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# Renewable Energy Policy, Economic Growth and Employment in EU Countries: Gain without Pain?

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## Abstract

Given the intensifying debates whether governments should use industrial policies to promote particular renewable energy technologies, the main objective of this study is to investigate the long-run effects of renewable energy support policies on economic growth and employment in 15 European Union (EU) member states for the 1990-2012 time period by using panel-data time-series econometric techniques. The first hypothesis is that the EU's renewable energy support policies lead to technological advancement, followed by economy growth, *in the long-run*. The second hypothesis states that these policies at least generate an increase in output and employment *in the short-run*. In summary, our results provide some evidence in support of the second hypothesis, but, in contrary to the similar studies, our findings do not support the first hypothesis that these policies promote growth in the long-run.

**Keywords**: economic growth, EU, Granger causality, panel cointegration, policy, renewable energy
**JEL:** O44, Q43, Q48

## 1. Introduction

The role of renewable energy is gradually increasing in modern economic and social development. Over the last couple of decades the deployment and use of renewable energy sources (RES) have been significantly growing worldwide. According to the International Energy Agency's statistics, the share of renewable electricity generation in the global electricity mix increased from 18 per cent in 2007 to almost 22 per cent in 2013 (IEA 2014). Worldwide, renewable electricity generation is now on par with that of natural gas.

Indisputably, renewable energy helps to mitigate air pollution and increases energy security and diversification for countries that are net energy importers. However, the *net* economic effects of increasing renewable energy on economic growth and employment are ambiguous and subject to empirical and modelling scrutiny. As discussed by Lehr, Lutz et al. (2012), in the short run, the *gross* effect of increasing investments into renewable energy sources on economic activity and employment of RES related industries is obviously positive.[1] This argument is usually highlighted by policy makers when promoting the development of renewable energy. However, in the long-run, these positive short-run effects might be diminished or even offset by negative impacts which originate from two different sources: first, green energy investments might crowd out investments in other potentially more productive conventional energy sectors; second, renewable energy, at least initially, translates into additional energy costs for households and firms. This reduces their expenditure in other sectors resulting in lower output and fewer jobs in the respective sectors.

Renewable energy has been promoted through different support schemes in several European Union (EU) member states for a long time ago. However, only in the early 1990s, promotional programs picked up the speed across most EU member states.[2] Since then the cost of subsidising renewable energy has been rapidly growing in all EU countries. In 2011 the annual subsidies to renewable energy in the EU amounted to EUR 36 billion, more than half of the total worldwide subsidies to renewable energy (European Commission 2014). The

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[1] The European Commission expects that the development of renewable energy will bring benefits in terms of growth and jobs. Gross employment in the renewable sector is forecasted to rise to 3 million by 2020. While the net employment effect of renewable policy (taking into account job losses in other sector) is forecasted to range between 300,000 - 400,000 new jobs (European Commission 2014).

[2] See Haas, Panzer et al. (2011) for a historical review of promotion strategies for electricity from renewable energy sources in EU countries.

costs of supporting renewable energy are still increasing. For instance, in Germany they increased from EUR 9.5 billion in 2010 to EUR 12.7 billion in 2012, and in Spain – from EUR 5.4 billion to EUR 8.4 billion in 2012 (European Commission 2014).

From the economics perspective, only a mix of three externalities, namely, air pollution, energy security and promotion of learning-by-doing (or knowledge spillover), can justify the strong support for renewable energy expansion (Canton and Johannesson Lindén 2010). The negative externality of air pollution has been largely addressed by the EU's Emission Trading System and other national climate change programmes. Therefore the remaining key objective[3] of the EU's renewable energy support policies is to create economies of scale and to induce new technology developments through learning-by-doing and knowledge spillovers in the relevant industrial sectors.

However, in general, industrial and innovation policies, which can be defined as attempts by governments to promote growth of particular industrial sectors, remain controversial. For example, the *Economist's* article "*Picking Winners, Saving Losers*" (The Economist 2010, August) criticises increasing subsidies to promote certain green technologies warning that "picking industrial winners nearly always fails."

Given the intensifying debates whether governments should use industrial/innovation policy strategies to promote particular renewable energy technologies, the main objective of this study is to investigate the long-run effects of renewable energy support policies on economic growth and employment in 15 European Union (EU-15)[4] member states for the 1990-2012 time period by using panel-data time-series econometric techniques, such as heterogeneous estimators, unobserved common factor models and panel causal analyses in a vector error correction model. In particular, this paper aims to expand the existing literature in the following three unexplored directions.

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[3] In this study, we consider energy security objective as less important since, according to Canton and Johannesson Lindén's (2010) conclusions, which are based on the literature review, the benefits of increased energy security seem to be quite modest.

[4] The term EU-15 refers to the 15 member states of the European Union as of December 31, 2003, before the new Member States joined the EU. The 15 member states are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

First of all, this study focuses on a rather development-wise homogenous EU-15 region, which has promoted renewable energy for a long time and which is the most coordinated in terms of renewable energy policies, what makes it a well-suited case for examining the long-term effects of such policies. The EU's renewable energy policy is unique in that it has a unilateral renewable energy target. The Renewable Energy Directive (European Parliament and Council 2009) requires the EU to fulfil at least 20 per cent of its total energy needs with renewables by 2020 – to be achieved through the attainment of individual national targets. Despite the common EU renewable energy target and promotion of cooperation, EU member states are free to choose distinctive measures to meet their individual obligations. This has resulted in a number of different industrial policies, such as feed-in tariffs, tradable green certificate systems, tax breaks, investment subsidies, just to name a few.

Secondly, instead of using total renewable energy consumption or generation, as done in the earlier similar empirical studies on renewable energy-economic growth nexus (see our literature review below), we use renewable energy *capacity* of solar and wind energy as the proxy variables for the EU's renewable energy policies.[5] The rationale of using capacity instead of consumption is that capacity, not its consumption, is a better measure for comparing the *efforts* of renewable energy policies to enhance the learning-by-doing effects.

Thirdly, we perform our analysis at three different data aggregation levels to understand the effects of renewable capacity expansion not only on overall economy, but also on total manufacturing and manufacturing of machinery and equipment. By performing analysis at three different economic activity levels, we will be able to provide more insights about the impacts of renewable energy policies on the EU economy.

Specifically, this study tests two hypotheses. The first hypothesis is that the EU's renewable energy support policies lead to technological advancement, followed by economy growth, *in the long-run*. The second hypothesis states that the EU's renewable energy support policies at

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[5] We are not oblivious to the fact that renewable energy policies are not only limited to solar and wind, and therefore our proxy variables might not completely cover all renewable policies. Nevertheless, solar and wind are the leading renewable energy sources that are attracting the greatest interest among policy makers and in the industry, at least at the EU level. Therefore most of the renewable energy policies in the EU are often centred on solar and wind.

least generate an increase in output and employment *in the short-run*. In summary, our results provide evidence in support of the second hypothesis that the EU's renewable energy policies promote growth and employment in the short-run, especially in the case of wind capacity, but do not support the first hypothesis that these policies promote growth in the long-run.

The remainder of the paper is organised as follows: Section 2 provides a short summary and a discussion of the relevant literature on renewable energy-economic growth nexus. In Section 3 we present the theoretical considerations, the main hypotheses, the empirical strategy and the data. Section 4 contains the empirical results and their discussion. A short summary and the concluding remarks are presented in the final section.

## 2. Brief Literature Review

The question of renewable energy-economic growth nexus has been researched rather intensively for more than one decade. On one hand the recent surge in this literature has been endorsed by the focus of policy-makers to promote renewable energy worldwide. On the other hand, the advances in time-series and panel-data econometric techniques as well as the availability of long data series have allowed researchers to investigate this question for different countries and regions. Also, growing number of studies in this area suggests that researchers have not yet found a consensus on whether or not renewable energy is promoting economic growth. A recent study by Sebri (2015) synthesises the empirical literature on this topic using the meta-analysis approach and finds that the variation in the supported hypothesis is due to a number of characteristics, including model specification, data characteristics, estimation techniques, and the country's level of development.

Below we summarise some of the results from 16 empirical studies that used time-series and panel-data econometric techniques to analyse the question of renewable energy-economic growth nexus for the European Union's countries or for a group of countries that includes at least one EU country. Table 1 provides information on the geographical and time scope, definition of renewable energy variable, long-run elasticities computed using the panel cointegration techniques, existence of causality from renewable energy to economic growth and causality from renewable energy to total employment.

