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Renewable electricity and sustainable development goals in the EU

Ranjula Bali Swain[a,b,1], Amin Karimu[c,*]

[a] Misum, Stockholm School of Economics, Stockholm, Sweden
[b] Södertörn University, Stockholm, Sweden
[c] University of Ghana Business School, Legon, Ghana

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ABSTRACT

Renewable energy (RE) has a strong synergy with some of the sustainable development goals (SDGs), thus its successful deployment can potentially result in an impact on these SDGs. In this study, we examine the synergy effect of renewable electricity on selected SDGs via the electricity prices for the European Union (EU) countries. Using panel data and a two-step estimation approach, our findings indicate a strong synergy effect between renewable electricity prices, SDG 7 (affordable and clean energy) and SDG 8 (decent work and economic growth). The results further reveal that SDG 12 (responsible production and consumption) accounts for most of the future renewable electricity price variation (excluding self-effect), whereas future variation in SDG 7 (affordable and clean energy) and SDG 13 (climate action) are explained mostly by SDG 8 and SDG 12, respectively.

1. Introduction

The sustainable development of the energy system lies at the core of sustainable development and it critically depends on three technological changes – energy savings, energy efficiency and replacement of fossil fuels with renewable energy sources (RES) Lund (2007).[2] Renewable energy is considered among policy makers as one of the potential solutions to climate change, energy security and sustainable growth. The share of renewables in final energy consumption in the EU have increased to about 17 percent in 2016, an increase of 8.5 percent over the 2004 value. The environmental benefits of scaling-up renewables are substantial in the electricity sector, with replacement of the carbon-based systems. There is a clear link between the up-take in renewables, especially in electricity generation and carbon emission reduction. The growth in EU's renewable energy between 2005 and 2015 resulted in an estimated 436 Mt of gross avoided CO2 emissions (EEA, 2017). Out of this, renewable electricity accounted for 76 percent of the CO2 reduction; heating and cooling accounted for 15 percent; while the transport sector resulted in the remaining 9 percent. This suggests that the enormous environmental benefits of renewable energy will be generated mostly from the electricity sector. However, the benefits of scaling-up renewables in the energy system may also pose certain challenges such as the possibility of negative prices for generated electricity from intermittent sources such as wind and solar.[3]

Our objective is two-fold. First, we assess the impact of renewable electricity demand on electricity price. Second, we investigate the impact of renewable electricity on key sustainable development goals (SDGs) that are closely connected to renewable energy via the price effect. Studies in this area focus on the impact of renewable energy price on the energy system in silos (Lund,

* Corresponding author.
E-mail addresses: Ranjula.Bali@hhs.se (R.B. Swain), a.karimu@ug.edu.gh (A. Karimu).

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[2] Achieving a significant replacement of fossil fuels with renewables is difficult as compared to energy savings and energy efficiency. This is partly due to the fact that, energy systems of most countries are built on conversional energy technology (fossil fuel). Introducing a large share of renewables into such a system requires a significant infrastructure, technology and personnel change, for a smooth transition towards renewables. Another challenge is the intermittency of supply in a system with near 100 percent renewables. This is especially problematic in the electricity sector, where storage is difficult.

[3] For instance, periods with low demand but with a high supply of electricity (generated from wind and solar energy) may lead to the possibility of negative prices.

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1999; Lund, 2007) without studying their impact on other sectors. We extend this investigation to include the impact on SDGs such as SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 12 (responsible production and consumption) and SDG 13 (climate action), chosen because of their close association with energy use. High energy prices affect affordability of clean energy due to the different impact it has on the various income groups within the society. It also has implications on jobs and economic growth via cost of production. High energy prices may also affect both consumption and production patterns, and also have an effect on the climate. According to Wuester et al. (2015), the world avoided about 3.1 gigatons of CO2 equivalent emissions in 2012 due to uptake in renewables in electricity generation. This figure translates to about 20 percent global emission reduction.

We focus on the electricity sector instead of the aggregate energy due to three main reasons. First, it is a sector that is projected to grow rapidly in the future due to increasing electrification of end-uses of energy from the households to the transportation sector. It is projected that electricity will account for 40 percent of the rise in energy demand from the current level to the projected 2040 level (IEA, 2017). Second, it is a sector, where the EU has achieved a significant renewable penetration, about 28 percent in 2014 (EEA, 2017). This is significant compared to the biofuels penetration in the transport sector, which has managed to achieve only 6 percent penetration. Third, the progress being made in the penetration of electric vehicles and the potential for future uptake (made possible by improvement in technology and reduction in costs), will contribute significantly to the future demand for electricity. Moreover, projections on the reduction in the cost of battery technology suggests future dramatic increases in the electricity demand, especially for the EU region, which is among the fastest growing region for electric vehicles (IEA, 2017).

The analysis in this study is based on Eurostat data for 28 EU countries over the period 2000–2016. Additional variables are merged from the World Development Indicators (WDI). Employing the Seemingly Unrelated Regression Estimation (SURE) we first estimate the renewable electricity prices. In step two, the Vector Autoregressive (VAR) framework is used to model the interlinkages between the renewable energy prices and the selected SDGs.

Our results suggest that there is a strong synergy effect of renewable electricity price on SDG 7 and SDG 8. It also reveals that the future renewable price movements are likely to be influenced more by SDG 12 (excluding the effect from itself), whereas the future movement in both SDG 7 and SDG 13 is likely to be influenced more by SDG 8 and SDG 12. More importantly, the impact of shocks on renewable electricity price, SDG7 and SDG13 are non-permanent in nature.

Recent literature focuses on establishing energy indicators for sustainable development (e.g., Frondel, Ritter, Schmidt, and Vance (2010), Mathiesen, Lund, and Karlsson (2011), Blazejczak, Braun, Edler, and Schill (2014) and assessing motives for renewable energy adoption (Arkesteijn & Oerlemans, 2005; Balcombe, Rigby, & Azapagic, 2014; Bergek and Mignon, 2017). Lund (1999, 2007) examine the impact of renewable energy price on the energy system, but stop there. The interlinkages to and impact on other SDGs remain largely uninvestigated. Intuitively high energy prices impact affordability of clean energy (SDG 7) due to the differential impact it has on the various income groups within the society. Correspondingly, it also has implications on jobs and economic growth via cost of production. It thus, affects both consumption and production pattern and has an effect on the environment and consequently climate change.

The structure of the paper is as follows. The next section presents a review of the literature. This is followed with a description of the theoretical underpinnings and the methods used (in Section 3). The data and the results are discussed in the next two sections. And the final section presents the main conclusions.

2. Literature review

Previous studies on renewable energy broadly address three main focus areas, its effect on the economy (e.g., Frondel et al., 2010, Mathiesen et al., 2011; Blazejczak et al., 2014), the price effect (e.g., Sensfu et al., 2008; Traber and Kemfert, 2009; Lund and Mathiesen, 2009; Mulder & Scholtens, 2013) and the green energy plan and strategies for sustainable development (e.g., Lund,1999; Lund, 2007; Streimikiene et al., 2007; Vera and Langlois, 2007; Tsai, 2010). These studies however, do not consider the indirect effect of renewable energy uptake on SDGs through the price channel, which has behavioral consequences.

Blazejczak et al. (2014) study the net economic effect associated with renewable energy resource deployment in Germany until 2030 using a sectoral energy-economic econometric model (SEEEM). The result of the study reveals a positive net effect on economic growth for Germany. Their study does not consider the potential environmental impacts nor the price effects of promoting renewable energy deployment. In a related study, Mulder and Scholtens (2013) investigate the impact of renewable energy on electricity prices in Netherlands for the period 2006–2011 using a reduced form equation. The results of the study reveal that the average wind speed in Germany negatively affects Dutch electricity prices. This effect is fairly constant despite the significant increase in German wind energy capacity. However, the impact of wind speed in the Netherlands on Dutch electricity prices, slightly increased.

Investigating the economic impact of promoting renewable energy technologies in Germany between 2001 and 2008, Frondel et al. (2010) find that Germany's principal mechanism of supporting renewable technologies through the feed-in tariffs imposes high costs without any positive impacts on employment, emissions reductions, energy security or technological innovations. This finding is contrary to Blazejczak et al. (2014) findings of a net positive economic effect. It is important to interpret the two studies in the context of the period covered. Frondel et al. (2010) covered an early time period, where the potential economic benefits had not matured to reflect a positive effect on specific components such as employment, emission reduction, energy security and the maturity of the policy.

Traber and Kemfert (2009) assess the impact of German support for renewable energy on electricity prices, emissions and firms by employing quantitative electricity market model. Their research reveals that the total effect of the German renewable support policy, increases the German consumer price marginally by 3 percent whereas the producer price decreases by 8 percent. In addition, emissions from electricity generation in Germany are reduced by 11 percent but are barely changed on the European scale.

Analyzing the impact of renewable electricity generation on spot market price in Germany for the period of 2001–2006, Sensfu, Ragwitz, and Genoese (2008) generate an agent-based simulation platform, which revealed that the financial volume of the price reduction is considerable. The substantial value of the merit-order effect indicates that the cost for the Erneuerbare Energien Gesetz (EEG)[4] support to renewable electricity generation for consumers is dramatically reduced once this effect is considered. Suggesting that, without such a support, the cost of generated

[4] This is the German renewable electricity act which set-up a feed-in payment obligation by government to producers of renewable power in Germany. The payment generally refers to as feed-in-tariff is prescribed by law and guaranteed for 20 years.

electricity from renewables would be less competitive relative to that from non-renewable sources.

Lund (2007) discusses the problems and perspectives of converting the present energy system into a 100 percent renewable energy system in Denmark. The study uses Energy-PLAN energy system analysis model as an estimation technique. It concludes that such development is feasible with the necessary renewable energy sources present, if further technological improvements of the energy system are achieved, the renewable energy system can be created. Especially technologies of converting the transportation sector and the introduction of flexible energy system technologies are crucial. This study however did not consider the electricity price effect of such a system and how that will affect affordability and access.

Also, Streimikiene, Ciegis, and Grundey (2007) examine energy indicators for sustainable development in Baltic states using Energy Indicators for Sustainable Development (EISD) tool for analyzing trends, setting energy policy goals and monitoring progress towards these goals for Baltic States. The study reveals that the analysis of targeted indicators shows some positive trends in relation to sustainable development in the Baltic States energy sector. Some of the issues require more attention such as energy intensity, security of supply, including promotion of renewable energy sources and energy efficiency improvement.

Most studies focus on one of the three main themes in the literature, namely, economic effects of renewables, the price effect of transitioning into renewables and the energy indicators for sustainable development. No study, however, empirically investigates the link between these three themes, to understand the interlinkages and trade-offs of the various aspects of renewable energy and accounting for the price effect for the possible interlinkages.

3. Empirical strategy

3.1. Theoretical underpinnings

The theoretical foundation of our empirical model is based on the theory of demand. A common approach in the literature is to derive demand via a multi-stage budgeting process based on utility maximization or cost minimization principle. In the case of energy goods, previous studies (Filippini and Hunt, 2011; Karimu and Brånnlund, 2013) derive the energy demand function to depend on real energy price, real GDP, policy variables such as taxes and weather conditions. Taking the derived model from the previous literature, the reduced-form energy demand function may be presented as:

$$E^D = f(Price; RGDP; Policy; Weather) \tag{1}$$

where E^D is the energy demand, Price is the real energy price, RGDP is the real gross domestic product, a proxy for income, Weather denotes weather conditions, and Policy denotes the government policies such as taxes levied on energy demand (consumption) - a key policy variable for the derived demand. We assume that price of energy is endogenous, induced by the interdependency between demand and price. As a consequence, we jointly model price and demand as a system of equation in our empirical estimation. The aggregate energy demand (E^D) is further decomposed into renewable (RE) and brown energy (BE)[5]. Disaggregating allows us to estimate the effect of the renewable energy component and assess its interlinkages with SDGs. It is important to note that we demand energy not for its own sake but rather for the services it provides such as transportation, lighting, refrigeration etc. As a consequence, the production and use of energy has both direct and indirect connection to the SDGs either through production and/or consumption (e.g., carbon emissions) or from the services it provides (e.g., health via cooling and heating requirements in building). This enables us to assess the links between energy and the related SDGs.

[5] Brown Energy (BE) is energy from carbon-based sources such as oil.

3.2. The model

We employ a system of equation approach that is based on the theoretical underpinnings to address the key research questions in this study. First, the Seemingly Unrelated Regression Estimation (SURE) is employed for jointly modelling the energy demand and prices. In step two, the Panel Vector Autoregressive (PVAR) framework is used to model the interlinkages between the renewable energy prices and the selected SDGs. The SURE model is basically an ordinary least square (OLS) model that allows the error terms in each equation to depend on each other. The empirical application of the PVAR model was made possible only recently. A brief explanation below clarifies how the interlinkages are inferred from the model estimates.

In the VAR framework, each variable in the system is explained by its own lags, lagged values of the other variables, time fixed effect and unobserved individual effect. The panel autoregressive distributed lag model (PVAR) can generally be specified as

$$y_{it} = \sum_{t=1}^{n} \beta_t y_{it-1} + \mu_{it} \tag{2}$$

where y is k*1 vector of k variables, $\beta$is a k*k vector of parameters to be estimated and μ_{it} is a composite term that is made up of time fixed effects ($\mathrm{v_t}$), unobserved individual effect (γ_{i}) and random error term ($\varepsilon_{\mathrm{it}}$), t is time period and i is individual unit, which in this study represents countries. All variables in the model are considered endogenous except those specifically restricted by the researcher to be exogenous. Given the lag dependent structure, estimating a system of fixed effect model will suffer from nickel bias (where the lag depended variable is correlated with the fixed effect) in a small sample. The standard procedure to address such a bias, as suggested by Arellano and Bover (1995) is to use a generalized method of moment procedure (GMM), where lagged variables are used as instruments. Other measures include instrumental variable approach and the use of VAR models, where each variable is assumed endogenous unless restricted.

The SURE model is applied to a system of energy demand and price equations. Since the available statistics only provide aggregate energy price (which includes both brown and green energy price), the goal here is to estimate the response of energy price to renewable energy demand and construct renewable energy price. This first step is done through (3) and (4) below:

$$ELEC^D_{it} = \alpha^P Elec.price_{it} + \alpha^{RGDP} RGDP_{it} + \alpha^W Weather_{it} + \mu^D_{it} \tag{3}$$

$$Elec:price_{it} = \theta^{RE} RE_{it} + \theta^{BE} BE_{it} + \theta^{RGDP} RGDP_{it} + \theta^W Weather_{it} + \mu^p_{it} \tag{4}$$

where $\mathrm{ELEC^D}$ is electricity demand and Elec:price is electricity price. The aggregate electricity demand ($\mathrm{ELEC^D}$) is further decomposed into renewable (RE) and brown electricity (BE), μ^D_{it} and $\mu^p_{it}$are composite error terms for the electricity demand and electricity price equations, respectively as explained in Eq. (2), which are jointly estimated. Based on the coefficient estimate for renewable electricity (RE) from Eq. (4), we compute the renewable electricity price for each country by multiplying the electricity price by the estimated coefficient on renewable electricity (RE).

In the second step, the PVAR model in Eq. (2) is applied to estimate the coefficients of the interlinkages between renewable energy and the selected SDGs via renewable electricity prices.

The basic model for the second stage analysis is presented compactly as:

$$X_{it} = \sum_{t=1}^{n} \rho_t X_{it-1} + \eta_{it} \quad (5)$$

where X is a seven variable vector which is composed of renewable energy price, SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 12 (responsible production and consumption) and SDG 13 (climate action). We therefore have an equation for each of the variables in the vector expressed in Eq. (5), η_{it} is a composite term with time fixed effect, unobserved individual effect and a random error term. Each equation in the model has one of the variables in the vector as a dependent variable and the others as independent variables (lagged), implying a system of equations written compactly. All the equations are estimated jointly as a system, which makes it possible to trace the feedback effect from each variable on the other. Thus, we can assess the potential trade-offs or complementarity of renewable energy effect indirectly on each of the selected SDGs via the price channel and how each of the goals also influence the others.

The PVAR approach avoids the usual problem of endogeneity, given the interdependent nature of the variables that are of interest in the study. Moreover, important policy questions such as, how specific variables of interest respond to unexpected changes in other variables can also be analyzed via the PVAR approach. For instance, whether unexpected changes in renewable energy price due to more deployment of renewables causes a positive, negative or no reaction by SDG 13, can be assessed from the PVAR approach for the countries under study. Note that the VAR framework makes it possible to interpret the results as causal especially the impulse response functions, which are based on how a variable respond to a standard deviation of the error (shock) from another variable in the VAR structure.

4. Data

The analysis in this study is based on data that covers 28 EU countries from 2000 to 2016. Most of the variables are sourced from Eurostat database, while others are merged from the World Development Indicators (WDI). The key variables of interest include energy price, brown and green energy consumption, a variable to capture weather conditions and indicators for SDGs. There is a lack of reliable data on SDGs for periods before the year 2000.

The energy price variable is sourced from Eurostat for both consumers and the industry with taxes included in the price. Each of the price components (households electricity price, industrial electricity price) contribute to the final electricity consumer price. Energy consumption (demand) is divided into two sources, brown and renewable energy consumption. Both variables are taken from the Eurostat data base on energy. The weather variable is proxied by heating and cooling degree days. These proxies are constructed to reflect the average day's temperature below (above) which a building will require heating (cooling) to be hospitable. The threshold temperature for heating (and cooling) degree days is below (above) 18 °C.

The next set of variables are the SDGs, our focus is not on all the SDGs but rather those that are directly connected to energy use. Specifically, we are interested in SDGs 7, 8, 9, 12 and 13. The indicators used to capture each of these SDGs are presented in Table A1 in the Appendix.

The indicators for SDG 7 include primary energy consumption, final energy consumption, final energy consumption in households per capita, share of renewable energy in gross final energy consumption by sector, energy dependence by product, and greenhouse gas emissions intensity of energy consumption. Indicators for SDG 8 are divided into two components. A work component (8W) and a growth component (8G) of goal 8. Indicators for SDG 8W are young people neither in employment nor in education and training by sex, employment rate by sex, long-term unemployment rate by sex, involuntary temporary employment by sex, and inactive population due to caring responsibilities by sex. Indicators for SDG 8G are real GDP per capita, resource productivity and domestic material consumption.

In the case of SDG 9, the indicators used are gross domestic expenditure on research and development by sector, employment in high and medium-high technology manufacturing sectors and knowledge-intensive service sectors, research and development personnel by sector, patent applications to the European Patent Office, share of collective transport modes in total passenger land transport by vehicle, share of rail and inland waterways activity in total freight transport, and average CO2 emissions per km from new passenger cars.

For SDG 12, the indicators comprise of consumption of toxic chemicals by hazardousness, resource productivity and domestic material consumption, average CO2 emissions per km from new passenger cars, volume of freight transport relative to GDP, primary energy consumption, final energy consumption, energy productivity, and share of renewable energy in gross final energy consumption by sector.

Another directly connected SDGs to energy is SDG 13, under which we use greenhouse gas emissions per capita (CO2) from WDI. We used CO2 to represent SDG 13 due to the fact that it is a major climate concern globally, has reliable data information and furthermore, is a major reason used by policy makers to promote renewable electricity. Each SDG is captured by several indicators that are listed, which complicate any meaningful econometric analysis due to overlapping of some of the target variables across some of the SDGs. For instance, we have final energy consumption as one of the indicators for both SDG 7 and SDG 12. We combine each of the target variables under each SDG into one index via principal component analysis approach.

The summary statistics for the variables for the study is reported in Table A1 in the Appendix, which reveals strong heterogeneity among countries in terms of cooling degree days, renewable energy and non-renewable energy demand, primary energy consumption, and patent application, as their respective standard deviations are of larger magnitude than their means. A variable with a larger standard deviation relative to its mean, suggests high variability in the variable and therefore a strong heterogeneity.

5. Results and discussion

We first present the results for step one using Eqs. (3) and (4) via the SURE model. The results are reported in Table 1. Next, we estimate the model presented in Eq. (5) based on the PVAR[6] approach described in the methodology section for a model with seven variables that comprises renewable energy price (Res.P), affordable and clean energy (SDG 7), decent work and economic growth (SDG 8W for decent work and SDG 8G for growth), industry, innovation and infrastructure (SDG 9), responsible production and consumption (SDG 12) and Climate action (SDG 13). The results for

[6] Though we controlled for the country fixed effects in the panel VAR estimations, which to a large extend should control for country specific effects, we also estimated individual country VAR model. The diagnostics suggested that the individual VAR models are not reliable based on both the model stability and white noise (residual autocorrelation) of the residuals as reported in Table A2 in the Appendix. As a consequence, we relied on the PVAR model as the appropriate model to avoid the small sample problem of the individual VAR model. The individual country VAR estimates are available but not reported in the paper.

Table 1
SURE, model estimates for electricity demand and price.

	ln electricity demand	ln electricity price
ln electricity price	−0.058	
	(−4.85)	
ln renewable electricity demand		0.0074
		(2.48)
ln nonrenewable electricity demand		−0.012
		(−3.47)
ln GDP	0.410	1.282
	(15.37)	(16.06)
ln cooling degree days	0.0008	0.0003
	(0.61)	(0.06)
ln heating degree days	0.055	−0.228
	(1.69)	(−1.91)
constant	18.90	−13.39
	(46.84)	(−9.81)
R-square	0.998	0.671
Chi2	334938.17	1006.95
	[0.000]	[0.000]
N	493	49

Note: t-statistics in parenthesis, p-values in square brackets

the seven variable PVAR model are reported in Table 2. The impulse response functions (they explain the time profile of the effect of a shock on expected future value of a variable in a dynamic system) for a sub-set of the key variables of interest, specifically renewable energy price shock, SDG 7 and SDG 13 are reported in Figs. 1–3, respectively. This is followed by the variance decomposition of each of the variables in the system, which is presented in Table 3 for five periods and ten periods into the future. This is consistent with the previous literature on PVAR (Love & Zicchino, 2006) and also in line with the period over which the impulse-response functions are constructed.

Before discussing the results, it is important to first check the model fit and stability of the model. More importantly since we are interested in the shocks of key variables of interest, and how the other variables in the system respond to such shocks, the stability of the model is very important. Furthermore, we are interested in the variance decomposition of each variable in order to assess how each variance of the variable is explained by the other variables, hence model stability is an important requirement. First, with regard to the model fit, since the model estimation approach is based on generalized method of moment (GMM), we perform the Hansen-J test for over-identification, which is more of a specification test to determine if the over-identifying restrictions are valid. The test results reported in Table 2 suggest that our model fit the data generation process (DGP).

The model stability test requires that the moduli of the companion matrix of the eigenvalues are strictly less than 1 (Hamilton, 1994; Lütkepohl, 2005). These are reported in Table A2 in the Appendix. They indicate that the model is stable as the eigenvalue are all less than 1. Our estimated model therefore satisfies both the model fit test and the model stability test.

5.1. SURE results

The demand equation results based on the first stage estimation are presented in Table 1, and are consistent with the prior literature (e.g. Eskeland & Mideksa, 2010; Azevedo, Morgan, & Lave, 2011; Blazquez, Boogen, & Filippini, 2013; Cialani & Mortazavi, 2018). Both in terms of the sign and the magnitude, the values lie within the range (−0.04 to −0.2 for the EU) as obtained in the literature. Our results indicate a negative association between the electricity demand and electricity price. The price elasticity of demand is approximately −0.1, whereas the price elasticity of income is positive and statistically significant with a magnitude of 0.4 for the EU-28.

The results reveal a significant positive effect of heating degree days, which is consistent with the finding by Cialani and Mortazavi (2018). Their study covers the same time period as this study, but unlike them we find the effect of cooling degree days to be statistically insignificant. The price equation also suggests a significant positive association between electricity price and renewable electricity demand but a negative significant electricity price and non-renewable electricity demand. This suggests that a renewable electricity demand tends to increase the electricity price.

This can be explained via two channels: the direct per unit cost; and the indirect cost arising from the difficulty of handling intermittent generation of the renewable electricity. The first channel is the initial investment cost of renewable electricity generation, which has been high till recent years. In recent years, the cost of some of the renewable energy generation (such as wind and in some cases solar) has become competitive to conventional (brown) electricity. Estimates from a report by ECOFYS (2014) suggest that the minimum range of the Levelized Costs of Energy (LCOE) for natural gas in 2012 in the EU is 50 euros/MWh, while that of onshore wind and solar energy is 62 euros/MWh and 88 euros/MWh, respectively.

The second channel can be explained by the fact that in most EU countries, real time pricing contracts are not available to consumers. In such an environment, having a sizable share of electricity generation from intermittent sources, imposes an additional cost in managing the shortfalls (excess demand over generation) when the wind is not blowing, or the sun is not shinning at peak hours (or vice-versa).

5.2. Step-two results

The results as reported in Table 2 suggest that from the renewable electricity price equation, all the SDGs (except SDG 7) are significant causal factors at any of the conventional significance level, but the magnitude of the effects are relatively small. A possible explanation is that renewables electricity is still a small proportion of overall energy share for most of the countries, which in most cases are supported by a deliberate government policy in order to promote their penetration. This makes it less directly dependent on the SDGs.

Despite the small coefficient estimates for the renewable electricity equation, there are very interesting finding with respect to unemployment and growth effects on renewable electricity price. Both variables have a reduction effect on renewable electricity price, likely driven by the affordability as argued in the discussion section below.

Results also show a negative effect of SDG 12 on renewable electricity price, while the effect of SDG 9 is positive and significant at any of the conventional significance level. The results from SDG 7 equation suggests that previous levels of SDG 7, 9, 12 and 13 are significant causal factors.

SDG 8G equation also reveals that renewable electricity price and each of the SDGs are significant causal factors. Specifically, renewable electricity price and SDG 12 impact the growth positively, whereas the other SDGs such as SDG 7, SDG 8W, SDG 9 and SDG 13 have a negative impact on growth.

In the case of SDG 8W, results show that price and each of the SDGs (except SDG7) have a significant impact on SDG 8W.

The results further reveal that SDG 7, SDG 8G and SDG 13 are significant factors in the SDG 9 equation. From SDG 12 equation results, we find that SDG 7, SDG 8G and SDG 9 are significant factors. In the case of SDG 13 equation, the results reveal that only SDG 8G, SDG 8W, SDG 12 and the past value of SDG 13 are the significant factors at any of the conventional significance level.

Table 2
PVAR estimates.

Response of:	Response to						
	$ResP_{t-1}$	$Goal7_{t-1}$	$Goal8G_{t-1}$	$Goal8W_{t-1}$	$Goal9_{t-1}$	$Goal12_{t-1}$	$Goal13_{t1}$
$ResP_t$	1.021***	−0.0001	−0.001*	−0.0002*	0.001***	−0.002***	−0.0002
	(21.84)	(−0.10)	(−1.74)	(−1.84)	(3.73)	(−3.33)	(−0.76)
$Goal7_t$	14.52*	0.346***	0.0353	0.0233	−0.125***	0.363***	−0.215***
	(1.75)	(3.75)	(0.58)	(1.01)	(−3.41)	(3.11)	(−3.08)
$Goal8G_t$	10.10*	−0.248***	0.622***	−0.054***	−0.064**	0.293***	−0.239***
	(1.70)	(−3.74)	(7.40)	(−2.91)	(−2.54)	(2.94)	(−5.09)
$Goal8W_t$	36.79*	−0.133	−0.953***	0.793***	0.114*	0.443*	0.243*
	(1.96)	(−0.67)	(−4.00)	(12.31)	(1.94)	(1.74)	(1.89)
$Goal9_t$	−16.60	−0.444*	1.235***	0.015	0.836***	−0.414	−0.340**
	(−0.90)	(−1.81)	(5.11)	(0.25)	(10.19)	(−1.48)	(−2.31)
$Goal12_t$	3.707	−0.249***	0.123**	0.019	−0.048*	1.017***	−0.079
	(0.53)	(−3.09)	(2.25)	(1.16)	(−1.78)	(11.74)	(−1.56)
$Goal13_t$	−1.884	0.0192	0.719***	−0.114***	0.089	−0.961***	0.383***
	(−0.15)	(0.11)	(4.90)	(−3.00)	(1.50)	(−4.33)	(3.16)
Observation	306						
J-Stats	144.132						
P-value	[0.551]						

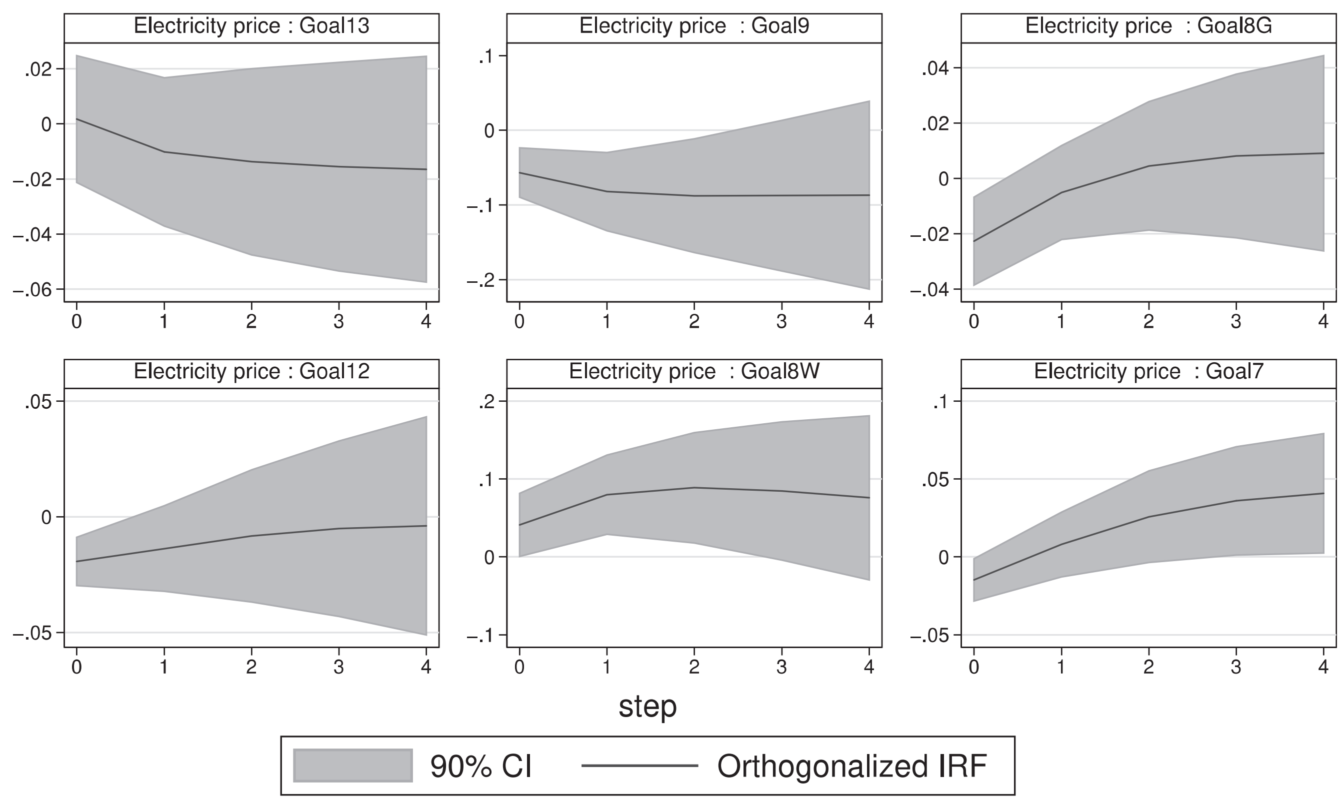

Fig. 1. Responses to shock to renewable electricity price. Note: The shaded area is the 90 percent confidence band constructed based on 1000 replications. The vertical axis are the one standard deviation shock and the horizontal axis is period ahead of the response.

5.3. Impulse-response functions

In order to isolate the response of renewable electricity price to the different SDGs such as SDG 12 and 8G, we utilized impulse-responses within the VAR framework. We specifically focus on the orthogonalized impulse-response functions. These functions capture the response of one variable of interest (e.g., renewable electricity price) to an orthogonal (variates) shock in another variable of interest (e.g., SDG 13). Using this approach, we are able to identify the effect of one shock at a time, while holding other shocks constant.

The estimated impulse-response functions, reported in Fig. 1, indicates the impulse-response of unemployment (SDG 8W) to an increase in one standard deviation of renewable electricity price. It is positive and significant up to the third period, but insignificant thereafter. Growth (SDG 8G) is marginally negative. SDG 9 and SDG 12 also respond negatively to electricity price shocks for up to the second period.

Results presented in Fig. 2 on the other hand implies a significant negative impulse-response of SDG 13 to an increase in one standard deviation in SDG 7 for approximately three periods. Both SDG 8 and 12 respond negatively to an unexpected increase in SDG 7.

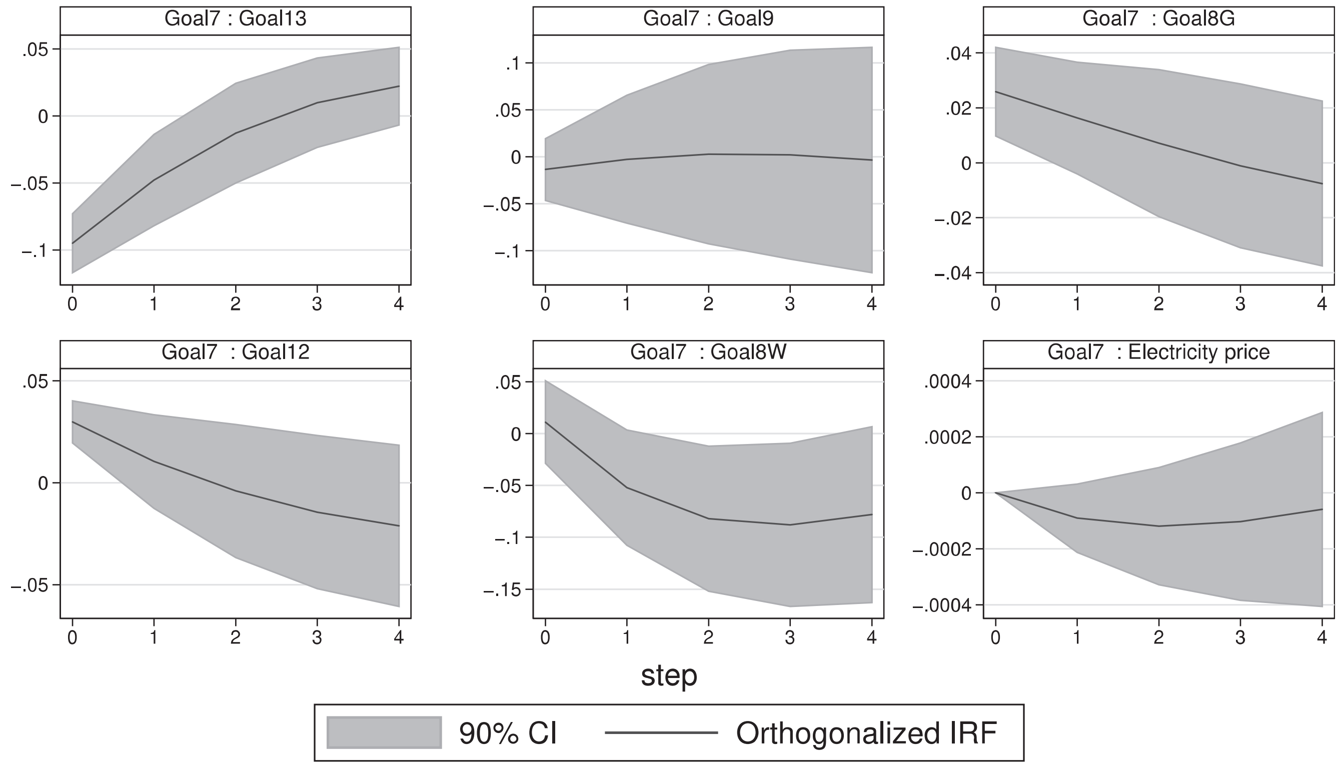

Fig. 2. Responses to shock to goal7. Note: The shaded area is the 90 percent confidence band constructed based on 1000 replications. The vertical axis are the one standard deviation shock and the horizontal axis is period ahead of the response.

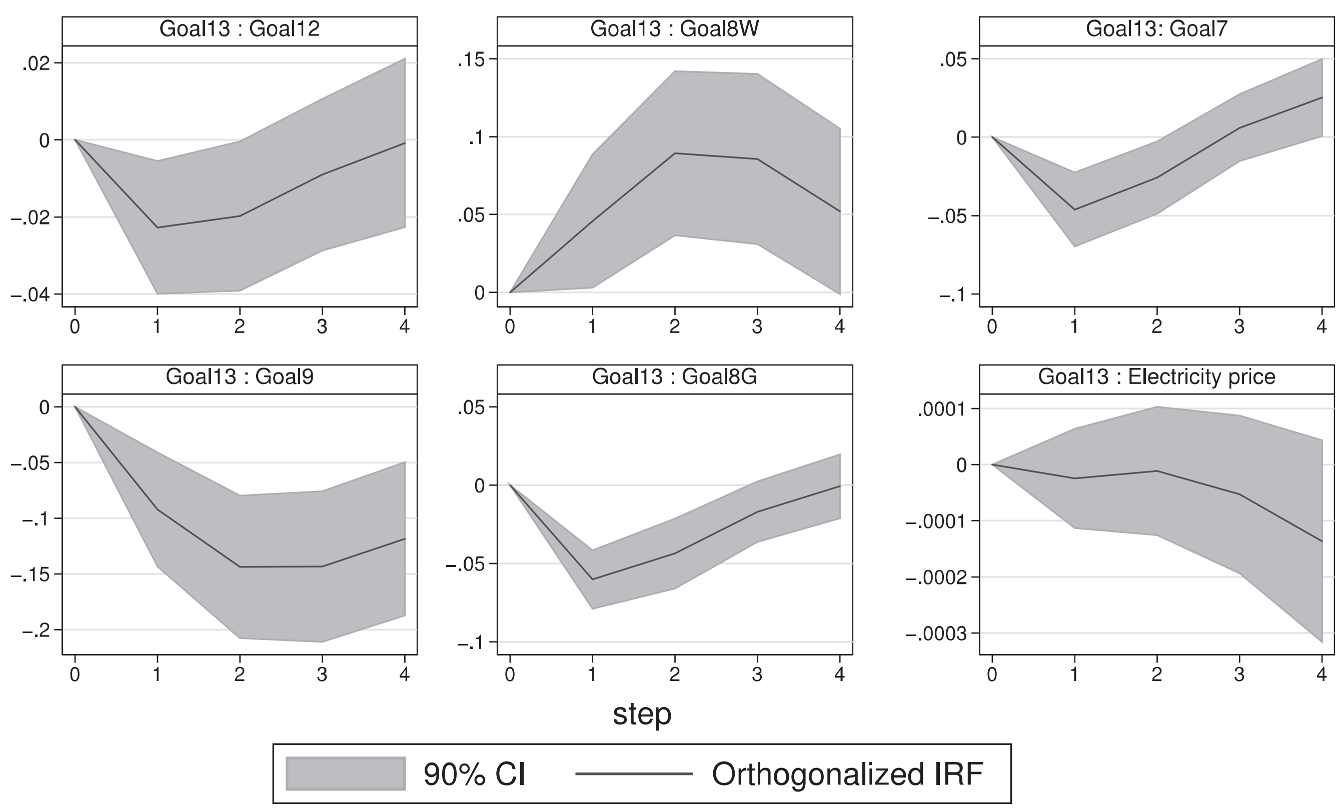

Fig. 3. