al., 2007). Being endogenous (without considering its dependence on weather conditions) renewables might provide long - term alternatives that will tackle energy security.

Even though renewables are argued to be an important component of energy security, it is quite difficult to quantify the impact of renewable energy deployment on it. Another parameter that is related to energy security and may quantify the renewable energy gains is trade balance. In this context two elements should be considered: energy products trade (i.e. fossil fuels), and trade in goods and services related to renewables (equipment, consulting services, patents).

[9] In the end of 2014, OPEC share in world crude oil reserves was 81% (OPEC 2015).

According to IRENA, globally USD 2 trillion was spent on net imports of fossil fuels in 2011, "...of which more than USD 230 billion was spent in China (about 3% of Chinese GDP) and USD 120 billion in India (nearly 7% of GDP)" (IRENA 2015d). At the same time the majority of EU member states are net oil and/or gas importers. While 60% of EU total gas and 80% EU total oil consumption is purchased abroad (Maestroni 2015). Substituting fossil fuel for renewable energy improve the trade balance by decreasing import leading to considerable savings. According to the EU Commission report the avoided imported fuel cost in electricity generation amounted to EUR 10.2 billion for EU-27 in 2010 (European Commission 2014). While the estimations for the following years are not available yet, it is expected that the level of savings on fossil fuel cost will exhibit a positive trend. In turn, in fuel-exporting countries renewables can partially fulfill domestic energy demand that will increase the amount available for export. According to estimation presented by Ferroukhi et al. (2013) during 2012-2030 around 3.9 billion barrels of oil equivalent could be saved thanks to renewable energy targets. This may yield a benefit of approximately USD 200 billion.

However, in the short - run renewable energy sources don't always affect the trade balance in a positive way. The development of renewables requires significant capital installation that most of the time is imported from other countries in case there is no domestic production of it. In such case the benefits from renewable energy generation might be outweighed by the cost of equipment, which finally could lead to increasing cost of import and affect trade balance negatively. Countries that specialized in the production of such equipment/technology may have large trade balance gains. For example, US-China solar technologies trade channel is worth approximately USD 6.5 billion (REN21 2014b). "More than US$ 923 million worth of wind energy goods and services were exchanged between the two countries in 2011". Denmark also exports renewable energy supply products, namely wind turbines (UNEP 2013). Therefore, summing all up we can expect that in the long run the impact of renewable energy on trade balance will be positive.

Since the beginning of 21st century, the share of different renewable energy sources in the global energy mix has increased considerably. In the beginning the main drivers of renewables encouragement were their potential in dealing with emission reduction targets. However, thanks to the fast technological progress and considerable governmental support renewables are starting to become competitive with conventional power sources. Positive economic impacts that contribute to countries' development are important co-benefits that make renewable energy sources attractive not only from the environmental perspective.

Despite all these advantages it has been argued a lot that such fast success would be impossible without significant policy support. It is true that on average the costs of renewable are still higher than those for fossil fuels, so their ability to compete in the market still relies on subsidies. Pursuing the aim of renewable energy cost reduction and attracting necessary investment flows, authorities spent significant funds to facilitate renewables deployment. Examining energy subsidies, Ecofys reports that for the period 1990-2007 "...cumulative interventions in EU totaled to about €70-150 billion, with Sweden, Germany, the UK and Denmark having the highest levels of public support (Ecofys 2014). In 2012 this amount reached €40 billion. Achieving the trends projected in countries' policy scenarios would require global renewables subsidies to cumulatively rise to around USD 240 billion in 2035 (IEA, 2012).

In a number of countries renewables deployment programs went over - budget. As a result governments are struggling to keep paying for clean energy generation. Renewables (especially solar energy) has been claimed to be a reason for the jump in the electricity price, and indeed being supported via increased households' electricity bills. The review of energy prices in Australia found that green energy schemes caused 1.3% increase in electricity price (IPART 2013). Across Europe the highest electricity price is in Germany, Spain, and Denmark, with a significant share of tax included (Böttcher 2015). Overspending on renewables has become a hot issue in recent political debates. British, and Australian authorities have already announced new policy direction to decrease renewable energy support. However, accounting for the differences in estimation methodologies, hidden cost of fossil fuels, and number of other factors, it still remains unclear whether increase of electricity bills caused by renewables really harm households' budget (Maxwell and Scholar 2015).

From the discussion above we can see that renewable energy has already become an important component of world economic and energy future. At the current stage of renewable market development it is crucial to get an understanding of all its positives and negative aspects. A deeper knowledge on the link between and economic activity will help to improve energy policy design and implementation.

3. Energy-growth hypotheses and literature review

One of the main theory of economic growth developed by Solow (1956) considers capital and labor as primary factors of production, while ignoring or giving intermediate role to other production inputs such as energy (Acemoglu 2008). From this point of view energy use has a silent role for the economic development. The later economic approaches don't declaim the importance of natural resources in economic development (Stiglitz 1974). However, the main attention was given to physical and human capital. At the same time Stern (2004) provides detailed analysis of key factors that cause and affect the linkage between energy use and economic activity insisting that energy is a significant production input.

Despite the fact that above mentioned economic theories defines energy as a secondary factor of production, the relationship between energy consumption and economic growth has been discussed since the late 80th. The first empirical work on the energy growth nexus was presented by Kraft & Kraft (1978). Although empirical results haven't agreed on a single conclusion about the nature of this relationship, the literature can be grouped into four hypotheses (Apergis & Payne, 2009).

The *neutrality hypothesis* implies that there is no causal relationship between energy consumption/production and economic growth. In this case energy conservation policies will have very little or no impact on economic activity.

The results which define causal linkage running from economic growth to the energy variable, provide support to the *conservation hypothesis*. In line with neutrality hypothesis, any changes in energy use will have no impact on the economy, and so conservation energy policy won't harm economic growth.

The *growth hypothesis* claims that energy use influences the economy, and so considers it to be one of the factors that contribute to economic growth. In this case, any policy decisions related to changes in energy use may have a destructive impact on the economy. However, it should be noted that energy consumption may negatively affect economic growth. It might have place in the countries, which are moving towards less energy intensive production or caused by relatively low productivity level in energy intensive sectors of the economy.

The *feedback hypothesis* is supported, when both economic growth and energy affect each other. Such bidirectional causality implies interdependence between these variables. Thus, any changes in energy use will have an impact on economy, as well as a higher/lower level of economic growth will influence the amount of energy consumption/production.

The literature survey by Payne (2010) discussed the empirical results of more than a hundred studies on the causal relationship between energy consumption and economic growth alone. Ozturk (2010) summarizes the main conclusions from the studies focusing on either energy consumption–economic growth or electricity consumption–economic growth causality nexus. Moreover, Stern et al. (2013) conducted a meta-analysis to test whether energy-growth field of research possessed actual genuine effects or just misspecification and publication selection biases. The main conclusion from these analyses is that there is no "…clear consensus on the relationship between energy consumption and growth" (Payne 2010). The presence of conflicting results can be attributed to the heterogeneity in countries' conditions, varying energy consumption patterns, stages of economic development within a country, the alternative econometric methodologies employed along with the varying time horizons of the studies conducted (Payne 2010). Therefore, due to the differences in the research questions, most of the studies can be subdivide into several research dimensions.

The first studies were focused on the nature of the relationship between economic growth and energy consumption. The first paper in this field was Kraft & Kraft (1978), who analyzed the relationship between Gross National Product (GNP) and energy consumption over the period 1947-1974 for the US. The evidence of unidirectional causal relationship running from GNP to energy consumption showed that energy conservation policies should not harm economic activities. Not long after an analysis of the employment - energy relationship in the US for the period of 1950-1970 pointed out that the support of the conservation hypothesis obtained by Kraft & Kraft (1978) was spurious by changing the time period by 2 years (Akarca and Long 1980). Authors also found that the relationship between energy consumption and employment became significant only if the contemporaneous terms were considered. A study by Stern (1993) argued that the analytical tools used in previous studies were not comprehensive enough to look into the energy-growth relationship. Applying a multivariate Vector Autoregressive (VAR) model that included GDP, capital, labor and quality weighted final energy use index, he found that energy Granger - caused GDP.

Sari and Soytas (2003, 2006) are more recent studies conducted for the G-7 countries but from different perspectives. The first paper was aimed on the investigation of causality relation between GDP and energy consumption and also included top emerging economies. The obtained results demonstrated that the character of the energy- growth relationship differed across countries. While four countries presented evidence of growth hypothesis, nine other economies had no connection with energy consumption, and only for Argentina bi-directional causality was discovered (Soytas and Sari 2003). The other paper was focused on the level of income as an indicator of economic growth (Soytas and Sari 2006). Even though the results obtained were mixed, all analyzed states demonstrated the existence of the income –energy consumption relationship.

Taking into account the possibility of structural breaks in the time series Lee & Chang (2007) applied bivariate VAR technique for the sample of forty countries. Authors stressed that in developed countries causality between energy consumption and GDP was bidirectional, while in case of developing countries energy was a variable affected by economic growth. Along with this conclusions Chontanawat et al. (2006) revealed that causality from aggregate energy consumption to GDP was more prevalent in the developed than in the developing countries. Their paper analyzed 30 OECD and 78 non-OECD countries adopting the Human Developing Index (HDI) to distinguish between countries' development levels. Authors also argued that only very poor nations exhibited weak causality running from GDP to energy. The possible explanation could be in a large dependence of these economies on the agriculture sector and so less energy uses.

The analysis of ten Asian countries brought up with mixed results (Chen et al., 2007). While single country estimations presented no evidence for the existence of long-run causality between real GDP and electricity consumption, the results for the panel showed a bi-directional long-run causality and a uni-directional short-run causality running from economic growth to electricity in all considered countries. The energy-growth nexus in African countries was investigated by Wolde-Rufael (2006), who implemented a panel cointegration test and concluded that twelve out of seventeen countries showed a causal relationship between electricity consumption per capita and real GDP per capita, from which three supported the growth hypothesis. However, it is stressed that the small share of electricity in total energy consumption in Africa might lead to spurious results. Applying the same techniques Apergis & Payne (2009) examined the relationship between energy consumption and economic growth for six Central American countries. The causality test results indicated the presence of both short-run and long-run causality from energy consumption to economic growth in the whole sample, which supported the growth hypothesis.

The majority of the reviewed studies focused on the causal relationship between energy consumption and economic growth using aggregate energy consumption data. However, due to the use of aggregate energy the results may veil the specific impact of various energy types (Payne 2010). Therefore, a second line of research analyzes the relationship between disaggregate energy consumption and economic growth.

Yang (2000) was the first who brought an attention on the disaggregate energy issues. He argued that countries might depend on different energy resources and, therefore, it was impossible to identify the impact of a specific energy type using aggregate data. Considering the energy–GDP relationship in Taiwan Yang (2000) found bidirectional causality between aggregate energy consumption and economic activity. However, when looking on the each energy source separately the causality direction was ambiguous. The same feedback hypothesis was supported for the GDP-electricity and GDP-coal pairs. But in case of GDP-oil relationship causality ran from GDP to oil consumption, while natural gas-GPD link exhibited unidirectional causality running from the gas consumption to GDP.

Sari & Soytas (2004) applied variance decomposition analysis to examine to which extent the variance of income growth in Turkey can be explained by changes in the amount of energy generated from different sources. Authors concluded that alternative energy was almost as important as employment for Turkey. Along with Yang (2000) their results showed that different sources of energy consumption effected economy in a different way. Applying the same methods for the monthly data Ewing et al. (2007) focused on the case of US. Even though some energy sources had impact on variation of GDP (among which coal and gas exhibited the highest explanatory power) employment appeared to be the most important factor affecting the economic growth in the US.

However, analysis of the US sectoral energy consumption data presented by Bowden and Payne (2010) reveal mixed results. Employing Toda-Yamamoto long-run causality tests over the period 1949–2006 their results support neutrality hypothesis for the renewable energy consumption in the commercial and industrial sectors. On the other hand, authors define a positive unidirectional Granger-causality from residential energy consumption to GDP.

The presence of interdependence between economy and energy consumption was also confirmed by Tugcu C. (2013). This study used total factor productivity growth as a measure of economic development of Turkey over 1970- 2011 period. The results of auto regressive distributive lag (ARDL) model showed that an increase in the share of nuclear and fossil energy consumption in total energy consumption decreased the growth of total factor productivity, whereas an increase in the share of renewable energy consumption in total energy consumption raised the total factor productivity growth (Tugcu C., 2013).

Another country specific study evaluated relationship between energy (renewable and nonrenewable) consumption and economic growth in Pakistan for the period of 1972-2011 (Qasim, Ahmer, Khalid Ahmed 2012). Accounting for structural breaks authors proceeded ARDL and Vector error correction (VEC) tests. The results indicated that both renewable and nonrenewable energy consumption enhances economic growth.

In a series of studies Apergis and Payne (2011, 2012a, 2012b) looked into the causal relationship between disaggregated energy consumption and economic growth for many groups of countries ranging from developed to developing countries. The authors used various cointegration techniques and causality approaches within a panel data framework. In case of Central American countries bidirectional causality was found between both renewable (in the long run) and nonrenewable energy (both in the short- and the long-run) consumption and growth (Apergis & Payne, 2012a). Slightly different results were presented in their encompassing paper that covered data on 80 countries(Apergis & Payne, 2012b). The evidence of bidirectional causality between renewable and non-renewable energy consumption and economic growth in both the short- and long-run suggested that both types of energy sources are important for economic growth. Contrary to their preceding results the study focused on the developing market economies and concluded that in the short run causality was running from economic growth to renewable electricity consumption; while bidirectional causality had been obtained, in both short-run and long-run, between non-renewable electricity consumption and economic growth (Apergis & Payne, 2011).

A broad research conducted by Tiwari (2011) analyzed the relationship between renewable energy consumption, nonrenewable energy consumption, economic growth and CO_2 emissions for the case of Europe and Eurasian countries covering the period 1965-2009. Employing panel VAR technique author concluded that each of the energy types contributed differently in the dynamics of GDP. The main findings demonstrated that non-renewable energy consumption had a negative impact on the GDP, but the response of the economic growth to renewable energy consumption was positive confirming the growth hypothesis.

The influence of the different energy consumption categories on economic activity was also examined by Ucan et al. (2014), using data from fifteen EU countries within multivariate framework. The results from a panel cointegration test confirmed the findings of Tiwari (2011). Although an increase in renewable energy consumption resulted in real GDP growth, total non-renewable energy consumption had a negative impact on economic activity. However, disaggregated energy data demonstrated that the nature of the impact varied. While solid fuels (like coal) remained harmful for the economy, petroleum had a positive impact on real GDP.

Tugcu et al. (2012) examines the relationship between renewable and non-renewable energy consumption and economic growth in G-7 countries for 1980–2009 period. The results of ARDL approach concluded that in case of augmented production function, which appeared to be more effective on explaining energy-growth relationship, renewable energy consumption caused the economic growth only in three countries (bidirectional causality in England and Japan, and support for the conservation hypothesis in Germany). Based on the long-run estimators author stated that "…either renewable or non-renewable energy consumption matters for economic growth" (Tugcu et al. 2012).

Increasing concerns over the climate changes made the worldwide community consider the use of other nonconventional sources. Since the renewable energy generation is characterized by significantly lower GHG emission than the conventional one, the third line of research is focused on the economic and environmental benefits of renewable energy consumption.

It should be noted that some of the previously mentioned studies referred some of their conclusions to the role of renewable energy sources if the economy (Apergis & Payne, 2012; Apergis & Payne, 2011; Apergis et al., 2010; Apergis et al., 2010; Sari et al., 2008; Bowden & Payne, 2010; Tiwari, 2011; C. T. Tugcu et al., 2012; C. Tugcu, 2013). The examination of the different energy consumption categories for Turkey showed that waste energy consumption explains 17.3% of the forecast error variation in real GDP; hydropower consumption 10.6%; and wood consumption roughly 3.5% (Sari and Soytas 2004). While the investigation of US economy concluded that over a 25-month horizon hydroelectric power explains 1.9% of the forecast error variance for industrial production; solar 3.8%; waste 10.6%; wood 6.0% and wind energy consumption -5.8 % (Ewing et al. 2007).

Sadorsky (2009b) provided a support for the conservation hypothesis. The analysis for the G7 countries was carried through a multivariate model, including renewable energy consumption, real GDP, CO2 emissions, and oil prices (Sadorsky 2009b). The same author in a different study employed panel cointegration techniques and VEC model to look into the renewable energy-income relationship of 18 emerging economies (Sadorsky 2009a). The findings from both of the studies showed that the higher an economy grows, the more renewable energy sources are consumed. However, there was not a bidirectional feedback between the variables analyzed.

Applying the same methodology Apergis & Payne (2010) examined the causal relationship between renewable energy consumption and economic growth for a panel of 20 OCDE countries over the period 1985-2005. The authors found a long-run equilibrium relationship between real GDP and renewable energy. Results also revealed that renewable energy sources affected GDP indirectly - through capital formation channel. Furthermore, the Granger causality test indicated bidirectional causality between the two variables in both, short- and long-run. Similar conclusions were provided by Inglesi-Lotz (2013). The analysis was extended to thirty OECD countries within the multivariate framework based on Cobb-Douglas production function. The panel cointegration estimators confirmed the long-run equilibrium relationship between real GDP per capita and renewable energy consumption. The results indicated that a 1% increase of renewable energy consumption will increase GDP by 0.022% and GDP per capita by 0.033% (Inglesi-Lotz 2013).

An analysis of 27 European countries for the period 1997-2007 by Menegaki (2011) did not find either short- or long-run Granger causality from renewable energy consumption to economic growth. Additional variables included in his multivariate panel framework were greenhouse gas emissions and employment. According to the results of a random effects model the increase of greenhouse gas emissions had a larger positive effect on GDP than consumption of renewable energy. The minor role of renewables author could explain by the high cost of renewable energy investments which made them less competitive (Menegaki 2011).

Based on the multivariate model Sebri & Ben-Salha (2014) focused on the role of renewable energy in the BRICS countries. The empirical evidence from ARDL and VEC models indicated bidirectional causality between renewable energy consumption and growth. The authors stressed the growing role of renewable energy in stimulating economic growth as well as in dealing with environmental issues that were one of the bases for energy policy decisions.

The study presented by Silva et al. (2011) analyzed the causal relationship between GDP, CO2 emissions, and electricity generation from renewable energy sources in four countries (Denmark, Portugal, Spain, and US) during the period of 1960-2004. Authors argued that the increasing share of the electricity produced from the renewables might initially harm economic growth (except of USA). However, the uses of renewable energy sources might contribute to the CO_2 emission reduction.

Interesting aspect on the relationship between economy and renewable energy was presented by Kazar & Kazar (2014). Instead of economic growth this study measured the development by HDI. In order to determine whether the direction of causality changes between different development levels the sample of 154 countries was divided into 5 country groups each of which was separately analyzed. Their results showed that in the long run economic development increased the level of renewable energy production, while in the short- run these variables were interrelated. Moreover, the nature of this relationship varied across countries with different levels of HDI.

Although literature on the energy–growth nexus is very rich, it is difficult to draw a final conclusion that would describe the nature of the relationship between energy and economic development. The results from the papers reviewed differ from country to country and over time. Additionally, the causality between energy consumption and economic growth may be sensitive to the choice of the methodology used for the empirical analysis (ARDL, panel cointegration, variance decomposition, Toda-Yamamoto, panel random effect model, panel error correction model) (Payne 2010). However, the majority of the existing studies confirm the causal relationship between different energy variables and economic growth showing that energy is, in fact, an important determinant of economic growth.

It has also been shown that the use of aggregate energy data leads to the discrepancies in the empirical findings. The extent to which different countries depend on various energy sources is not the same (Yang, 2000). That is why focusing on purely aggregate data might be unable to identify the impact of a specific energy type on economy (Sari et al. 2008). So far comparatively little attention has been placed on the different types of renewable energy and its impact on economic activity. To our knowledge there is only one study that is focused on causal relationship between economic growth and energy generated from different renewable energy sources. Analyzing a set of OECD member countries Ohler & Fetters (2014) find out that the way different renewables affect GDP varies from one energy type to the other. They find that while biomass and waste energy production appear to have a negative impact on economic growth, hydroelectricity and wind energy might contribute to economic growth. However, the results obtained seem to be sensitive to the methodology applied in the study. All this demonstrates the complexity of the relationship between economic growth and renewables. Our study differs from Ohler & Fetters (2014) by changing intuition behind methodological approach (mainly account for cointegration test size properties, and interrelationship between countries) which has been shown to affect final results significantly. We also focus on OECD member countries but our sample includes a different set of countries. Additionally, the time span considered is not the same as Ohler and Fitters (2014). Moreover, due to the small number of countries that use geothermal energy sources our analysis is focused on hydro, wind, biowaste, and solar energy sources. Therefore, by disaggregating the impact of renewable energy sources we seek to contribute to the existing empirical literature on the renewables-growth nexus. Additionally, using new panel data methods we attempt to deal with issues that may cause misleading conclusions, but haven't been taken into account in the previous studies. All these would enable us to look deeper into the behavior of the renewables-economic growth link.

4. Data and methodology

a) Data description

This study examines the relationship between disaggregate renewable energy production and GDP for a set of OECD countries. The main of the earlier studies on this topic applied bivariate framework. However, due to the problem of omitted variables, such an approach leads to wrong conclusions about causal inference (Lütkepohl 1982). Despite this drawback, researches should be cautious with adding random variables that don't rely on a sound theoretical background. Thus, following several energy studies that consider a multivariate setting we apply a Cobb-Douglas production framework including energy (electricity) as one of the inputs. We assume that the production function has the following functional form:

$$Y_{i,t} = A_i K_{i,t}^{\alpha} L_{i,t}^{\beta} N_{i,t}^{\gamma 1} \prod_{j} R_{i,j,t}^{\gamma^2} \tag{1}$$

where $Y_{i,t}$ stands for county i's aggregate output at a certain t, $K_{i,t}$ is country's stock of capital, $L_{i,t}$ is - labor force, $N_{i,t}$ denotes the input of conventional energy, while $R_{i,j,t}$ – stand for the input of each of the j renewable energy sources considered, A_i stands for i's country technological progress.

To reduce heteroskedasticity in residuals and avoid possible problem of not normal distribution all variables are transformed into the logarithmic form (Acemoglu 2008). Thus, final model looks the following way:

$$lnY_{i,t} = a_i + \alpha lnK_{i,t} + \beta lnL_{i,t} + \gamma_1 lnN_{i,t} + \gamma_2 lnR_{i,t} \tag{2}$$

where $a_i = \ln(A_i)$. Coefficients α and β measure the elasticity of output with respect to capital and labor, while $\gamma_1$and $\gamma_j$define, respectively, the elasticity of total output with respect to conventional (non-renewable) energy sources and each of the renewable ones. The model presented includes a time dimension denoted by t $(t = 1,2, \dots, T)$, and cross sectional dimension denoted by i $(i = 1,2, \dots, I)$. This shows that our approach compute both time series and panel data characteristics.

Our study includes twenty out of a total thirty four OECD member states over the 1993-2012 period. These countries are Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, Portugal, United Kingdom, United States of America, Japan, South Korea, and Mexico. Because this research aims to answer the question whether renewable energy types have different impacts on economic, and if they influence country in the same way, we decided to consider those countries. In many countries the usage of renewable energy sources was negligible or even zero. According to OECD statistics (http://stats.oecd.org/) countries such as Chile, Israel, Slovak Republic, Turkey, for example, have started using wind energy only around the turn of the century. Slovenia still produced no wind power by 2012. The exploitation of solar energy is even less common. Along with above mentioned countries New Zealand, Estonia, and Iceland don't generate energy from the sun. Hungary, Ireland and Poland started doing it only recently providing no more than four or five nonzero data points. This leads to the problem of excess zeroes. Moreover, for robust estimation with panel time series data the variables should have temporal variation, otherwise, the estimated coefficients might be incorrect and lead to wrong conclusions.

At the same time it should be noted that the methodological procedure, which has been widely used for the analysis of the energy-growth nexus and is the most appropriate for our study, is based on the averaging (or weighted averaging) of the estimated coefficients that are used for a further test statistic computation. Such a procedure is sensitive to the presence of outliers as they can significantly change the computed average (Ciarlone 2011). Another important assumption that is crucial for econometric approaches based on pooling data is restriction on some parameters to be the same across panel (for instance, pooled mean group estimator by Shin, Pesaran, & Smith (1999). Consideration of the countries that don't have certain energy type in their energy portfolio may lead to the so called nonresponse problem, when there is no information required for the analysis available (Baltagi 2005). Therefore, pooling such countries in one sample may cause misleading conclusions.

In order to investigate the relationship between renewable energy sources and economic growth the following variables are considered under our production function framework :

- Gross domestic product (GDP) measured in constant 2010 million US dollars. In the frame of this study this variable is applied in its natural logarithmic form and so can be treated as a proxy of economic growth. The data was obtained from the OECD statistics.
- Capital reflects the level of gross fixed capital formation. Although, production function includes data on capital stock there is no available statistics. However, according to perpetual method if the rate of depreciation is constant then the capital flows can be

approximated by changes in investments (Sari et al., 2008; Soytas & Sari, 2006). The data for gross fixed capital formation expressed in constant 2010 million US dollars was calculated by authors on the basis of GDP level (obtained from OECD statistics) and the value of the share of gross fixed capital formation of country's GDP (provided by World Bank Development Indicators).

- Labor force presents the amount of economically active population according to the ILO definition, and expressed in thousands of people. The data on this variable was obtained from OECD statistics.
- Conventional stands for the level of non-renewable electricity generation. It was calculated as a sum of electricity generated from fossil fuels and nuclear energy sources.
- Hydro presents the level of net electricity generation from the hydro energy sources.
- Bio waste represents the level of electricity generated from the organic non-fossil material of biological origin.
- Wind measures the level of electricity produced via wind energy plants.
- Solar reflects the level of net electricity generated from the solar energy sources.

The data for all energy variables is measured in million kilowatt hours and obtained from the US Energy Information Administration.

It is important to mention that for all energy variables included in our model we use statistical information on electricity generation from corresponding energy source. The reason is that energy from renewable sources is used for three main purposes: electricity production, heating, and biofuels. That is why the only available data on energy production from renewables reflects electricity generation. Therefore, in order to make the impact of different energy sources on the economy comparable between each other, this study considers energy from the point of view of electricity production (for both, renewable and non-renewable energy sources). Moreover, according to IEA (2014b) electricity is the fastest growing form of energy with an increasing share in total energy production. Therefore, following Apergis & Payne, (2009); Apergis & Payne (2010); Soytas & Sari (2003); Apergis et al. (2010); Apergis & Payne (2014); Sadorsky (2009b) and others we focus our research on electricity generation from different energy sources.

As was shown in equation (2) all variables are transformed into their natural logarithmic form. Consequently, the first differences can be considered as an approximation for the variables' growth rates. The descriptive statistics of the variables are presented in Table 1.

Table 4. Descriptive statistics

Variable	Mean	Standard deviation	Maximum	Minimum	Number of observations
lnGDP	13.56308	1.274914	16.55884	10.56767	400
lncapital	12.14371	1.287468	15.05286	8.535115	400
lnLabor	9.302410	1.390979	11.97456	5.604389	400
lnconventional	4.179229 11.08698	1.589589	8.242634 15.15039	-1.650260 5.257496	400
lnhydro	2.635749 9.543504	2.442827	5.931465 12.83922	-4.074542 2.442827	400
lnbiowaste	1.193522 8.101278	1.584170	4.268427 11.17618	-11.51293 -4.60517	400
lnwind	-1.041993 5.865762	3.100313 3.1000313	4.947497 11.85525	-11.53273 -4.60517	400
lnsolar	-3.704745 3.20301	2.581422	3.272606 10.188036	-9.210340 -2.302585	400

The graphical representation of variables that are in our main focus is shown in the Figure A3, Figure A4, Figure A**5**,

Figure A6,

Figure A7 in the Appendix A. From the individual plots of logarithm of real GDP that are presented on the Figure1 we see that all countries exhibit an upward trend. Most of the countries have a drop in real GDP level that is a result of the financial crisis of 2008.

Figure A4 shows the logarithm of hydropower generation. The behavior of the variable varies from country to country, which is natural given the dependence of surface river flows on each countries climate and particular weather in a given year. At the same time it is difficult to distinguish any upward or downward trend. Figure A**5** and

Figure A6 present the dynamics of biowaste and wind energy usage respectively. We can see that both of the energy sources exhibit upward trends, though the slope that corresponds to biowaste energy varies across countries more. In Norway, Finland, and Mexico, the logarithm of electricity generation from biowaste is characterized by comparatively higher variation than in other states. From

Figure A7 we can say that period before 2000 (for some countries 2004) was a challenging one for solar energy sources as many countries experienced almost no changes in exploiting solar power. However, after the cost of solar energy started to decrease we see an upward trend in the level of electricity generation from this energy source.

b) Methodology

This chapter describes the econometric techniques that have been applied to investigate the relationship between different types of renewable energy sources and economic growth.

The presented study focuses on the energy - growth nexus in a group of countries over a relatively short period of time (1993-2012).We consider panel time series data methods to be the most appropriate for that task and hand. Comparatively to individual country time-series estimation, the panel data approach provides an improvement by including information on the cross-sectional dimension and improving efficiency of the tests by eliminating the problem of low degrees of freedom. Especially when time series are short, such techniques as unit root or cointegration tests are proved to have low statistical power[10] (Choi, 2001; Campbell & Perron, 1991). Panel estimators rely on the fact that in case of similarities or connections between the data generating processes across groups, combining the data can improve the efficiency of the parameters estimation. For instance, Pedroni (2001,1999,2004) shows that the panel approach can significantly improve the power of cointegration tests. More detailed analysis of the panel time series methodology's advantages can be found in Baltagi (1995).

Cross-sectional dependence

One of the major concerns in panel data studies is related to the possibility that individual groups are interdependent. It has been shown that due to the strong inter-economy linkages cross-section dependence (CSD) is likely to be one of the features of macroeconomic data generated processes (Westerlund and Edgerton 2008). In case of CSD, residual based tests might lead to incorrect statistical inference. In particular, Phillips & Sul (2003) show that ignorance of CSD significantly diminishes the efficiency gains from data pooling.

[10] The probability with which a statistical rejects the null hypothesis when it is false.

This study considers twenty countries and so there is a high probability of economic factors in one country to have an impact on the other countries. Moreover, renewable energy and its regulation are in the focus of different international agreements, which may affect energy policies and energy sectors of all participating states. Furthermore, renewable energy deployment highly depends on the sector innovations, whose shocks (a technological progress) will spread out across all countries. Therefore, it is important to test the presence of CSD in our sample.

To verify whether the selected countries exhibit interdependence we use the test statistics proposed by Pesaran (2004b). His approach is based on the individual OLS regressions for each panel member. The author considers the following panel data model:

$$y_{i,t} = \alpha_i + \acute{\beta}_i x_{i,t} + \varepsilon_{i,t} \tag{3}$$

where i presents the cross sectional dimension and t the time dimension. $x_{i,t}$ is a vector of individual-specific and common regressors. The individual intercepts, α_i, and the slope coefficients, β_i, are allowed to vary across panel members. For each cross section, residuals are assumed to be independent and identically distributed, although they might be cross-sectionally correlated.

In the next step these residuals are used to compute the pair-wise cross-section correlation coefficients, which afterwards are averaged across all pairs. In essence this approach sums cross-sectional error correlations to evaluate if they are consistent with the null hypothesis of no CSD between panel members. Under the assumption that the underlying error processes are symmetrically distributed the test statistics is given by:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{i,j}\right) \tag{4}$$

where $\hat{\rho}_{i,j}$ is the sample estimate of the pair-wise correlation of the OLS residuals.

According to the results of Monte Carlo experiments this test performs well in small samples, and has satisfactory power even under a weak degree of cross-section dependence. In addition, it is robust to single or multiple structural breaks and non-stationarity (Pesaran 2004b).

Unit root test

The first step of long-run relationship analysis is testing for the order of cointegration of variables, i.e. to test stationarity against the presence of unit root. Due to the fact that panel data bring a substantial amount of unobserved heterogeneity, which as a result cause the parameters to become cross section specific, the use of the Augmented Dickey-Fuller test or other traditional unit root tests might bring a misleading conclusion (Mátyás and Sevestre 2008). Moreover, due to the strong economic and political linkages between different countries it is important to consider a possibility of cross sectional dependence. Therefore, we carry out two different panel unit root tests that take into account the countries' specific characteristics and allow for different forms of cross sectional dependence.

Im, Pesaran and Shin Test (IPS)

Based on individual Augmented Dickey Fuller regression estimations Im, Pesaran, & Shin (2003) design a procedure that doesn't constraint parameters heterogeneity under the alternative hypothesis. The information obtained from each member regressions is used to perform a panel unit root test, which allows for residual serial correlation, heterogeneity of the dynamics and error variances across groups.

The model is the following:

$$\Delta y = \alpha_i + \delta_i y_{i,t-1} + \varepsilon_{it} , \qquad i = 1,2, \dots , N \qquad t = 1,2, \dots , T \tag{5}$$

The null hypothesis defines each series in the panel as non-stationary, i.e. $H_0: \delta_i = 0$ for all i, against the alternatives $H_1: \delta_i < 0$ for $i = 1,2, \dots N_1$, and $\delta_i = 0$ for $i = N_1 + 1, N_1 + 2, \dots , N$. Thus, the alternative hypothesis allows for some (but not all) of the individual series to have unit roots. We see from δ_i in equation (5555) and so permits its value to vary across the panel members. Thus, instead of pooling the data, IPS uses separate unit root tests for the N cross-section units.

For a fixed time period and lag orders equal to zero for all panel members Im et al. (2003) consider the following average statistics:

$$t\_bar_{N,T} = \frac{1}{N} \sum_{i=1}^{N} t_{i,T} \tag{6}$$

where $t_{i,T}$ is a standard Dickey–Fuller statistic for the ith group.

This test is based on the (augmented) Dickey-Fuller statistics averaged across groups. However, in case of serial correlation, IPS uses the ADF t-statistics for individual series. For such cases it is crucial to identify a proper order of the ADF regression and so include sufficient number of lags. Underestimation will leave certain level of correlation between residuals that will affect the test statistics values.

For cases, when the lag order is higher than zero at least for one of the cross sections, Im et al. (2003)show that a properly standardized $t_{i,T}$ has normal asymptotic distribution. Hence, test statistics for this situation, when one wants to control for possible cross serial correlation, is calculated in the following way:

$$t_{IPS} = \frac{\sqrt{N}(t_{bar} - \frac{1}{N}\sum_{i=1}^{N} E\left[t_{i,T}|\delta_i = 0\right])}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} var\left[t_{i,T}|\delta_i = 0\right]}} \tag{7}$$

From the formula above we see that normalization of test statistics is done via applying simulated values of $E\left[t_{i,T}|\delta_i = 0\right]$ and $var\left[t_{i,T}|\delta_i = 0\right]$ tabulated by the authors for different values of T and for a different number of lags. It should be noted that this test requires the time period to have the same length for all of the panel members. Our sample includes balanced panel data, and so we can freely consider this test for the stationarity analysis.

Monte Carlo simulations reveal that the small sample performance of the IPS test is better than previously developed unit root test that restrict parameters to be the same across panels (Levin et al. (2002) for instance). However, this test relies on the assumption of identically and independently distributed data (cross sectional independence), which might be too restrictive. According to Banerjee et al. (2005) the presence of cross sectional dependence leads to size distortions and poor performance of panel unit root tests.

Pesaran (2007) unit root test

(Pesaran 2007) proposes to augment standard Dickey–Fuller regressions with the cross-section averages of lagged levels and first-differences of the individual series. According to the author this approach allows to control for contemporaneously correlation between panels.

The procedure is built on the analysis of the following dynamic linear panel data model:

$$\Delta y_{i,t} = \alpha_i + \delta_i y_{i,t-1} + \gamma_i f_t + u_{i,t} \tag{8}$$

The last part ($\gamma_i f_t + u_{i,t}$) stands for has the single-factor structure of the error term, where f_t presents an impact of unobserved common factor, which captures cross-sectional dependence in the panel, and $u_{i,t}$ is the individual-specific error.

The null hypothesis is that the series contains unit root, and hence can be expressed as $H_0: \delta_i = 0$ for all i. The alternative hypothesis allow higher level of heterogeneity and states that at least one of the series in the panel is stationary, which can be determined as $H_1: \delta_i < 0, i = 1,2, \dots, N_1, \beta_i = 0,\ i = N_1 + 1, N_1 + 2, \dots, N$.

Under the assumptions, the unobserved common factor, f_t is characterized by stationary process and affects the panel members differently that is determined by individual specific factor γ_i. Individual specific errors assumptions are in line with the previously discussed unit root tests. Mainly, they are independently distributed as across panel groups and across time, have zero mean, variance σ_i^2, and finite fourth-order moment (Pesaran 2007).

The common factor, which causes cross sectional dependence, is proxied by the cross-sectional mean of $y_{i,t}$, and it is equal to $\bar{y}_t = \frac{1}{N}\sum_{j=1}^{N} y_{j,t}$ and its lagged values $\bar{y}_{t-1}$, $\bar{y}_{t-2}$, … Thus, the non-stationarity test is based on the t-ratios from the OLS estimation of the following cross-sectional ADF (CADF) regression:

$$\Delta y_{i,t} = \alpha_i + b_i y_{i,t-1} + c_i \bar{y}_{i,t-1} + d_i \Delta \bar{y}_t + e_{i,t} \qquad (9)$$

Pesaran (2007) suggests running regression (equation (9)) for each member in the panel and collecting t-statistics. Afterwards, these robust for cross sectional dependence t-statistics are used to compute the CADF version of the IPS test (CIPS):

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \qquad (10)$$

It should be noted that the distributions of both CADF and CIPS statistics are nonstandard. However, the author provides critical values calculated through Monte Carlo simulations for different lengths of panel and time period considering options with and without trend or intercept included.

Pesaran (2007) shows that the test procedure performs well and doesn’t suffer from size distortion for both uncorrelated and serially correlated residuals, although in the last case the test size has to be stabilized by augmentation of CADF regression with $\Delta y_{i,t-1}$. Moreover, this test is robust against heteroskedasticity in the unobserved common factor (Hashiguchi & Hamori, 2010).

Despite of all advantages this test has one shortcoming, which is mainly related to the assumption that there is only one common unobserved factor. This requirement is quite restrictive, especially if there is a possibility for panel sections to be affected by several factors simultaneously.

Cointegration test.

The concept of cointegration refers to situations when time series present co-movement over the long run. From the economic point of view, such a behavior provides an evidence of stable long run relationship between the variables. Another feature of cointegration relationship that makes it to be very important for data estimation is its impact on the estimation output. If the presence of cointegration relationship is not taken into account, a problem of spurious regression may occur (Mátyás and Sevestre 2008)**.** Statistically, if each time series is integrated of order one and their linear combination is stationary we can conclude that the variables are cointegrated. Therefore, the analyzed time series “build” a long run equilibrium (cointegrating vector) that determines their behavior and assures that the variables are interdependent.

It is worth to mention that a panel cointegration relationship has a feature that distinguishes it from the original cointegration approach developed by Engle & Granger (1987) and Johansen (1991, 1988). While the initial cointegration approach is focused on the single country case, the presence of long run relationship in a panel framework requires such variables interdependence to hold across all members of the panel. This may restrict research in terms of countries to be included in the sample, as the absence of long run relationship in at least one of the cross-sections may lead to conclusion of no long run relationship for all panel members.

Pedroni (1999) cointegration test

Although pooling data is motivated by its possibility to increase test power, it also involves a substantial sacrifice of permissible heterogeneity in individual time series (Pedroni 2004). The technique proposed by Pedroni (1999) includes several tests that allow heterogeneity of error variance and deterministic trend across panel members. This is a residual based test, and so the first step is to obtain the residuals from the following regression for each of the panel member:

$$y_{i,t} = \alpha_i + \delta_i t + \sum_{m=1}^{M} \beta_{mi} x_{mi,t} + \epsilon_{i,t} \tag{11}$$

where $t = 1, \dots, T$; $i = 1, \dots, N; m = 1, \dots, M$; M is the number of regressors; $\epsilon_{i,t}$ are residuals indicating deviations from the long run equilibrium. Variables y and x are assumed to be integrated of order one. As we can see, the intercept α, time trend δ, and slope coefficients β are permitted to vary across panel individuals.

The null hypothesis states that $\epsilon_{i,t}$ is I(1), i.e. no cointegration relationship. Therefore, the second step is to pool residuals computed on the first stage and test its order by estimating following equations:

$$\epsilon_{i,t} = \rho_i \epsilon_{i,t-1} + u_{i,t} \tag{12}$$

$$\epsilon_{i,t} = \rho_i \epsilon_{i,t-1} + \sum_{j-1}^{p} \gamma_{i,j} \epsilon_{i,t-j} + v_{i,t} \tag{13}$$

Pedroni (1999)conducts seven different statistics to test the null hypothesis of $\rho_i = 1$. Four of them consider homogeneous alternative hypothesis, i.e. $\rho_i = \rho$ and $\rho = 1$, and are called within dimension(panel) test statistics. The rest three test statistics are conducted to test $\rho_i = 1$, and are referred to between dimension(group) statistics. In the latter case the alternative null hypothesis defines a situation where cointegrating vectors are not homogeneous across panel individuals, and so slope coefficients are allowed to vary. In fact, the true slope coefficients are likely to vary across individuals, and so group statistics may provide more reliable results.

The calculation of test statistics is based on the values of long run and simple variance of $u_{i,t}$. The panel statistics are based on pooling the data across the within dimension of the panel, which implies that the test statistics are constructed by summing the numerator and denominator terms separately for the analogous conventional time series statistics (Pedroni 2004). Whereas, the between dimension statistics are constructed by first computing the ratio for conventional time series statistics before to summing over the panel dimension. Through such construction the point estimates can be treated as the mean value for the cointegrating vectors. A detailed description of the computation can be found in Pedroni (1999). After appropriate standardization these seven statistics are normally distributed. Using a number of simulations the author provides the required moments for the standardization. It is important to note that as this method is residual based, it is impossible to test for more than one cointegrating relationship. Due to the fact that second group of test statistics permits cointegration relationship to vary across panels and, thus, is designed for heterogeneous panels, this study is more focused on the results for these test statistics.

Taking CSD into account – Westerlund (2007) cointegration test.

It is important to note that the technique proposed by Pedroni (1999) relies on the assumption of cross-sectional independence. However, if there is a place for CSD then the assumption of residuals independence would be violated resulting in misleading conclusions. As it was noted by Westerlund & Edgerton (2008) testing of the null of no cointegration may "…suffer from low power when the equilibrium errors are highly persistent under the alternative of cointegration."

To assure the robustness of Pedroni cointegration tests results this study also applies panel cointegration test statistics proposed by Westerlund (2007). Two of them stand for group mean statistics that are based on weighted sums of the error coefficients estimated for each of the individuals, whereas panel statistics consider error coefficient estimate for the panel as a whole. Contrary to common factor restriction, which is the underlying assumption of residual- based tests, his approach is based on the weak exogeneity assumption. Each of the tests is designed to test the null of no cointegration by verifying whether the error correction term in a conditional error correction model is statistically insignificant. Therefore, the tests consider the following data generation process:

$$\Delta y_{i,t} = \delta_i d_t + \alpha_i\left(y_{i,t-1} - \beta_i x_{i,t-1}\right) + \sum_{j=1}^{p_i} \alpha_{i,j} \Delta y_{i,t-1} + \sum_{j=-q_i}^{p_i} \gamma_{i,j} \Delta x_{i,t-j} + e_{i,t} \tag{14}$$

Where d_t represents the deterministic component, for which there are three cases. In the first case, $d_t = 0$, so we consider no deterministic term; the second case stands for $d_t = 1$ so the data generation process includes constant; and in third case, $d_t = (1, t)$ so $\Delta y_{i,t}$ is generated with both a constant and a trend. Thus, the null of no cointegration is formulated as $H_0\colon \alpha_i = 0$ for all i. The alternatives reflect two scenarios. The heterogeneous case doesn't require $\alpha_i s$ to be equal, and so $H^g{}_1\colon \alpha_i < 0$ for at least one i (group mean test statistics), while the second case test the null of

$H^p{}_1: \alpha_i = \alpha < 0$ (panel test statistics). The lag order p_i can vary across panels. To normalize t-statistics Westerlund (2007) suggests using the moments provided in the paper. For the normalization of group mean statistics, the author notes that one should be careful with the inclusion of a too large number of lags as it causes too frequent the rejection of the null. The detailed description on test statistics computation can be found in the original paper by Westerlund (2007).

These tests are able to accommodate individual-specific short-run dynamics, including serially correlated error terms, non-strictly exogenous regressors, individual specific intercept and trend terms, and individual-specific slope parameters (Westerlund 2007). In order to account for CSD author proposes to use bootstrap procedure.

We would like to stress that the majority of studies presented in the energy-growth literature rely upon the seven test statistics proposed by Pedroni (1999). The results of Monte Carlo stimulations provide an evidence that in the presence of CSD the test proposed by Westerlund (2007) has better size accuracy and vastly superior power in comparison with the residual-based tests (such as Pedroni (1999)).

Causality analysis

Verification of the cointegration relationship between variables provides us an evidence of their long run interdependence. However, it doesn't give us any information on the nature of this linkage, namely the direction of causality. Therefore, if variables are proved to be cointegrated the causal relationship between them can be examined within Engle & Granger (1987) approach. This method presents error correction model that accounts for the long run relationship. Firstly, the residuals from long run equations, where each of the variables is considered as dependent, are estimated. The lagged value of these residuals reflects the deviation from the long run equilibrium and presents error correction part of this method. Afterwards, the first difference of each variable is expressed as a function of the lagged level of the explanatory variable(s) and error correction term. The lagged component in such models transforms variables in their dynamic form.

There are several most common techniques to estimate dynamic panel data. Dynamic fixed effect estimator restricts all parameters to be the same across all members in panel allowing heterogeneity only for individual specific intercepts. The generalized method of moments (GMM) applies lagged variables as instruments to deal with the endogeneity problem that can arise after considering lagged dependent variable as one of the regressors. However, Pesaran & Smith (1995) point out that the GMM estimator can be consistent only for cases when cross sectional dimension exceeds time dimension. In this study we use pooled mean group estimator (PMG) that accounts for relatively high level of heterogeneity in the panel.

Shin et al. (1999) rely on the fact that it is inconceivable for dynamic specifications to be identical across countries but plausible for long run parameters to be common. Their estimator allows the intercepts, short-run coefficients, and error variances to vary across groups, but constraints the long run coefficients to be the same. PMG includes both the pooling implied by the homogeneity of the long-run coefficients and the averaging across groups used to obtain means of the estimated error-correction coefficients and the other short-run parameters of the model (Shin et al. 1999). Therefore, PMG estimator seems to be a good compromise between estimators that are based on coefficients homogeneity constraint and heterogeneous dynamic approach.

The procedure is based on the estimation of ARDL (p_i, q_i) model:

$$y_{i,t} = \sum_{j=1}^{p} \gamma_{i,j} y_{i,t-j} + \sum_{j=0}^{q} \delta_{i,j} x_{i,t-j} + \mu_i + \varepsilon_{i,t} \tag{15}$$

where $x_{i,t}$ is a set of explanatory variables for each group, μ_i represents the country-specific intercepts, $\gamma_{i,j}$ and $\delta_{i,j}$ reflect short term country-specific coefficients, ε_i is the error term in each cross section. As there is no restriction imposed on the short run coefficients the dynamic specification (i.e. the number of lags considered) is allowed to vary across panel (Shin et al. 1999). In case the variables are proved to be cointegrated this model can be re-parameterized in the following way:

$$\Delta y_{i,t} = \varphi_i\big(y_{i,t-1} - \theta_i x_{i,t}\big) + \sum_{j=1}^{p-1} \gamma_{i,j} \Delta y_{i,t-1} + \sum_{j=0}^{q-1} \delta_{i,t} \Delta x_{i,t-j} + \mu_i + \varepsilon_{i,t} \tag{16}$$

where φ is an error-correcting term. The means of the error correction coefficients are estimated by the average of the individual coefficients. If this parameter appears to be insignificant (i.e. $\varphi_i = 0$), then there is no evidence on a log-run relationship. In case the examined variables are cointegrated φ_i is expected to be significantly negative, under the assumption that after any shock variables would return to their long run equilibrium level.

The equation (16) is estimated via likelihood approach under the initial assumption of residuals ε_t to be normally distributed, although this assumption is not crucial for obtaining asymptotic results. Moreover, estimating PMG model in differences and including a sufficient number of lags of the regressors ensures that residuals are uncorrelated and the explanatory variable is exogenous. It is important to note that this approach provides a consistent result for both stationary and non-stationary regressors (Shin et al. 1999), which is a big advantage of this technique.

It is worth mentioning that if homogeneity of long-run slope coefficients doesn't hold then pooling data and applying the PMG estimator would provide misleading conclusions. In such situation the long-run coefficients can be computed from the average of each country regressions. This approach is called Mean Group (MG). To obtain MG estimates the model (16) is estimated for each of the panel section to get individual δ that are averaged over all panel members. Thus, it estimates the mean of the long run slope coefficients. However, Shin et al. (1999) state that MG it is more efficient than PMG only if the assumption of heterogeneity holds.

In order to check data poolability, the authors suggest to apply Hausman (1978) test for the difference between the PMG and MG with the null of both estimators to be consistent (i.e. slope homogeneity). If the null hypothesis is not rejected then PMG estimator is preferable to MG estimator. However, Shin et al. (1999) stresses that if the focus of the investigation is on across countries (average) effects (energy elasticity in our study) PMG would be superior to MG as it is less sensitive to outliers and has more precision.

At the same time there are several important issues that we would like to stress on. Firstly, the MG procedure is based on the individual group estimates. Therefore, panel length should be long enough to fit ARDL estimation to each of the country. Although the MG estimator is consistent, it is unlikely to be a good estimator when either N or T are small. Using Monte Carlo simulations it has been shown that the MG estimator performs reasonably well for a large time span, but might be substantially biased when T is small (Pesaran and Smith 1995). Taking into account that the time period considered in this study is twenty years, which might be considered as small or medium T, we can conclude that the MG estimator might provide inaccurate results.

As we have already pointed out, the possibility of countries interdependence (panel CSD) might have a significant impact in the efficiency of model estimators. Following Pesaran (2004) to allow for cross-serial correlation we may specify the error terms as:

$$\varepsilon_{t,i} = \acute{\tau}_i f_t + u_{i,t} \tag{17}$$

where f_t represents a common factor, which captures the source of error term dependences. The impacts of these factors are reflected in the parameter $\acute{\tau}_i$ that, as we see, is allowed to vary across countries. There are no restrictions on error variance heterogeneity or requirements for the individual-specific regressors to be identically and/or independently distributed over the cross-section. So the feedbacks on the same shock can be country specific. However, it is assumed that the individual-specific regressors and the common factors to be stationary and exogenous.

Even though f_t is modeled as unobservable, its impact can be controlled via augmenting the ARDL model (15) with cross- sectional averages of all explanatory factors and regressant itself. These cross-sectional means can be treated as proxies for the common factors. Therefore, combining (15) and (17), and averaging across panels gives us following model:

$$y_{i,t} = \sum_{j=1}^{p} \bar{\gamma}_{i,j}\bar{y}_{i,t-j} + \sum_{j=0}^{q} \bar{\delta}_{i,j}\bar{x}_{i,t-j} + \bar{\mu} + \bar{\acute{\tau}}_i f_t + \bar{u}_t \tag{18}$$

where $\bar{y}_{t-j} = \frac{1}{N}\sum_{i=1}^{N} y_{i,t-j}$; $\bar{\tau}_i = \frac{1}{N}\sum_{i=1}^{N} \tau_{i,j}$; $\bar{x}_{t-j} = \frac{1}{N}\sum_{i=1}^{N} x_{i,t-j}$; $\bar{\delta}_j = \frac{1}{N}\sum_{i=1}^{N} \delta_{i,j}$; $\bar{\mu} = \frac{1}{N}\sum_{i=1}^{N} \mu_i$; $\bar{\gamma}_i = \frac{1}{N}\sum_{i=1}^{N} \gamma_{i,j}$; and $\bar{u}_t = \frac{1}{N}\sum_{i=1}^{N} u_{i,t}$; $j = 0,1,\dots,p$.

Since $\varepsilon_{i,t}$is assumed to be identically distributed across time and sectional dimension it tends to zero mean square error as N becomes large. Thus, cross- sectional correlation in $u_{i,t}$ can be taken into consideration through a liner combination of the cross- sectional averages of dependent and independent variables. With few manipulations (detailed procedure description can be found in Pesaran (2004a)) the augmented error correction representation of the panel ARDL model can be expressed as:

$$\Delta y_{i,t} = \mu_i + \varphi_i y_{i,t-1} + \theta_i x_{i,t} + \sum_{j=1}^{p-1} \gamma_{i,j}\Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{i,j}\Delta x_{i,t-j} + \vartheta_i \bar{y}_t + \acute{\omega}_i \bar{x}_t + \sum_{j=0}^{p-1} v_{i,j}\Delta\bar{y}_{t-j} + \sum_{j=0}^{q-1} \acute{\beta}_{ij}\Delta\bar{x}_{t-j} + u_{i,t} \tag{19}$$

The important results in the equation (19**Erro! A origem da referência não foi encontrada.Erro! A origem da referência não foi encontrada.**191919) is that error term $u_{i,t}$ is identically and independently distributed even in the presence of common effects, just like $\varepsilon_{i,t}$under cross- sectional independence. Such an estimator specification is called a Common Correlated Effects estimator and is available for both version of ARDL model PMG and MG. Though, as it has been stressed before, due to the sample features of the present study we suppose the pooled version of the estimator to be superior to mean one.

5. Empirical results

To verify whether the variables of our interest are interdependent we apply Pesaran (2004b) cross-sectional dependence test. The test is performed with *xtcd* Stata command (Eberhardt 2011). All empirical estimations and statistical tests are performed in Stata 13, except when mentioned otherwise. Table 5 reports the average correlation coefficients and CD_p test statistics. From the obtained results we can reject the null hypothesis of cross-section independence at 1% level of freedom for all tested variables. Therefore, we conclude that GDP, gross fixed capital formation, labor, and energy production from the energy sources considered are dependent across countries. These findings highlight the need to take into account the possibility of countries interdependence when studying energy-growth relationship. To avoid misleading inference[11] a presence of cross-section correlation will be taken into account in further steps of this study.

Table 5. Cross-section dependence test

Variable	CD- test	p-value	Correlation
Ln(GDP)	59.90***	0.000	0.972
Ln(capital)	33.06***	0.000	0.536
Ln(labor)	48.69***	0.000	0.790
Ln(conventional)	34.25***	0.000	0.596
Ln(hydro)	4.60***	0.000	0.075
Ln(biowaste)	48.99***	0.000	0.795
Ln(wind)	57.14***	0.000	0.927
Ln(solar)	53.99***	0.000	0.876

[11]Particularly, when common shocks (the source of CSD) are correlated with the regressors (Andrews 2005).

Table 6. Unit root testssummarizes the results of panel unit root tests. The first column of the table reports the IPS W_{tbar} statistics (statistics computation was done using Stata command *xtunitroot* with an option *ips* (StataCorp 2013)), which is the so called first generation panel unit root test that allows for individual unit root in each of the section. IPS doesn't account for CSD but it is widely used in multi-country studies on energy-growth nexus. For all of the variables the test includes a constant and a trend. Under the null hypothesis of non-stationarity we can conclude that GDP, gross fixed capital formation, labor, conventional, wind, bio-waste, and solar in their logarithmic form have a unit root. The p-values of the IPS test for the first differences of these variables allow us to reject the null of the existence of a unit root in the variables in differences. The original variables are therefore not integrated of order 2. At the same time we see that for the level value of hydro power energy the null of the unit root can be rejected at the 1% level of significance.

Table 6. Unit root tests

Variable	**IPS**		**CIPS**	
	t-statistics	**p-value**	**t-statistics**	**Critical t-statistics**
GDP ΔGDP	5.8745 - 7.9434	1.0000 0.0000	- 1.980 - 3.423	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630
Capital Δ Capital	1.3420 - 8.1898	0.9102 0.0000	- 1.946 - 3.894	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630
Labor Δ Labor	- 0.7186 - 3.6763	0.2362 0.0000	- 2.512 - 3.546	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630
Conventional Δ Conventional	0.5104 - 13.1771	0.6951 0.0000	-2.946	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630
Hydropower	- 7.2658	0.0000	- 3.994	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630
Biomass Δ Biomass	-0.1595 -9.9638	0.4366 0.0000	-1.894 -4.035	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630
Wind	-1.3483	0.0888	- 2.119	Cv1: - 2.920 Cv5: - 2.70

Δ Wind	- 10. 2479	0.0000	- 3.663	Cv10: - 2.630
Solar Δ Solar	4.9209 - 15.2109	1.0000 0.0000	- 1.906 - 3.402	Cv1: - 2.920 Cv5: - 2.70 Cv10: - 2.630

Since the results of CSD test identifies the presence of countries interdependence we also implement Pesaran (2007) unit root test that allows for CSD. The test is implemented with Stata command *xtcd* (Eberhardt 2011). Its results are presented in the second column of Table 6. Along with IPS test, the results of CIPS test (see equation (1010101010))[12] indicate the presence of a unit root for the levels of gdp, capital, labor, biomass, wind, and solar energy sources. However, after variables differentiation we can reject the null at the 5% level of significance. Significantly negative values of CIPS statistics allow us to reject the null of unit root for the levels of hydropower energy. The unit root test for conventional energy with no time trend reveals that the null of the variable being non-stationary in its levels can't be rejected. However, inclusion of the trend significantly changes value of CIPS statistics, leading to the conclusion that conventional energy is trend stationary. The difference in the unit root test outputs for the conventional energy demonstrates the importance of controlling for CSD.

The conclusion on hydropower to be a stationary variable is in line with the results presented by Lean & Smyth (2014) who analyzes the behavior of hydropower generation in 55 countries[13].

The stationary nature of non-renewable electricity generation can be related to the fact that during last decade developed countries (and so the majority of OECD member states) have been focused on decreasing the energy-intensity level. Thus, the amount of electricity generated from conventional energy sources has been stable relatively to economic growth. For example during the period of 1990-2012 the annual growth of electricity consumption in the EU was around 1.4% (EEA 2013)[14], while the annual GDP growth rate of EU-28 varies from 1.5% to 2.1%[15]. At the same time (Observ' RE 2013) reports that during 2002-2012 the mean annual increase of per capita electricity output in North America was even slightly negative. This positive trend in energy intensity indicators (electricity generation per unit of GDP) can provide an evidence of successful GHG emission reduction policies.

[12] CIPS is a cross-sectionally augmented version of the IPS test (Pesaran 2007).
[13] In this study, the authors apply LM unit root test for 55 countries over the period of 1965 -2011. The rejection of unit root was supported for three quarters of their sample among which majority of OECD members.
[14] Whereas, total electricity produced from solid fuels decreased by 18.8% between 1990 and 2010, at an annual average rate of 1%.
[15] According to OECD annual statistics information

Given the presence of cross country dependence, we believe that Pesaran (2007) unit roots test gives more reliable inference than those methodologies that do not account for CSD. Therefore, we can conclude that conventional and hydropower sources are trend stationary and stationary respectively, while all other variables are integrated of order one.

It should be noted that the order of integration is an important issue for further long–run relationship analysis. According to Pedroni (1999), cointegration refers to the idea that for a set of nonstationary variables, some linear combination of these variables exhibits stationary nature. Thus, GDP and hydropower electricity generation as well as GDP and conventional electricity production can't have a long-run relationship as they have different orders of integration. Therefore, conventional and hydro energy sources are not included in the next step of our analysis which is testing for the presence of cointegration relationship.

The test statistics proposed by Pedroni (1999) has been widely used in the energy-growth literature (Apergis & Payne, 2009; Ohler & Fetters, 2014; Ucan et al., 2014; Sadorsky, 2009). One of the main assumptions of this cointegration test is the independence across cross-sectional units. However, the initial analysis of our sample reveals the presence of CSD between the panels. That is why, in addition to Pedroni (1999) cointegration test we apply the technique proposed by Westerlund (2007) that is robust to CSD. Pedroni test statistics are calculated via the econometric software Eviews 8.0, while Westerlund (2007) cointegration test is performed with Stata command *xtwest* (Persyn 2010). Both tests consider the models with a constant and a time trend.

To control for CSD, Westerlund (2007) unit root test is performed with 500 bootstrap replications. Table 7 provides robust p-values for group test statistics (that impose homogeneity restriction on estimated parameters) and for panel test statistics. The first three rows present outputs for the models that consider different renewable energy sources individually, and the last row-for the model that simultaneously includes these three power sources (biomass, wind and solar energies). The robust probability values for all models specifications report that there is no reason to reject the null of no cointegration between variables. Therefore, we can conclude that there is no long-run equilibrium relationship between economic growth and renewable energy sources.

Table 7. Westerlund (2007) cointegration test

Energy variable	**G_t - statistics**	**G_a-statistics**	**P_t -statistics**	**P_a -statistics**
Biomass	0.946	0.962	0.922	0.834
Wind	0.984	0.316	0.942	0.858

Solar	0.420	0.516	0.530	0.320
Biomass, wind, solar	0.194	0.440	0.678	0.254

Table 8 reports seven statistics suggested by Pedroni (1999). The obtained p-values from the models that analyze relationship between individual renewable energy sources and GDP show that there is no strong reason to reject the null of no long–run relationship. In case of GDP-biomass pair only p-value for the panel-ADF statistics is less than critical level of 5% allowing us to reject the null hypothesis. According to the results for GDP-wind and GDP-solar models the null is also rejected by only one of the test statistics - group-PP and group-ADF respectively.

Table 8. Pedroni (1999) cointegration test

	Biomass		**Wind**		**Solar**		**Biomass, wind, and solar**	
Test	**t-statistics**	**p-value**	**t-statistics**	**p-value**	**t-statistics**	**p-value**	**t-statistics**	**p-value**
Panel v-Statistic	0.6852	0.2466	0.0681	0.4728	1.2496	0.1057	-1.1119	0.8689
Panel rho-Statistic	3.0839	0.9990	3.3921	0.9997	3.3821	0.9996	4.6117	1.0000
Panel PP-Statistic	-1.1104	0.1334	0.6496	0.7420	0.7167	0.7632	-1.3990	0.0809
Panel ADF-Statistic	-1.8264	0.0339	-0.0734	0.4707	-0.4456	0.3278	-1.6019	0.0546
Group rho-Statistic	4.6998	1.0000	4.2758	1.0000	4.4138	1.0000	6.1583	1.0000
Group PP-Statistic	-0.9234	0.1779	-2.0909	0.0183	-0.8136	0.2079	-5.3687	0.0000
Group ADF-Statistic	-0.8502	0.1976	-1.1631	0.1224	-1.7908	0.0367	-2.1821	0.0146

The t-statistics calculated for the model, which tests cointegration relationship between GDP and three renewable energy types simultaneously, don't provide the clear evidence of the long–run relationship between them. The p-values of Group PP-statistics and Group ADF statistics are less than critical level of 5%, while the level of group ADF-statistics is slightly higher. These results allow us to reject the null of no cointegration. However, four test statistics remain suggesting that we have no reason to reject the null.

In light of the results inconsistency (obtained in the last model) we should identify which of the considered statistics has a higher power. In the number of experiments (Pedroni 2004) shows that in small size samples group-rho statistics dominates other test statistics. According to Pedroni

(2004) small sample studies can be relatively confident about group-rho statistics results as "…it is slightly undersized and empirically the most conservative of the tests." On the other hand one of his experiments was performed for the case of $N = 20$ (number of panels considered in our study) and showed that panel-t tests (PP and ADF) had the highest power. Similar conclusion were reported by Örsal (2007).

Summing up we can state that, since the time span and the number of countries in our sample is relatively short, the possibility of null hypothesis rejection is best determined by group-rho statistic followed by panel-t statistic. The p-values of two of these statistics show that we have no reason to reject the null of no cointegration at the 5% level of significance (with rho-statistics suggesting strong non-rejection of the null).

Hence, taking into account both CSD and the size properties of the Pedroni (1999) cointegration test we conclude that there is no long run relationship between GDP and renewable energy sources considered (biomass, wind, and solar energy).

It has to be noted that the procedure of the cointegration tests applied in our study is conducted in a way to verify the null hypothesis of long–run relationship in each of the panel members. Taking this into account we should add that our results don't reveal a long–run linkage between GDP and renewables simultaneously in all countries included in the sample. However, it doesn't necessarily mean that none of the analyzed countries exhibits the cointegration relationship between these variables. It might be the case that the nature of the linkage between GDP and renewables in the long run is country specific. Nevertheless, its presence is not identified in all panels simultaneously leading to the conclusion of no cointegration relationship between economic growth and renewable energy sources.

Our conclusions, however, are not in line with those presented by Ohler & Fetters (2014), who state that only solar and geothermal (latter one is not analyzed by our study) energies "…exhibit weak cointegration relationship with GDP", while the rest of renewables affect economic growth in the long–run. One of the reasons can lay in the differences between the samples studied by Ohler & Fetters (2014) and the analyzed in our paper. It is worth noticing that the interpretation of Pedroni (1999) cointegration test presented by Ohler & Fetters (2014) are based on the number of t-statistics that reject the no cointegration null, without accounting for their size properties. However, as the sample considered by that study is also relatively small (20 countries over 18 years), conclusions based on a majority rule might not reflect the real character of the relationship between the variables. Moreover, the outputs of Westerlund test in our analysis are consistent with those provided by Ohler & Fetters (2014), although in the latter the authors' final conclusions still confirm the long-run interrelationship between majority of renewable energy sources and GDP.

Despite the fact that our study defines that there is no long–run relationship between economic growth and renewables we can analyze whether in the short–run these energy variables affect economic activity. The panel ARDL approach proposed by Shin et al. (1999) has been widely used for short-run coefficients estimation in recent energy economics studies (Ohler & Fetters (2014), Salim et al. (2014), Apergis & Payne (2014)). This approach suggests two estimators for model estimating, the choice between which depends on prior heterogeneity assumptions (see Methodology description). It should be noted that the main source of heterogeneity allowed by MG is through the cross-sectional variations in the long-run parameter Pesaran & Smith (1995). But due to the fact that cointegration tests results provide an evidence that in the long run analyzed variables are not interrelated, the long run estimation part of PMG/MG is no longer in our main focus. As there is no long run co-movement between considered variables we expect the error correction term (EC), which tests the presence of long-run relationship, to be insignificant. Consequently, our following step is to examine short–run dynamics. However, Pesaran & Smith (1995) note that above mentioned MG bias "...is caused by the bias in the estimation of the short-run coefficients…". Moreover, reliability of the long–run coefficients obtained within ARDL technique requires sufficiently long time span (Favarra 2003). Thus, we believe that for the short–run coefficient estimations PMG estimator would perform better than MG.

Therefore, in order to examine short-run relationship between GDP and different types of renewables we apply panel ARDL approach, which accounts for CSD, developed by Pesaran (2004). Due to the limited number of observations we aren't able to estimate model specification that consider more than three explanatory variables[16]. Moreover, data limitation restricts the number of factors' means to be included in the model (see chapter Methodology description) to three. However, we suppose that for the analysis of economic growth removing a variable of capital or labor is theoretically wrong. Therefore, using the production function framework (see equation 1and 2) we augment the model with the means of GDP, capital, and energy variable, without controlling for interdependence of labor force between panels. The analyzed models are conducted in a way to investigate the impact of renewable energy sources on GDP one by one separately. Estimations of the equations, which include the first difference of GDP as a dependent variable and lagged

[16] For the size of our sample the ARDL model can be estimated with seven regressors maximum. However, to account for CSD we follow Pesaran (2006) and augment estimated models with the means of each of the variables (independent and dependent), which consequently limited the number of regressors we can include in the model.

differences of the explanatory factors, have been carried out using the Stata command *xtpmg* (Blackburne and Frank 2007b)[17].

The outputs of panel ARDL estimations are presented in Table 9. The models for hydropower and solar energy show that EC terms are not significant at the 5% level of significance. This confirms our previous conclusion of no cointegration relationship between these energy variables and economic growth. The results from biomass and wind power model specifications show that the coefficients of the EC terms are statistically significant and negative, which means that these two energy sources are cointegrated with GDP. The long–run coefficient of wind energy generation is significant and positive meaning that over the long–run this energy source is expected to contribute to economic growth. On the contrary, biomass energy use negatively affects economic activity. Although, due to the value of its long–run coefficient (-0.0163), this impact is relatively small. Such finding differs from Ohler & Fetters (2014) results, who conclude on biomass to affect economy positively. However, for the long–run estimations authors use different methodological technique (Fully Modified OLS) and that might be a reason for the results inconsistency.

The short-run estimates show that two renewable energy sources, biomass and wind, have an impact on economic growth. While biomass positively affects GDP, the coefficient for the wind energy is negative meaning that wind power generation might have a negative influence of economic activity in the short run. The negative impact of wind energy on GDP might be related to the cost of the wind equipment import. According to the recent statistics worldwide wind turbine manufactures are concentrated in several countries among which China, Denmark, and Germany have the biggest market shares (Energy Digital 2015). In 2012, for example, the amount of imported wind power equipment increased the US trade imbalance on USD 2.6 billion (NREL 2013). Therefore, the wind power installation spending might be a reason for this energy source affects GDP negatively, but only over short run.

Table 9. Panel ARDL estimation

Model specification	Capital		Labor		RE variable		EC term
	Long-run	Short - run	Long-run	Short – run	Long-run	Short - run	
Hydropower	0.5885 (0.000)	0.1381 (0.000)	0.0525 (0.572)	0.2328 (0.121)	0.0512 (0.001)	0.0025 (0.563)	- 0. 075 (0.097)
Biomass	0.4048	0.133	-0.1472	0.2066	-0.163	0.0122	-0.1639

[17] Detailed description of the command can be found in (Blackburne and Frank 2007a).

	(0.000)	(0.000)	(0.047)	(0.283)	(0.018)	(0.023)	(0.008)
Wind	0.2729 (0.000)	0.0973 (0.025)	0.5478 (0.000)	0.1906 (0.433)	0.0166 (0.000)	-0.0066 (0.007)	-0.2159 (0.021)
Solar	0.0704 (0.291)	0.1424 (0.000)	0.9800 (0.000)	0.3201 (0.126)	0.1421 (0.000)	-0.0021 (0.792)	-0.758 (0.190)

At the same time the p-value of the coefficient for solar energy shows that in short run this energy source has neither positive nor negative impact on GDP. This conclusion is in line with the findings presented by Ohler & Fetters (2014)[18]. This fact might be explained by the share of solar energy sources in total electricity generation, which remains relatively low (BP 2015). Similar to Silva (2012), whose structural VAR analysis shows that changes in the hydropower generation don't affect GDP, our results reveal that hydropower has no short–run impact on economic growth. One possible explanation is the "decreasing dominance" of hydropower sources partially caused by the rapid growth of other renewables (EmployRES 2009). Moreover, according to the latest reports China, Asia, and South America are the leaders in the amount of hydropower capacity added (IHA 2015), whereas the majority of countries considered in our study don't exhibit significant hydropower deployment. Here we also would like to recall the study presented by Chien & Hu (2008), who conclude that renewables affect GDP by the means of increasing capital formation level. Therefore, we might suspect that the actual impact of renewable energy sources depend not on the amount of energy produced but the level of new capacity installed, which would explain the nature of short–run relationship between hydropower and economic growth.

[18] According to the results of panel error correction model that account for CSD

6. Conclusions

Growing concerns about global warming problem and increasing energy demand call our attention to the need to expand the use of renewable energy sources. Providing a possibility to decrease an environmental impact and improve energy security renewables are becoming an important part of the countries' energy mix. Even though there are several papers focusing on the renewable energy–growth nexus, little consideration has been given to the disaggregate analyses of these energy sources.

This study examines the relationship between economic growth and different types of renewables (hydropower, biomass, wind, and solar energies) for twenty OECD member states over the 1993-2012 period. For this purpose, we implement relatively new panel time series techniques, mainly panel unit root tests, panel cointegration tests, and panel ARDL approach for short–run estimation.

The initial analysis of our sample reports the interdependence between countries, which has been taken into account throughout the empirical part of this study.

The results of the cointegration tests show that there is no long-run relationship between individual renewable energy sources and economic activity. Moreover, according to the unit root test outputs, hydropower generation is stationary, while GDP is nonstationary that provides evidence on no interrelationship between these variables over the long run.

The estimations of the short–run dynamics reveal that two renewable energy sources influence economic activity in the short-run. While biomass power generation contributes to economic growth, wind energy affects economic growth negatively. However, this impact is very low and can be related to a high level of initial capital costs, which, nevertheless, are most likely to be outweighed in the long–run.

We should note that the results of our study are contrary to those provided by Ohler & Fetters (2014), who also analyze different categories of renewables and conclude on the positive long–run relationship between economic growth and majority of energy sources. However, due to the fact that the study sample and econometric methodologies applied in Ohler & Fetters (2014) differ from ours the final results are not completely comparable. Moreover, such difference might reflect the sensitivity of the conclusions on renewable energy–growth nexus to the sample choice and estimation technique.

Even though our results don't find a support for a long–run relationship between economic growth and renewable energy we believe that these energy sources are important tools for sustainable development. It is important to bear in mind that the primary goal of the recent expansion of renewable energies is to reduce GHG emissions and thus help to fight global warming. Despite the significant growth of renewable energy usage, they are mostly used for electricity generation (besides the production of biofuels, solar and geothermal heating and cooling systems), while the highest share of total final energy consumption (TFEC) belongs to oil (in 2012 it accounted for 40.7% (IEA 2014a)). Moreover, our study examines disaggregate renewable energy sources, whose share in TFEC is even lower. Therefore, considering a relatively small share of individual renewable energy sources in the TFEC their impact on economic activity might be not strong enough.

It should be pointed out that due to data limitation we couldn't analyze the impact of different renewables and traditional energy sources on GDP simultaneously. Therefore, further research might consider a longer time span and estimate the influence of disaggregate categories of conventional and renewable energy sources on economic activity together, checking for bidirectional causality. At the same time because of the limited number of observations we don't control for the presence of interdependence between labor force across countries. Future investigation might create a data base that enables the estimation of the model augmented with the means for all regressors. The present study focused on OECD countries, while future research could provide an analysis for the case of developed and developing countries with further comparison of results. Given the importance of renewable energy in meeting emission reduction targets we also suggest examining the relative possibility of individual renewable energy sources to the level of CO2 emissions.

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Appendix:

Graphical representation of variables natural logarithms

Figure A3. Real Gross Domestic Product

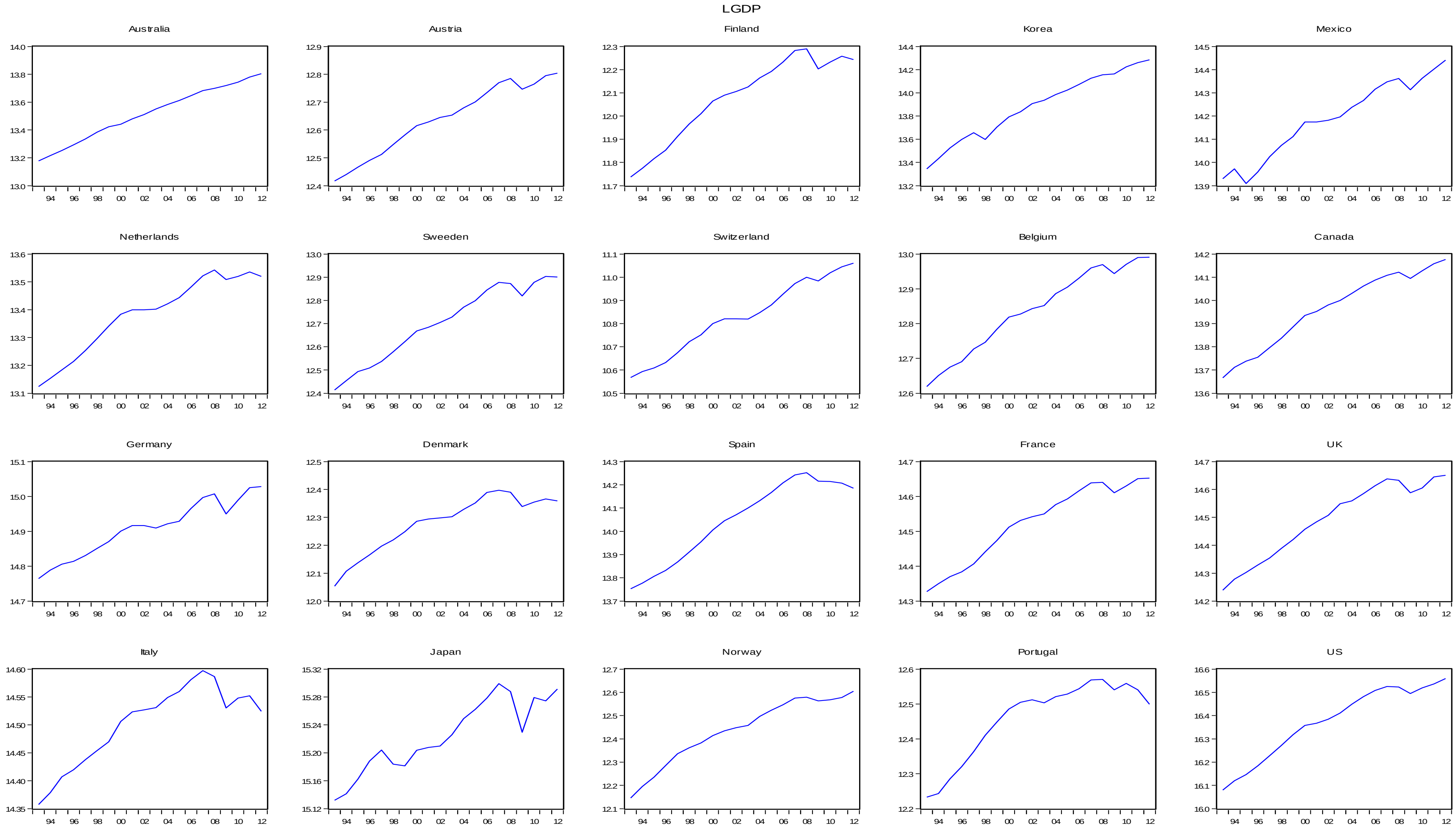

Figure A4. Net electricity generated from hydropower sources

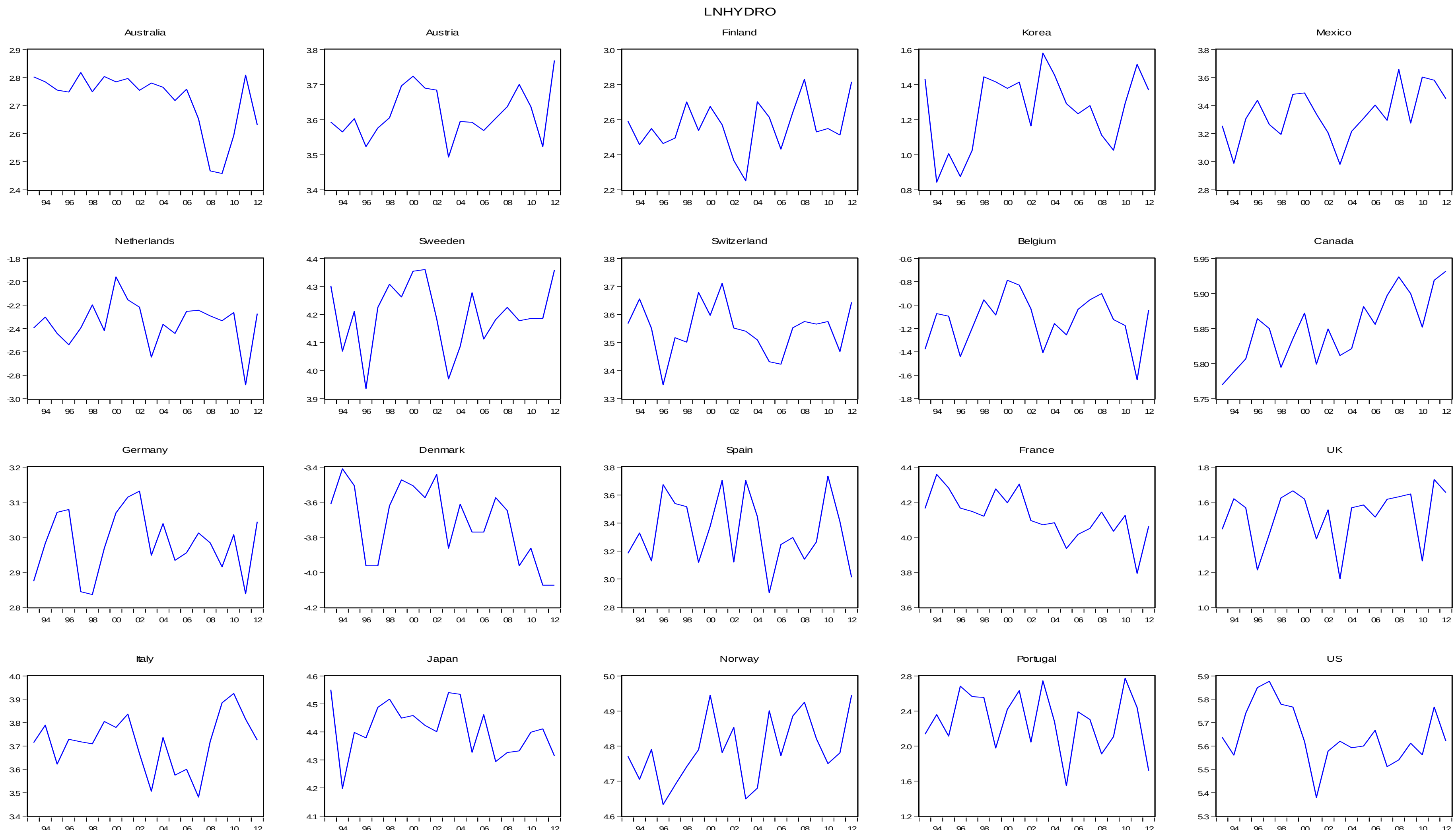

Figure A5. Net electricity generation from bio waste energy sources

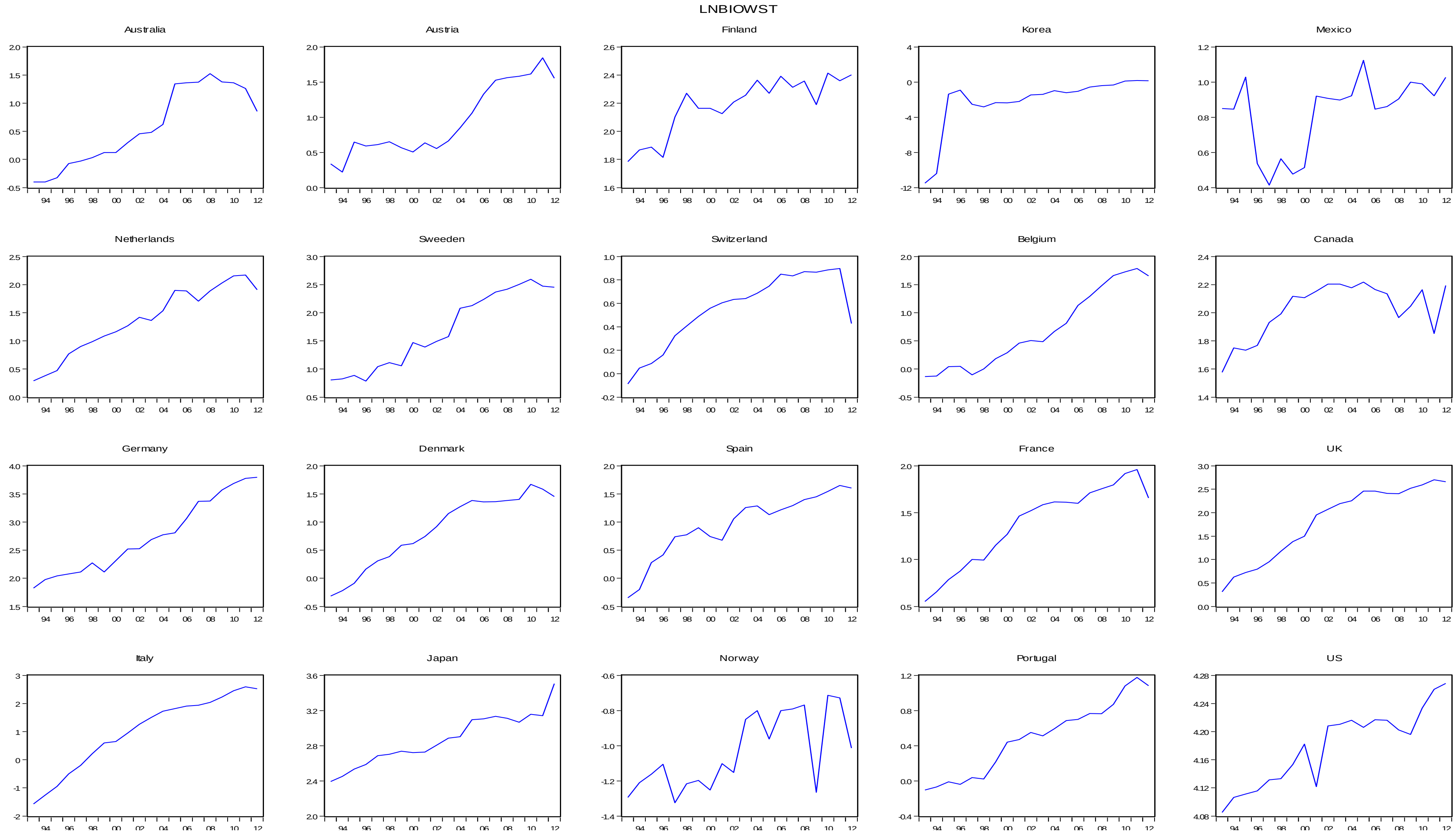

Figure A6. Net electricity generated from wind energy sources

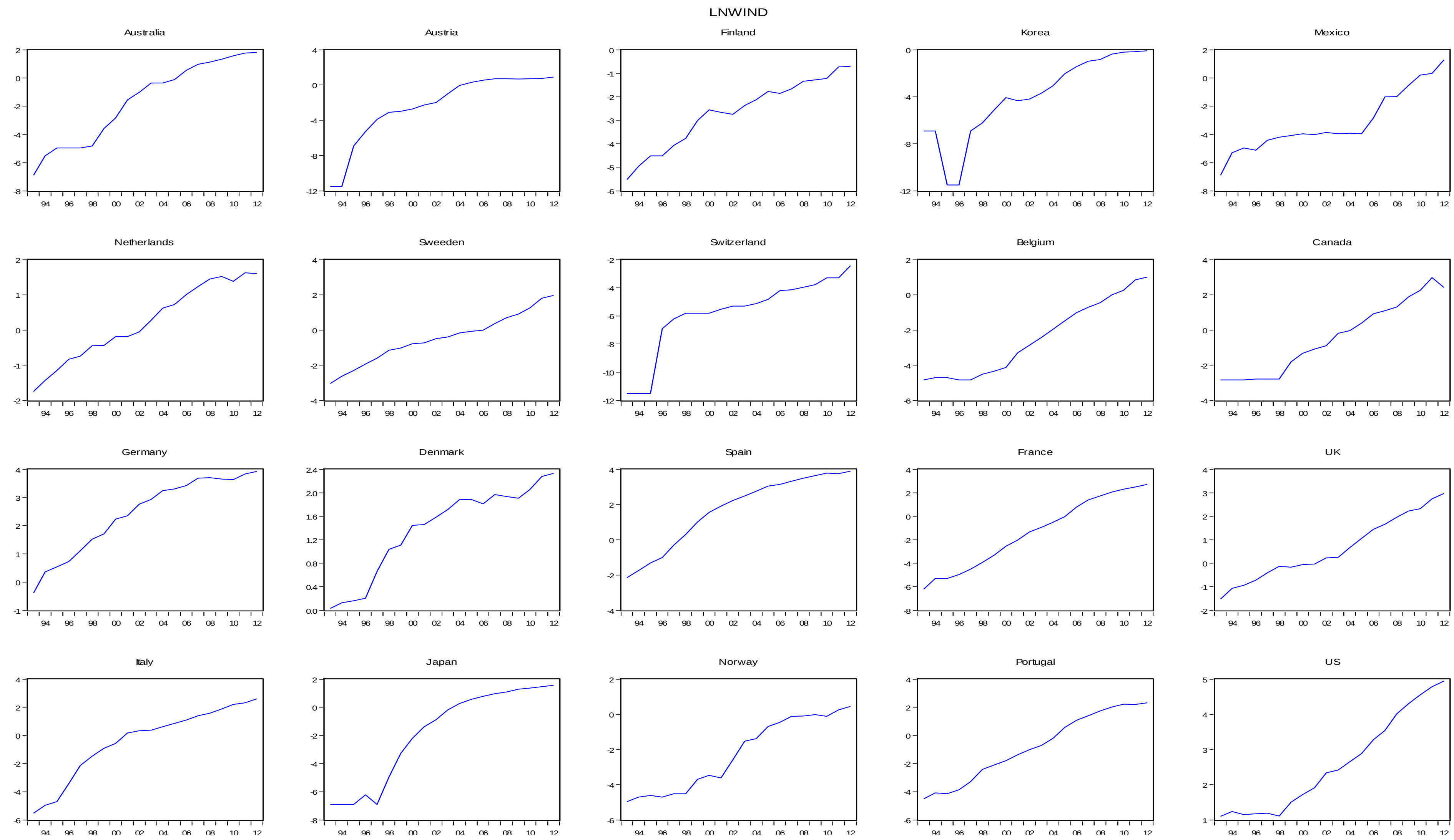

Figure A7. Net electricity generation from solar energy.