Only Menegaki (2011) and Ucan, Aricioglu et al. (2014) analysed renewable energy-economic growth nexus for EU countries. The other studies focus either on OECD countries or a mix of developed and developing/emerging countries. Most studies analyse over 20-30 years of historical data, starting at 1980 (the earliest) and running through 2012 (the latest).

The selected studies use different definitions of renewable energy variables. Most of them include *total* renewable energy consumption or *net* renewable energy consumption (see e.g. Sadorsky (2009)). Net consumption does not include the energy consumed by the generating units. The studies by Bayraktutan, Yilgör et al. (2011) and Ohler and Fetters (2014) use renewable electricity generation. A few papers use the ratio variables such as the share of total renewable energy consumption to total energy consumption (Menegaki 2011, Inglesi-Lotz 2015) and renewable energy consumption per capita (Kula 2014). A study by Ucan, Aricioglu et al. (2014) provides very little information about its renewable energy variable.

10 out of 16 selected studies report long-run elasticities computed using panel cointegration techniques. The reported coefficients are positive and statistically significant and they range from 0.001 to 0.76. These results indicate that a 1 per cent increase in let's say renewable energy consumption leads to 0.001 to 0.76 per cent increase in economic growth, which in most studies is measured as a change in real GDP. A study by Ohler and Fetters (2014) is different from the other selected studies in that it estimates the long-run elasticities across 20 OECD countries over 1990 to 2008 for each renewable energy source: biomass, geothermal, hydroelectricity, solar, waste, and wind. All estimated coefficients are positive and statistically significant. A 1 per cent increase in biomass increases real GDP by 0.129 per cent; a similar increase in hydroelectricity and waste generation increases real GDP by 0.1114 per cent and 0.096 per cent; geothermal, solar and, wind have the smallest impact with estimated long-run elasticities of 0.085, 0.055, and 0.053, respectively.

Most studies that infer the causal dynamics, find support for the feedback hypothesis implying that there is bidirectional causality between renewable energy and economic growth. That is, both variables influence each other. Only four selected studies find that causality between renewable energy and economic growth is absent. Ohler and Fetters (2014) disaggregate renewable energy sources and examine the causal relationship between each renewable energy source and economic activity. Interestingly, geothermal and wind energy both exhibit negative bidirectional causality with real GDP, while hydroelectricity and waste energy positively contribute to real GDP.

Finally, we are interested in whether renewable energy increases employment. This question is not explicitly considered in our selected studies, but a few of them included total employment as an important factor of economic activity and examine the causal relationship between renewable energy and employment. Six out of eight studies that consider employment find no support for causality between renewable energy and employment, while the remaining two studies (Menegaki 2011, Ohler and Fetters 2014) find that renewable energy contributes to employment. Ohler and Fetters (2014) analyse this relationship for each renewable energy source and find that biomass, hydro and wind energy support employment.

Unlike the summarised previous studies, this paper aims to expand the existing literature in the following unexplored directions. First of all, this study focuses on the EU-15 region, which is the most homogenous in terms of renewable energy policies. Secondly, instead of using total renewable electricity consumption or generation, we use renewable energy capacity of solar and wind energy as the proxy variables to capture the effect of the EU's renewable energy policies on economic growth. Thirdly, we disaggregate the data to understand the effects of renewable capacity expansion not only on the total economy, but also on the total manufacturing and the machinery and equipment sector. By doing this we will be able to provide more answers about the economic impacts of renewable policies.

**Table 1. The summary of the selected studies on renewable energy-economic growth nexus**

| Authors | Sample period | Sample countries | Definition of RES variables | LR elasticities between RE and economic growth | Causal relationship between RE and economic activity | Causal relationship between RE and labour |
|---|---|---|---|---|---|---|
| Sadorsky (2009a) | 1980-2005 | G7 countries (4 EU) | Net renewable electric power consumption | n/a | n/a | n/a |
| Sadorsky (2009b) | 1994-2003 | 18 Emerging countries (4 EU) | Net renewable electricity consumption | n/a | Neutrality | n/a |
| Apergis and Payne (2010a) | 1985-2005 | 20 OECD countries (12 EU) | Net renewable electricity consumption | 0.76 | Feedback | Neutrality |
| Apergis and Payne (2010b) | 1992-2007 | 13 Eurasian countries (2 EU) | Net renewable electricity consumption | 0.074 and 0.195 | Feedback | Neutrality |
| Apergis, Payne et al. (2010) | 1984-2007 | 19 Developed and developing countries (9 EU) | Net renewable electricity consumption | n/a | Feedback | n/a |
| Apergis and Payne (2011) | 1990-2007 | 25 Developed and 25 developing countries (19 EU) | Total renewable electricity consumption | 0.265 | Feedback | Neutrality |
| Bayraktutan, Yilgör et al. (2011) | 1980-2007 | 30 OECD countries (19 EU) | Total renewable electricity generation | n/a | Feedback | n/a |
| Menegaki (2011) | 1997-2007 | 26 EU countries and Norway | Share of renewable energy sources in gross inland energy consumption | 0.44 | Neutrality | Growth |
| Apergis and Payne (2012) | 1990-2007 | 80 countries (19 EU) | Total renewable electricity consumption | 0.371 | Feedback | Neutrality |
| Apergis and Payne (2014) | 1980-2011 | 25 OECD countries (15 EU) | Total renewable electricity consumption | n/a | Feedback | n/a |
| Ben Jebli and Ben Youssef (2014) | 1980-2007 | 69 countries (15 EU) | Total renewable electricity consumption | 0.04-0.042 | Neutrality | Neutrality |
| Kula (2014) | 1980-2008 | 19 OECD countries (11 EU) | Renewable energy consumption per capita | n/a | Neutrality | n/a |
| Ohler and Fetters (2014) | 1990-2008 | 20 OECD countries (12 EU) | Total renewable electricity generation | 0.149 all RES, 0.129 biomass, 0.114 hydro; 0.096 waste; 0.085 geothermal; 0.055 solar; 0.053 wind. | Feedback - total RES; separate results for each RES | Feedback - total RES; separate results for each RES |
| Salim, Hassan et al. (2014) | 1980-2012 | 29 OECD countries (17 EU) | Total renewable electricity consumption | 0.0745-0.1018 | Growth - Model I; Feedback - Model II | Neutrality |
| Ucan, Aricioglu et al. (2014) | 1990-2011 | EU 15 countries | Total renewable energy | 0.001-0.002 | n/a | n/a |
| Inglesi-Lotz (2015) | 1990-2010 | 30 OECD countries (19 EU) | (1) Total renewable energy consumption; (2) the share of total renewable energy consumption to total energy consumption. | 0.105 | n/a | n/a |

## 3. Methodology

### 3.1 Theoretical Considerations

As previous research discussed above, this study augments the neoclassical Cobb-Douglas production function by incorporating energy in addition to capital and labour inputs. In particular, our model contains four explanatory variables: capital, labour, total energy consumption and the state of technology.

Generally, the production function can be written as

$$Y_{it} = f(K_{it}, L_{it}, EC_{it}, A_{it}), \qquad (1)$$

where $Y_{it}$ represents the aggregate output at time *t* for country *i*, $K_{it}$ is capital stock, $L_{it}$ is labour, $EC_{it}$ is total energy consumption, and $A_{it}$ is the state of technology. The state of technology is assumed to be the function of two variables:

$$A_{it} = (RE_{it}, TC_{it}), \qquad (2)$$

where $RE_{it}$ denotes EU policies for inducing renewable energy development at time *t*, and $TC_{it}$ is an exogenous technological change.

Since the beginning of 1990s most EU countries have introduced various policies to increase the share of renewable energy production in total energy production. These policies include investment subsidies, tax breaks, feed-in tariffs, among others (EWEA 2005). To examine the effects of RE policies on economic activity and employment it is virtually impossible to account for a wide range of these policies in our empirical setting. Thus, we need a proxy variable which could help us to aggregate different policy measures. We use solar and wind electricity production capacity (denoted by *SOL* and *WND*) as such proxy variables arguing that capacity is a better measure for comparing the *efforts* of renewable energy policies across EU countries.

Consequently, the following log-linear reduced-form of aggregate Cobb-Douglas production function is used to investigate the long-run and short-term relationships between economic activity, employment and RES policies:

$$lnY_{it} = \alpha lnK_{it} + \beta lnL_{it} + \gamma lnEC_{it} + \delta lnSOL_{it} + \theta lnWND_{it} + \vartheta TC_{it} + e_{it} \qquad (3)$$

The economic explanation of $\alpha$, $\beta$, $\gamma$, $\delta$, $\theta$ and $\vartheta$ are the elasticities of output with respect to capital, labor, total energy consumption, solar electric capacity and wind electric capacity, respectively. $TC_{it}$ stands for the exogenous technical change and $e_{it}$ denotes the error term.

To deepen our analysis, we estimate eq. (3) at three different data aggregation levels: (1) total economy, (2) total manufacturing and (3) manufacturing of machinery and equipment. Consequently, three different models are estimated:

> Model 1: Output (Total economy) = *f*(total economy capital (K), total economy labour (L), total economy energy consumption (EC), solar electric capacity (SOL), wind electric capacity (WND));
>
> Model 2: Output (Manufacturing) = *f*(manufacturing capital (K), manufacturing labour (L), manufacturing energy consumption (EC), solar electric capacity (SOL), wind electric capacity (WND)); and
>
> Model 3: Output (Machinery) = *f*(machinery capital (K), machinery labour (L), machinery energy consumption (EC), solar electric capacity (SOL), wind electric capacity (WND)).

### 3.2 Hypotheses

Based on the available data and the literature on renewable energy-economic growth nexus, we test and discuss two key hypotheses. The first hypothesis is based on the assumption that the expansion of renewable energy penetration through subsidies brings technological improvements and substantial benefits in terms of economic growth in the long-run. After decades of significant support to wind and solar electricity generation capacity across EU countries one might expect that these policy efforts should bear fruit, particularly, in sectors that are involved in producing renewable energy technologies.

> Hypothesis 1: *the EU's renewable energy support policies lead to technological advancement followed by economy growth in the long-run.*

Politicians advocating for renewable energy expansion have been claiming that these kinds of policies not only generate economic growth *in the long-run* but also employment and output growth *in the short-run*. Therefore our second hypothesis is that:

Hypothesis 2: *the EU's renewable energy support policies increase output and employment in the short-run.*

### 3.3 Econometric Strategy

Formally we specify the empirical production model as:

$$y_{it}^{s} = f(k_{it}^{s}, l_{it}^{s}, ec_{it}^{s}, sol_{it}^{s}, wnd_{it}^{s}, \beta'^{s}) + u_{it}^{s}, \qquad (4)$$

where $i$ denotes EU-15 member states, $t$ is time and $s$ indicates the level of data aggregation (Total economy, Manufacturing and Machinery). The variables are in natural logarithms and $y_{it}^{s}$ is economic activity, $k_{it}^{s}$ is capital, $l_{it}^{s}$ is labor, $ec_{it}^{s}$ is final energy consumption, $sol_{it}^{s}$ is solar capacity, $wnd_{it}^{s}$ is wind capacity, $\beta'^{s}$ is a vector of coefficients to be estimated and $u_{it}^{s}$ is composed of both unobserved common factors and a random error term. Eq. (4) is a general empirical representation of the growth model presented in the model section. In particular, the functional form is not specified and the vector of coefficients can be allowed to be country specific (heterogeneous) or constant across country (homogeneous). In this study, we will restrict the functional form to a log-linear specification just for simplicity (the issue of functional forms and its implication is beyond this study, for such issues see Li and Racine (2007). However, we will consider both – restricting the vector of coefficients to be homogeneous and allowing it to vary across countries (heterogeneous). As a consequence we apply two variants of estimators: homogeneous estimators, such as fixed-effect (FE), pooled OLS first-difference estimator among others and heterogeneous estimators such as Pesaran and Smith's (1995) mean group estimator (MG), Pesaran's (2006) common correlated mean group (CCMG) and the Eberhardt and Teal's (2010) augmented mean group estimator (AMG).

The econometric strategy is to apply a non-heterogeneous panel estimator (fixed-effect model) and three variants of the heterogeneous estimators – MG, CCMG and the AMG. Further, we assess the different estimators on how each fit the data generation process based on diagnostic testing to choose the best model among them, and base our analysis on the chosen estimator. Estimating Eq.(4) based on the usual panel estimators such as a fixed-effect model in a situation where unobserved common factors varies across country and time and are correlated with the included covariates, might result in estimates that are biased. To appropriately account for unobserved common factors, we apply an econometric modelling approach based on the "unobserved common factor framework" that will account for unobserved factors including spillovers on the estimated parameters of interest. The approach is briefly presented below, in which for easy exposition we define $x'_{it}$ as a vector of all covariates as specified in Eq. (4), and presented as follows:

$$y_{it}^{s} = \beta_{i}^{s} x_{it}'^{s} + u_{it}^{s} \tag{5}$$

$$u_{it}^{s} = \alpha_{1i}^{s} + \varphi_{i}^{s} f_{t}^{s} + e_{it}^{s} \tag{6}$$

$$x_{it}^{s} = \alpha_{2i}^{s} + \varphi_{i}^{s} f_{t}^{s} + \gamma_{i}^{s} g_{t}^{s} + v_{it}^{s} \tag{7}$$

Where $x_{it}'^{s}$ is a vector of explanatory variables, $v_{it}^{s}$ and $e_{it}^{s}$ are the stochastic error terms, while $f_{t}^{s}$ and $g_{t}^{s}$ are unobserved common factors with heterogeneous factor loading parameters $\varphi_{i}^{s}$ and $\gamma_{i}^{s}$, respectively. The country fixed effect is presented by $\alpha_{1i}^{s}$, which capture time-invariant heterogeneity across panel units. We assumed that, latent processes drive both the dependent variable via Eq. (6) and a vector of explanatory variables via Eq. (7) with possible different strength via $\varphi_{i}^{s}$ and $\gamma_{i}^{s}$. If on average the factor loading parameters are zero, then the usual panel data estimators such as fixed-effect, dynamic panel estimators and variants of them produce consistent and unbiased estimates for the parameter vector $\beta^{s}$, if the assumption that $\beta_{i}^{s} = \beta^{s}$ is true. However, if on average the factor loading parameters are not zero, then the usual panel estimators will be biased and inconsistent as shown in Eberhardt, Helmers et al. (2013).

The expression in Eq. (5) to (7) is estimated for each panel unit and the average panel coefficient for $x_{it}'^{s}$ is calculated as $N^{-1}\sum_{i=1}^{N}\beta_{it}^{s} = \beta^{s}$, hence given a long time period we can have estimates for each panel unit as well as the average over all the panel units to assess if the parameters vary across countries. Details on the unobserved common factor framework are in Pesaran (2006) and Kapetanios, Pesaran et al. (2011). Both the CCMG and AMG estimators are designed based on the unobserved common factor framework as described above, while the MG estimator is not (it only relaxes the homogeneous slope coefficients assumption but do not account for unobserved common factors). The MG approach allows for heterogeneity across panel units by making both the slope coefficients and the error variances to vary across panels units, it however does not incorporate information on unobserved common factors[6] that might be present in the data. The CCMG model unobserved common factors by including cross-sectional averages of the dependent and independent covariates as additional regressors. The idea is to strip-off all (potentially) unobserved common factor effects from the estimates of interest via the included cross-sectional averages. The AMG approach is an alternative to the CCMG, and was developed by Eberhardt and Teal (2010). The only difference between the AMG and the CCMG is in, how the correction is done for the unobserved common factors. Whereas in the CCMG approach, the correction parameters are treated as nuisance, in the case of the AMG estimator, it is treated as a common dynamic process which can have useful interpretation.

Before estimating the four models as presented, four key steps are needed in our empirical strategy: first, a unit root test to determine the time series properties of the data. Second, a cross-sectional dependency test to determine if unobserved common factors need to be accounted for in the estimation process. Third, a cointegration test to determine the long-run relationships between the variables in the model and lastly causality analysis to determine the causal dynamics and to answer our two key hypotheses as presented in the theoretical section.

Two unit root testing procedures are implemented in this study, specifically Pesaran (2007) CIPS test that allows for both heterogeneity and cross-sectional dependency in the unit root test, and CADF test which also accommodate both heterogeneity and cross-sectional dependence, but only differ from the CIPS test in the sense that the test statistic is not an average over the panel units . Details on the CIPS unit root test specification and the CADF test are in Pesaran (2007) and Pesaran (2003), respectively.

Cross-sectional dependence is tested using Pesaran (2004) CD-test, which employs correlation-coefficient between the time series for each of the panel units and use that to calculate the test statistic. The test statistic can generally be express as

$$CD = \sqrt{\frac{2}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{J=i+1}^{N}\sqrt{T_{ij}}\rho_{ij}\right)$$

(8)

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[6] If unobserved common factors are a common feature in the data, not incorporating such information will potential bias the parameter estimates.

Where $N$ is the number of panel units, $\rho_{ij}$ are the correlation-coefficients for each of the panel units and $T_{ij}$ is the number of common time series observations between panel unit $i$ and $j$.The Null hypothesis for this test is cross-sectional independence , and under this, the statistic is distributed standard normal for $T_{ij} > 3$ and large $N$ (Pesaran,2004). The CD-test statistic from various simulations in Pesaran (2004) proved to be robust to nonstationarity, structural breaks, parameter heterogeneity and above all, perform well in small samples. The above test is applicable both on the raw series and also on the estimated residuals. Whereas the cointegration test is implemented based on Pedroni (1999) and Pedroni (2004) panel cointegration approach for heterogeneous panel, where the null hypothesis of no cointegration is tested in nonstationary panels based on seven test statistics. The Pedroni cointegration test is commonly applied in the literature as a consequence, we refer the reader to Pedroni (1999, 2004) for details on this approach.

The last step in our empirical approach is to test for causality based on Granger methodology. We proposed to account for both short-run causality and long-run causality via an error correction framework, while at the same time allowing for parameter heterogeneity in the testing procedure. The causality relationships are examined based on a panel error correction model by taking a first difference of each variable as a function of a lagged difference of each covariate and an error correction term as express below:

$$\Delta y_{it}^{s} = \alpha_{1i}^{s} + \sum_{k=1}^{q} \phi_{11ik}^{s} \Delta y_{it-k}^{s} + \sum_{k=1}^{q} \phi_{12ik}^{s} \Delta k_{it-k}^{s} + \sum_{k=1}^{q} \phi_{13ik}^{s} \Delta l_{it-k}^{s} + \sum_{k=1}^{q} \phi_{14ik}^{s} \Delta ec_{it-k}^{s} + \sum_{k=1}^{q} \phi_{15ik}^{s} \Delta sol_{it-k}^{s}$$
$$+ \sum_{k=1}^{q} \phi_{16ik}^{s} \Delta wnd_{it-k}^{s} + \eta_{1i}^{s} e_{it-1}^{s} + \upsilon_{1it}^{s}$$

(9a)

$$\Delta k_{it}^{s} = \alpha_{2i}^{s} + \sum_{k=1}^{q} \phi_{21ik}^{s} \Delta y_{it-k}^{s} + \sum_{k=1}^{q} \phi_{22ik}^{s} \Delta k_{it-k}^{s} + \sum_{k=1}^{q} \phi_{23ik}^{s} \Delta l_{it-k}^{s} + \sum_{k=1}^{q} \phi_{24ik}^{s} \Delta ec_{it-k}^{s} + \sum_{k=1}^{q} \phi_{25ik}^{s} \Delta sol_{it-k}^{s}$$
$$+ \sum_{k=1}^{q} \phi_{26ik}^{s} \Delta wnd_{it-k}^{s} + \eta_{2i}^{s} e_{it-1}^{s} + \upsilon_{2it}^{s}$$

(9b)

$$\Delta l_{it}^{s} = \alpha_{3i}^{s} + \sum_{k=1}^{q} \phi_{31ik}^{s} \Delta y_{it-k}^{s} + \sum_{k=1}^{q} \phi_{32ik}^{s} \Delta k_{it-k}^{s} + \sum_{k=1}^{q} \phi_{33ik}^{s} \Delta l_{it-k}^{s} + \sum_{k=1}^{q} \phi_{34ik}^{s} \Delta ec_{it-k}^{s} + \sum_{k=1}^{q} \phi_{35ik}^{s} \Delta sol_{it-k}^{s}$$
$$+ \sum_{k=1}^{q} \phi_{36ik}^{s} \Delta wnd_{it-k}^{s} + \eta_{3i}^{s} e_{it-1}^{s} + \upsilon_{3it}^{s}$$

(9c)

$$\Delta ec_{it}^{s} = \alpha_{4i}^{s} + \sum_{k=1}^{q}\phi_{41ik}^{s}\Delta y_{it-k}^{s} + \sum_{k=1}^{q}\phi_{42ik}^{s}\Delta k_{it-k}^{s} + \sum_{k=1}^{q}\phi_{43ik}^{s}\Delta l_{it-k}^{s} + \sum_{k=1}^{q}\phi_{44ik}^{s}\Delta ec_{it-k}^{s} + \sum_{k=1}^{q}\phi_{45ik}^{s}\Delta sol_{it-k}^{s}$$

$$+ \sum_{k=1}^{q}\phi_{46ik}^{s}\Delta wnd_{it-k}^{s} + \eta_{4i}^{s}e_{it-1}^{s} + \upsilon_{4it}^{s}$$

(9d)

$$\Delta sol_{it}^{s} = \alpha_{5i}^{s} + \sum_{k=1}^{q}\phi_{51ik}^{s}\Delta y_{it-k}^{s} + \sum_{k=1}^{q}\phi_{52ik}^{s}\Delta k_{it-k}^{s} + \sum_{k=1}^{q}\phi_{53ik}^{s}\Delta l_{it-k}^{s} + \sum_{k=1}^{q}\phi_{54ik}^{s}\Delta ec_{it-k}^{s} + \sum_{k=1}^{q}\phi_{55ik}^{s}\Delta sol_{it-k}^{s}$$

$$+ \sum_{k=1}^{q}\phi_{56ik}^{s}\Delta wnd_{it-k}^{s} + \eta_{5i}^{s}e_{it-1}^{s} + \upsilon_{5it}^{s}$$

(9e)

$$\Delta wnd_{it}^{s} = \alpha_{6i}^{s} + \sum_{k=1}^{q}\phi_{61ik}^{s}\Delta y_{it-k}^{s} + \sum_{k=1}^{q}\phi_{62ik}^{s}\Delta k_{it-k}^{s} + \sum_{k=1}^{q}\phi_{63ik}^{s}\Delta l_{it-k}^{s} + \sum_{k=1}^{q}\phi_{64ik}^{s}\Delta ec_{it-k}^{s} + \sum_{k=1}^{q}\phi_{65ik}^{s}\Delta sol_{it-k}^{s}$$

$$+ \sum_{k=1}^{q}\phi_{66ik}^{s}\Delta wnd_{it-k}^{s} + \eta_{6i}^{s}e_{it-1}^{s} + \upsilon_{6it}^{s}$$

(9f)

Where $s$ denote the level of data aggregation, $k = 1, \ldots, q$ is the lag length, $\Phi$'s are the short-run coefficients, $e_{it-1}$'s are the lagged error terms from the long-run model and therefore represent the error correction term, while the $\upsilon_{it}$'s are the random error terms for the short-run model. We test short-run causality for each of the variables via the null hypothesis of $H_0$: each $\phi_{mnik}^{s} = 0$, while the long-run causality is via the null hypothesis of $H_0$: each $\eta_{mi}^{s} = 0$, $m$ indexes the equation number in the vector of equations and $n$ indexes the coefficient for each of the variables in the equation.

### 3.4 Data description

The annual data for a set of EU-15 member states covering the period from 1990 to 2012 is collected from Eurostat between May and September of 2014. This gives us a panel of maximum 345 country-level observations.

As discussed in the previous sub-section, we perform our analysis at three different data aggregation levels. Accordingly, three different sets of data are collected. Table 2 provides the detail description and measurement units of each variable used in the analysis.

In Model 1, gross domestic product (GDP) is used as a proxy for total economic output. Gross fixed capital formation proxies capital input, and total employment for labour input. Final energy consumption is used for total economy's energy consumption. In Model 2, gross value added in manufacturing sector, gross fixed capital formation in manufacturing sector, total employment in manufacturing sector and final energy consumption of manufacturing sector proxies total manufacturing's output, capital, labour and energy consumption, respectively. Finally, Model 3 adjusts the variables of Model 2 for the sector of manufacturing of machinery and equipment. This sector corresponds to class 28 in NACE Rev. 2. According to NACE Rev. 2, the statistical classification of economic activities in the European Community (European Commission 2008), the later sector (class 28 in NACE Rev. 2) includes the manufacture of wind turbines and solar collectors used for heating of water.[7] All models use total solar photovoltaic and thermal electric capacity and total wind electrical capacity as the proxy variables of renewable energy policies.

From the descriptive statistics presented in Table 3 it is evident that, on average, the manufacturing sector in the EU is rather energy intensive as it uses about 28 per cent of total economy's final energy consumption. The average share of total employment in this sector is about 18 per cent. The gross value added and final energy consumption of manufacturing of machinery and equipment correspond, on average, to about 12 per cent and 7 per cent of total manufacturing's gross value added and final energy consumption, respectively.

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[7] It is important to note that class 28 in NACE Rev. 2 does not include manufacture of solar cells used for direct transformation of solar power into electricity. This activity should be classified in NACE Rev 2. class 26.11 Manufacture of electronic components. However, this is not explicitly stated in NACE Rev 2. Classification document (European Commission 2008). For exploratory purposes we performed the same analysis for Manufacture of electronic components. However, we did not find any significant results related to wind and solar capacity variables. The full set of results of this exercise is available from the authors upon request.

## Table 2. The description of the variables

| Variable | Description | Measurement units |
|---|---|---|
| *Total Economy* | | |
| Gross domestic product | Gross domestic product at market prices, chained-linked volumes, reference year 2000 (at 2000 exchange rates) | Millions of euros |
| Gross fixed capital formation | Gross fixed capital formation, chained-linked volumes, reference year 2000 (at 2000 exchange rates) | Millions of euros |
| Total employment | Total employment in the economy (resident population concept - Labour Force Survey) | 1000 persons |
| Final energy consumption | All energy supplied to industry, transport, households, services and agriculture, it excludes deliveries to the energy transformation sector and the energy industries themselves | Terajoules |
| *Total Manufacturing, C NACE 2 Rev.* | | |
| Gross value added | Gross value added (at basic prices) in manufacturing, chain-linked volumes, reference year 2000 (at 2000 exchange rates) | Millions of euros |
| Gross fixed capital formation | Gross fixed capital formation in manufacturing, chain-linked volumes, reference year 2005 (at 2005 exchange rates) | Millions of euros |
| Total employment | Total employment in manufacturing - domestic concept | 1000 persons |
| Final energy consumption | All energy supplied to manufacturing industry, it excludes deliveries to the energy transformation sector and the energy industries themselves | Thousand tonnes of oil equivalent |
| *Manufacture of machinery and equipment, 28 NACE 2 Rev.* | | |
| Gross value added | Gross value added (at basic prices) in manufacture of machinery and equipment, chain-linked volumes, reference year 2005 (at 2005 exchange rates) | Millions of euros |
| Gross fixed capital formation | Gross fixed capital formation in manufacture of machinery and equipment, chain-linked volumes, reference year 2005 (at 2005 exchange rates) | Millions of euros |
| Total employment | Total employment in manufacture of machinery and equipment | 1000 persons |
| Final energy consumption | All energy supplied to machinery industry, it excludes deliveries to the energy transformation sector and the energy industries themselves | Thousand tonnes of oil equivalent |
| *RES proxy variables* | | |
| Wind electrical capacity | Wind electrical capacity of main activity producers and autoproducers | Megawatts |
| Solar photovoltaic and thermal electric capacity | Solar photovoltaic and solar thermal electric net maximum capacity | Megawatts |

**Table 3. The descriptive statistics**

| Variable | Measurement units | No. of obsv. | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|---|
| *Total Economy* | | | | | | |
| Gross domestic product | Millions of euros | 324 | 609 770.6 | 645 506.1 | 16 337.6 | 2 343 858 |
| Gross fixed capital formation | Millions of euros | 319 | 120 309.6 | 122 774.5 | 3 198.1 | 455 127.8 |
| Total employment | 1000 persons | 312 | 10 848.7 | 11 186.2 | 162.7 | 40 080 |
| Final energy consumption | Terajoules | 345 | 2 653 960 | 2 680 665 | 130 358 | 9 674 876 |
| *Total Manufacturing, C NACE 2 Rev.* | | | | | | |
| Gross value added | Millions of euros | 308 | 100 199.5 | 114 871.4 | 1 461.3 | 509 833.8 |
| Gross fixed capital formation | Millions of euros | 289 | 16 216.3 | 18 557.3 | 322.9 | 67 215.4 |
| Total employment | 1000 persons | 287 | 1 922.4 | 2 233.3 | 31.7 | 10 088 |
| Final energy consumption | Thousands TOE | 345 | 17 465.1 | 16 523 | 600.6 | 72 167.1 |
| *Manufacture of machinery and equipment, 28 NACE 2 Rev.* | | | | | | |
| Gross value added | Millions of euros | 261 | 11 486.6 | 17 271.3 | 249.6 | 7 6425.7 |
| Gross fixed capital formation | Millions of euros | 251 | 1 340.3 | 1 914.3 | 22.2 | 8 939.3 |
| Total employment | 1000 persons | 245 | 205.4 | 289.2 | 12.6 | 1 436 |
| Final energy consumption | Thousands TOE | 335 | 1 199.9 | 1 496.5 | 8.3 | 5 984.1 |
| *RES proxy variables* | | | | | | |
| Wind electrical capacity* | Megawatts | 345 | 540.5 | 2 796.9 | 1 | 32 644 |
| Solar photovoltaic and thermal electric capacity* | Megawatts | 345 | 2 018.8 | 4 818.5 | 1 | 31 305 |

* Note that as the several sample countries for a few years had no wind or/and solar electricity generation capacity, in order to be able to transform the data series to logarithms we have added 1 to the whole set of data on renewables.

## 4. Results and Discussion

The empirical analysis is done by estimating a fixed-effect model and the three variants of heterogeneous panel models motivated by different assumptions as indicated in the empirical approach section. Before presenting the results from the various estimators, it is important to present the time series properties of the data series and information on cross-sectional dependence before the estimations are done. We tested each of the series for unit root for each of the three levels of aggregation (total economy, manufacturing level and machinery level). The unit root testing is done using both CIPS and CADF tests. The results for the unit root test are presented in Table A1 to A3 in the appendix and provide evidence in support of $I(1)$ process for each of the series at the 5 per cent statistical significance level.

Further, we also tested for cross-sectional dependence and the results as presented in Table 4 indicate that each of the series in our data could not pass the null hypothesis test of cross-sectional independence, implying that each of the data series are correlated across panel units and therefore the econometric strategy should incorporate this into the estimation process, in order to reduce the potential problem of producing bias estimates. We also tested for cointegration, since each of the series in our data-set follow a $I(1)$ process and therefore the need to test if there is a long-run relationship between the variables as specified in equation (4). Pedroni's (1999) panel cointegration approach was implemented in the testing procedure and based on the *t* (non-parametric *t*-test) and Augmented Dickey Fuller (ADF) test statistics, the null hypothesis of no cointegration relationship is rejected at the 5 per cent significance level, implying evidence of the long-run relationship between the variables. This result is presented in Table A4 in the appendix.

The results for each of the four estimators (fixed-effect, MG, CCEMG and AMG) for the long-run model are presented in Table 5. In discriminating between the estimators, we relied on the models diagnostics, especially if the models' residuals pass the cross sectional independence test (Pesaran, 2006 CD-test) and are stationary – $I(0)$. The diagnostic test results as reported in Table 5 favour only the AMG estimator – its residuals are stationary implying non-spurious regression and also pass the CD-test at the 5 per cent significance level, which means that estimates are free from unobserved common factors bias. Whereas the residuals from both the MG and CCEMG estimators are stationary, they however did not pass the CD-test at the 5 per cent significance level for each of three levels of data aggregation. The FE model's residuals only passed the CD-test for both the economy and manufacturing levels of data aggregation at the 5 per cent level of significance, its residuals are however $I(1)$ for each of the three levels of our data analysis. The diagnostic tests therefore provide strong support for the AMG estimator relative to the other three estimators.

**Table 4: Cross-section dependence test (CD) for each of the series for each of three levels of data aggregation (total economy, manufacturing and machinery)**

| Variable | CD-test | *p*-value | Average correlation |
|---|---|---|---|
| | | *Total Economy* | |
| lnY | 41.24 | 0.000 | 0.935 |
| lnK | 31.5 | 0.000 | 0.709 |
| lnL | 33.28 | 0.000 | 0.748 |
| lnEC | 17.66 | 0.000 | 0.404 |
| lnSOL* | 19.68 | 0.000 | 0.896 |
| lnWND | 41.58 | 0.000 | 0.949 |
| | | *Manufacturing* | |
| lnY | 20.95 | 0.000 | 0.497 |
| lnK | 15.4 | 0.000 | 0.372 |
| lnL | 26.67 | 0.000 | 0.656 |
| lnEC | 15.08 | 0.000 | 0.385 |
| lnSOL | 19.68 | 0.000 | 0.896 |
| lnWND | 38.67 | 0.000 | 0.945 |
| | | *Machinery* | |
| lnY | 20.96 | 0.000 | 0.640 |
| lnK | 6.79 | 0.000 | 0.196 |
| lnL | 3.63 | 0.000 | 0.114 |
| lnEC | 1.52 | 0.129 | 0.056 |
| lnSOL | 29.03 | 0.000 | 0.901 |
| lnWND | 30.57 | 0.000 | 0.949 |

Notes: Under the null hypothesis of cross-section independence CD ~ N (0, 1), implying that a *p*-value less than 0.05, we reject the null of cross-section independence at the 5% significance level and will imply cross-sectional dependence.

We present the results of long-run elasticities of all estimated modes in Table 5. According to the estimates from the AMG model, in the long-run a 1 per cent increase in solar and wind capacity will result in 0.004 and 0.002 per cent drop in *total* EU economy’s GDP, respectively. However, these point estimates are barely significant at conventional significance levels. Our findings oppose the common findings of the comparable empirical studies that in the long-run expansion of renewable energy enhance economic growth. Interestingly, all our estimated long-run models provide similar long-run estimates for wind and solar capacity.

One might expect that the positive effects of renewable energy support schemes should be visible at least in manufacturing sectors, if any. However our estimators for our variables of interest remain largely consistent for total manufacturing and the sector of machinery and equipment (see Table 5). Therefore we conclude that we find no support for Hypothesis 1.

**Table 5: Regression results for four different estimators for long-run models**

| Variables | (FE) | (MG) | (AMG) | (CCEMG) |
|---|---|---|---|---|
| *Total Economy* | | | | |
| lnK | 0.191$^{**}$ | 0.271$^{***}$ | 0.154$^{***}$ | 0.177$^{***}$ |
| | (0.083) | (0.032) | (0.020) | (0.021) |
| lnL | 0.310 | 0.182$^{*}$ | 0.199$^{***}$ | 0.161 |
| | (0.241) | (0.102) | (0.073) | (0.122) |
| lnEC | 0.244$^{**}$ | 0.101$^{***}$ | 0.102$^{***}$ | 0.120$^{***}$ |
| | (0.097) | (0.028) | (0.023) | (0.036) |
| lnSOL | -0.013 | -0.011$^{*}$ | -0.004$^{*}$ | -0.002 |
| | (0.008) | (0.006) | (0.002) | (0.003) |
| lnWND | -0.006 | 0.003 | -0.002 | -0.002 |
| | (0.007) | (0.005) | (0.005) | (0.010) |
| *Diagnostics* | | | | |
| CD-Test | -0.84 | 7.37 | -0.62 | 6.16 |
| | (0.401) | (0.000) | (0.533) | (0.000) |
| Integration | *I* (1) | *I* (0) | *I* (0) | *I* (0) |
| *Manufacturing* | | | | |
| lnK | 0.134 | 0.142$^{***}$ | 0.0922$^{***}$ | 0.175$^{***}$ |
| | (0.088) | (0.032) | (0.024) | (0.053) |
| lnL | 0.332 | 0.196 | 0.234$^{**}$ | 0.275 |
| | (0.260) | (0.136) | (0.118) | (0.438) |
| lnEC | 0.427$^{**}$ | 0.496$^{***}$ | 0.181$^{***}$ | 0.288$^{**}$ |
| | (0.150) | (0.132) | (0.053) | (0.131) |
| lnSOL | -0.034$^{**}$ | -0.005 | 0.003 | -0.015$^{*}$ |
| | (0.014) | (0.006) | (0.004) | (0.008) |
| lnWND | -0.008 | -0.010 | -0.013 | -0.044$^{**}$ |
| | (0.019) | (0.020) | (0.011) | (0.021) |
| *Diagnostic* | | | | |
| CD-Test | 0.19 | 7.63 | -0.42 | 2.59 |
| | (0.846) | (0.000) | (0.677) | (0.010) |
| Integration | *I*( 1) | *I*(0 ) | *I*(0 ) | *I*(0 ) |
| *Machinery* | | | | |
| lnK | 0.111$^{*}$ | 0.151$^{***}$ | 0.127$^{***}$ | 0.252$^{***}$ |
| | (0.060) | (0.039) | (0.034) | (0.072) |
| lnL | 0.531$^{***}$ | 0.715$^{***}$ | 0.481$^{**}$ | 0.730$^{***}$ |
| | (0.161) | (0.215) | (0.192) | (0.231) |
| lnEC | -0.049 | 0.002 | 0.037 | 0.091 |
| | (0.038) | (0.074) | (0.054) | (0.127) |
| lnSOL | -0.044$^{***}$ | 0.016 | 0.012 | -0.036$^{**}$ |
| | (0.012) | (0.031) | (0.011) | (0.015) |
| lnWND | 0.023$^{*}$ | -0.062$^{***}$ | -0.017 | -0.058$^{**}$ |
| | (0.012) | (0.022) | (0.022) | (0.027) |
| Diagnostics | | | | |
| CD-Test | 8.06 | 10.89 | -0.81 | 2.25 |
| Integration | (0.000) | (0.000) | (0.417) | (0.024) |
| | *I* (0/1) | *I* (0) | *I* (0) | *I* (0) |

Notes: Under the null hypothesis of cross-section independence CD ~ N (0, 1), the integration indicate if the residual is stationary (*I* (0)) or otherwise. Fixed effect, mean group, augmented mean group and the common corrected mean group models are represented as FE, MG, AMG and CCEMG, respectively. Standard errors in parentheses (robust standard errors), $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

Table 6 reports the panel causality results from estimating the panel vector error correction models for each data aggregation level. In line with the findings of Ohler and Fetters (2014) we find that there is evidence of short-term Granger causality stemming from wind capacity to output at all data aggregation levels. This result lends support to our Hypothesis 2 suggesting that in the short-run the EU's renewable policies directed to wind capacity expansion have a direct positive impact on the EU's economy. This finding could be explained by the fact that local EU wind turbine manufactures have been competitive across the globe (European Commission 2014).

**Table 6: Causality test in panel ECM model with heterogeneous parameters**

| | Sources of causation (independent variables) | | | | | | |
|---|---|---|---|---|---|---|---|
| Dept.variable | ΔlnY | ΔlnK | ΔlnL | ΔlnEC | ΔlnSOL | ΔlnWND | ECT |
| *Total Economy* | | | | | | | |
| ΔlnY | | 119.3*** | 26.19* | 29.93* | 16.21 | 46.89*** | 44.91*** |
| | | [0.23] | [-0.00] | [0.01] | [-0.01] | [0.02] | [-0.39] |
| ΔlnK | 82.03*** | | 93.83*** | 11.62 | 21.51 | 34.05** | 64.72*** |
| | [1.05] | | [1.35] | [0.25] | [0.00] | [0.06] | [-0.28] |
| ΔlnL | 32.94** | 28.83* | | 44.59*** | 12.70 | 115.6*** | 262.19*** |
| | [0.002] | [0.02] | | [-0.09] | [0.00] | [0.01] | [-0.47] |
| ΔlnEC | 36.68** | 27.38* | 27.69* | | 35.59*** | 39.26** | 206.75*** |
| | [0. 91] | [0 .04] | [-0.56] | | [0 .03] | [-0.05] | [-0.80] |
| ΔlnSOL* | 16.05* | 19.58** | 2.68 | 24.96** | | 27.86*** | 38.75*** |
| | [-3.58] | [3.70] | [-1.23] | [4.02] | | [-0.69] | [-0.31] |
| ΔlnWND | 36.73** | 48.99*** | 30.14* | 68.47*** | 27.17* | | 87.05*** |
| | [-6.27] | [0.81] | [2.95] | [2.06] | [-0.24] | | [-0.49] |
| *Manufacturing* | | | | | | | |
| ΔlnY | | 68.68** | 30.75** | 59.94*** | 20.58 | 55.40*** | 92.94*** |
| | | [0.13] | [-0.21] | [0.21] | [-0.02] | [0.02] | [-0.61] |
| ΔlnK | 14.74 | | 78.82*** | 14.52 | 39.39*** | 15.75 | 130.95*** |
| | [-0.13] | | [1.84] | [-0.13] | [0.03] | [0 .11] | [-0.85] |
| ΔlnL | 24.15* | 23.85* | | 24.04* | 17.43 | 13.43 | 167.94*** |
| | [-0.01] | [0.01] | | [0.03] | [-0.01] | [0.01] | [-0.26] |
| ΔlnEC | 19.39 | 131.48*** | 18.26 | | 18.46 | 36.34*** | 99.48*** |
| | [-0.13] | [-0.06] | [-2.43] | | [-0.16] | [0.19] | [-1.45] |
| lnSOL* | 21.93 | 23.83* | 21.90 | 21.35 | | 31.58** | 22.63* |
| | [-0.65] | [0.09] | [-9.39] | [2.34] | | [-0.18] | [-0.28] |
| ΔlnWND | 23.95* | 18.64 | 27.79* | 15.89 | 17.05 | | 46.84*** |
| | [-1.45] | [-0.10] | [-5.21] | [1.84] | [-0.23] | | [-0.46] |
| *Machinery* | | | | | | | |
| ΔlnY | | 26.75*** | 43.57*** | 40.69*** | 42.07*** | 8.32 | 136.28*** |
| | | [0.17] | [0.52] | [-0.23] | [-0.05] | [0.08] | [-0.59] |
| ΔlnK | 10.75 | | 20.18* | 11.31 | 9.31 | 13.22 | 63.08*** |
| | [0.83] | | [-0.45] | [-0.16] | [0.19] | [-0.59] | [-0.69] |
| ΔlnL | 18.37* | 8.85 | | 17.06 | 28.21** | 4.94 | 67.42*** |
| | [0.47] | [-0.16] | | [0.08] | [0.06] | [-0.14] | [-0.15] |
| ΔlnEC | 25.66** | 16.59 | 23.35** | | 17.48 | 6.81 | 50.55*** |
| | [-1.04] | [-0.08] | [-0.90] | | [-0.23] | [0.48] | [-1.04] |
| ΔlnSOL | 14.17 | 7.24 | 11.17 | 15.77 | | 22.24* | 44.10*** |
| | [-7.26] | [3.29] | [6.58] | [-0.58] | | [1.79] | [-0.17] |
| ΔlnWND | 9.78 | 7.73 | 4.38 | 13.58 | 9.68 | | 35.01*** |
| | [1.80] | [-0.38] | [-1.76] | [0.86] | [0.37] | | [0.55] |

The test statistics are the values not in square brackets and the estimated coefficients are presented in square brackets. The null hypothesis is Granger non-causality. Level of significance for the test statistic is represented by stars: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

When it comes to the effects of wind capacity expansion on employment, we find that wind capacity has a positive and statistically significant impact on total employment in the short-run at the total economy level (again, in line with Ohler and Fetters (2014)), but not at the manufacturing and machinery sector levels. While this finding lends support to Hypothesis 2 for the case of wind capacity development, we do not find the same results for solar capacity.

The results presented in Table 6 show that solar capacity expansion has a negative effect on output not only in the long-run but also in the short-run (though this result is only significant at the machinery level). Given the very high subsidies per installed capacity for solar, this finding might be explained by crowding-out of capital from more productive sectors to less productive ones. Even though, we find that solar capacity expansion has a positive impact on employment in manufacturing of machinery and equipment, this is not the case at both the manufacturing and total economy levels.

In summary, our findings on the impacts of renewable energy expansion on *total* economic growth and *total* employment give us some evidence to support Hypothesis 2 in the case of wind power capacity expansion but not in the case of solar.

## 5. Conclusions and final remarks

Renewable energy has attracted a lot of interest both in the academia and among policy makers for the last decade, especially in the EU region. This surge in interest in renewable energy and consequently policies targeting the promotion of renewable energy is as a result of the increased awareness of the impact of human activities on the climate and the security concerns posed by high reliance on fossil fuel based energies. Promoting renewable energy is therefore seen as one of the options to mitigate climate change and foster learning-by-doing and knowledge spillovers in related manufacturing sectors. It is also seen as a measure to reduce energy insecurity and lastly as growth enhancing measure via job creation. These potential positive outcomes associated with renewable energy make it very appealing to policy makers.

In this paper we provided a detailed but careful analysis of the data to understand the impact of the EU's renewable energy policies on output and employment in the EU-15 region. Given the EU's Renewable Energy Directive requirement (that renewables accounts for at least 20 per cent of its total energy need), it is important to understand the potential implication of such a policy on output and employment both in the short-run and in the long-run. As a consequence, we explored many econometric methods that account for unobserved common factor effects, endogeneity, and both homogeneous and heterogeneous parameters to answer our key questions.

Moreover, instead of relying on renewable energy consumption or generation as commonly done in the literature, we use solar and wind capacity as the proxies for renewable energy policies. In general our results provide evidence in support of the hypothesis that renewable energy policies promote growth and employment in the short-run, especially in the case of wind capacity, but do not support the hypothesis that these policies promote growth in the long-run. A possible explanation for the insignificant effect of renewable energy on output in the long-run is that the renewable energy technologies are still not well developed to benefit from international trade that can generate employment opportunities beyond domestic markets to levels that can generate positive impact on growth. Another explanation could be from the crowding out channel, where renewable energy investments crowd out investments in other sectors that are more productive relative to the renewable energy sector. However, we must recognise that the potential total impact of renewable energy policies depends on many factors including the growth in the global demand for renewable energy, the primary target of the policy (such as reduction in fossil fuel use and related air pollution, security and sustainability concern and environmental damages from fossil fuel extraction), and the interactions between the renewable energy sector and the other sectors in the economy. Therefore the economic impacts of renewable energy policies are multi-dimensional: a poor outcome in one dimension might be overcome by a positive outcome in another dimension.

## References

Apergis, N. and J. E. Payne (2010). "Renewable energy consumption and economic growth: Evidence from a panel of OECD countries." Energy Policy **38**: 656-660.

Apergis, N. and J. E. Payne (2010). "Renewable energy consumption and growth in Eurasia." Energy Economics **32**: 1392-1397.

Apergis, N. and J. E. Payne (2011). "On the causal dynamics between renewable and non-renewable energy consumption and economic growth in developed and developing countries." Energy Systems **2**(3-4): 299-312.

Apergis, N. and J. E. Payne (2012). "Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model." Energy Economics **34**: 733-738.

Apergis, N. and J. E. Payne (2014). "The causal dynamics between renewable energy, real GDP, emissions and oil prices: evidence from OECD countries." Applied Economics **46**(36): 4519-4525.

Apergis, N., J. E. Payne, et al. (2010). "On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth." Ecological Economics **69**: 2255-2260.

Bayraktutan, Y., M. Yilgör, et al. (2011). "Renewable Electricity Generation and Economic Growth: Panel-Data Analysis for OECD Members." International Research Journal of Finance and Economics **66**: 59-66.

Ben Jebli, M. and S. Ben Youssef (2014). Output, renewable and non-renewable energy consumption and international trade: Evidence from a panel of 69 countries. MPRA paper.

Bergmann, A., N. Hanley, et al. (2006). "Valuing the attributes of renewable energy investments." Energy Policy **34**(9): 1004-1014.

Canton, J. and Johannesson Lindén, Å. (2010). “Support schemes for renewable elctricity in the EU.” Economic Papers, European Commission.

Eberhardt, M., C. Helmers, et al. (2013). "Do spillovers matter when estimating private returns to R&D?" The Review of Economics and Statistics **95**(2): 436–448.

Eberhardt, M. and F. Teal (2010). Productivity analysis in global manufacturing production. Economics Series Working Papers, University of Oxford, Department of Economics.

European Commission (2008). NACE Rev. 2 – Statistical classification of economic activities in the European Community. Eurostat: Methodologies and Working papers. Luxembourg, Office for Official Publications of the European Communities.

European Commission (2014). Energy Economic Developments in Europe. European Economy. **1-2014**.

European Parliament and Council (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance) t. E. P. a. t. C. o. t. E. Union.

EWEA (2005). Support Schemes for Renewable Energy: A comparative Analysis of Payment Mechanisms in the EU, European Wind Energy Association.

IEA (2014). Medium-Term Renewable Energy Market Report 2014: Market Analysis and Forecasts to 2020, International Energy Agency.

Inglesi-Lotz, R. (2015). "The impact of renewable energy consumption to economic growth: A panel data application." Energy Economics, http://dx.doi.org/10.1016/j.eneco.2015.01.003.

Haas, R., Panzer, Ch., Resch, G., Ragwitz, M., Reece, G., and Held, A. (2011). “A historical review of promotion strategies for electricity from renewable energy sources in EU countries. “ Renewable and Sustainable Energy Reviews **15**: 1003-1034.

Kapetanios, G., M. H. Pesaran, et al. (2011). "Panels with Nonstationary Multifactor Error Structures." Journal of Econometrics **160**: 326-348.

Kula, F. (2014). "The Long-run Relationship Between Renewable Electricity Consumption and GDP: Evidence From Panel Data." Energy Sources, Part B: Economics, Planning, and Policy **9**(2): 156-160.

Lehr, U., C. Lutz, et al. (2012). "Green jobs? Economic impacts of renewable energy in Germany." Energy Policy **47**: 358-364.

Li, Q. and J. S. Racine (2007). Nonparametric econometrics: theory and practice. Woodstock, the UK, Princeton University Press.

Menegaki, A. N. (2011). "Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis." Energy Economics **33**: 257-263.

Ohler, A. and I. Fetters (2014). "The causal relationship between renewable electricity generation and GDP growth: A study of energy sources." Energy Economics **43**: 125-139.

Pedroni, P. (1999). "Critical values for cointegration tests in heterogeneous panels with multiple regressors." Oxford Bulletin of Economics and Statistics **61**: 653-670.

Pedroni, P. (2004). "Panel Cointegration: Asymptotic and finite sample properties of pooled time series tests with application to PPP hypothesis." Econometric Theory **20**(3): 597-625.

Pesaran, M. H. (2003). A Simple Panel Unit Root Test in the Presence of Cross Section Dependence. Cambridge Working Papers in Economics.

Pesaran, M. H. (2004). General Diagnostic Tests for Cross Section Dependence in Panels. Cambridge Working Papers in Economics.

Pesaran, M. H. (2006). "Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure." Econometrica **74**(4): 967-1012.

Pesaran, M. H. (2007). "A simple panel unit root test in the presence of cross section dependence." Journal of Applied Econometrics **22**: 265-312.

Pesaran, M. H. and R. P. Smith (1995). "Estimating Long-Run Relationships from Dynamic Heterogeneous Panels." Journal of Econometrics **68**: 79-113.

Sadorsky, P. (2009). "Renewable energy consumption and income in emerging economies." Energy Policy **37**(4021–4028).

Sadorsky, P. (2009). "Renewable energy consumption, $CO_2$ emissions and oil prices in the G7 countries." Energy Economics **31**: 456–462.

Salim, R. A., K. Hassan, et al. (2014). "Renewable and non-renewable energy consumption and economic activities: Further evidence from OECD countries." Energy Economics **44**: 350-360.

Sebri, M. (2015). "Use renewables to be cleaner: Meta-analysis of the renewable energy consumption–economic growth nexus." Renewable and Sustainable Energy Reviews **42**: 657-665.

The Economist (2010, August). “The global riva of industrial policy: Picking winners, saving losers.”

Ucan, O., E. Aricioglu, et al. (2014). "Energy Consumption and Economic Growth Nexus: Evidence from Developed Countries in Europe." International Journal of Energy Economics and Policy **4**(3): 411-419.

## Appendix

### Table A1: Unit root test for each of the series at the total economy level

| | | CIPS test NO Trend | | CIPS test With Trend | | Pesaran CADF test |
|---|---|---|---|---|---|---|
| | Lags | Test Stats | Lags | Test Stats | Lags | Test Stats |
| lnY | 2 | 3.077 | 2 | 3.246 | 2 | 2.038 |
| | | (0.999) | | (0.999) | | (0.979) |
| ΔlnY | 0 | -5.374 | 0 | -4.705 | 0 | -5.374 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnK | 2 | 3.077 | 2 | 3.246 | 2 | 3.077 |
| | | (0.999) | | (0.999) | | (0.999) |
| ΔlnK | 0 | -5.439 | 0 | -5.282 | 0 | -5.439 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnL | 2 | 2.679 | 2 | 0.937 | 2 | 2.679 |
| | | (0.996) | | (0.826) | | (0.996) |
| ΔlnL | 0 | -3.593 | 0 | -3.966 | 0 | -5.439 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnEC | 2 | -2.708 | 2 | -1.133 | 4 | -2.082 |
| | | (0.003) | | (0.129) | | (0.106) |
| ΔlnEC | 0 | -11.098 | 0 | -10.121 | 0 | -4.550 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnSOL | 2 | 0.855 | 2 | 2.565 | 2 | -1.556 |
| | | (0.804) | | (0.995) | | (0.804) |
| ΔlnSOL | 0 | -3.859 | 0 | -2.275 | 0 | -2.737 |
| | | (0.000) | | (0.011) | | (0.000) |
| lnWND | 2 | -1.027 | 2 | 1.445 | 2 | -2.027 |
| | | (0.152) | | (0.926) | | (0.152) |
| ΔlnWND | 0 | -8.578 | 0 | -7.790 | 0 | -3.918 |
| | | (0.000) | | (0.000) | | (0.000) |

The null hypothesis is that of a unit root, both the CIPS and CADF test allows for heterogeneity and cross-sectional dependency in the unit root test. The first difference (change) is denoted by Δ and the numbers in parenthesis are the *P*-values for the unit root test statistic. The lag length is chosen base on AIC.

## Table A2: Unit root test for each of the series at the manufacturing level

| | | CIPS test NO Trend | | CIPS test With Trend | | Pesaran CADF test |
|---|---|---|---|---|---|---|
| | Lags | Test Stats | Lags | Test Stats | Lags | Test Stats |
| lnY | 2 | 31.665 | 2 | 14.977 | 2 | 2.291 |
| | | (0.383) | | (0.990) | | (0.989) |
| ΔlnY | 0 | -7.188 | 0 | -7.231 | 0 | -7.188 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnK | 2 | 0.899 | 2 | 2.549 | 2 | 0.899 |
| | | (0.816) | | (0.995) | | (0.816) |
| ΔlnK | 0 | -10.881 | 0 | -9.085 | 0 | -10.881 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnL | 2 | 4.197 | 2 | -0.184 | 2 | 4.197 |
| | | (1.000) | | (0.427) | | (1.000) |
| ΔlnL | 0 | -0.886 | 0 | -0.689 | 0 | -0.886 |
| | | (0.188) | | (0.246) | | (0.188) |
| lnEC | 2 | 3.308 | 2 | 1.799 | 2 | 3.308 |
| | | (1.000) | | (0.964) | | (1.000) |
| ΔlnEC | 0 | -11.485 | 0 | -11.466 | 0 | -11.485 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnSOL | 2 | 0.855 | 2 | 2.565 | 2 | -1.556 |
| | | (0.804) | | (0.995) | | (0.804) |
| ΔlnSOL | 0 | -3.859 | 0 | -2.275 | 0 | -2.737 |
| | | (0.000) | | (0.011) | | (0.000) |
| lnWND | 2 | -1.027 | 2 | 1.445 | 2 | -2.027 |
| | | (0.152) | | (0.926) | | (0.152) |
| ΔlnWND | 0 | -8.578 | 0 | -7.790 | 0 | -3.918 |
| | | (0.000) | | (0.000) | | (0.000) |

The null hypothesis is that of a unit root, both the CIPS and CADF test allows for heterogeneity and cross-sectional dependency in the unit root test. The first difference (change) is denoted by Δ and the numbers in parenthesis are the *P*-values for the unit root test statistic. The lag length is chosen base on AIC.

## Table A3: Unit root test for each of the series at the machinery level

| | | CIPS test NO Trend | | CIPS test With Trend | | Pesaran CADF test |
|---|---|---|---|---|---|---|
| | Lags | Test Stats | Lags | Test Stats | Lags | Test Stats |
| lnY | 2 | -0.994 | 2 | -0.339 | 2 | -0.994 |
| | | (0.160) | | (0.367) | | (0.160) |
| ΔlnY | 0 | -6.256 | 0 | -6.126 | 0 | -6.256 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnK | 2 | 3.095 | 2 | 2 4.198 | 2 | 3.095 |
| | | (0.999) | | (1.000) | | (0.999) |
| ΔlnK | 0 | -9.447 | 0 | -8.540 | 0 | -9.447 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnL | 2 | 2.736 | 2 | 4.792 | 2 | 2.736 |
| | | (0.997) | | (1.000) | | (0.997) |
| ΔlnL | 0 | -5.907 | 0 | -5.096 | 0 | -5.907 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnEC | 2 | 2.199 | 2 | 5.030 | 2 | 2.199 |
| | | (0.986) | | (1.000) | | (0.986) |
| ΔlnEC | 0 | -9.935 | 0 | -8.709 | 0 | -9.935 |
| | | (0.000) | | (0.000) | | (0.000) |
| lnSOL | 2 | 0.855 | 2 | 2.565 | 2 | -1.556 |
| | | (0.804) | | (0.995) | | (0.804) |
| ΔlnSOL | 0 | -3.859 | 0 | -2.275 | 0 | -2.737 |
| | | (0.000) | | (0.011) | | (0.000) |
| lnWND | 2 | -1.027 | 2 | 1.445 | 2 | -2.027 |
| | | (0.152) | | (0.926) | | (0.152) |
| ΔlnWND | 0 | -8.578 | 0 | -7.790 | 0 | -3.918 |
| | | (0.000) | | (0.000) | | (0.000) |

The null hypothesis is that of a unit root, both the CIPS and CADF test allows for heterogeneity and cross-sectional dependency in the unit root test. The first difference (change) is denoted by Δ and the numbers in parenthesis are the *P*-values for the unit root test statistic. The lag length is chosen base on AIC.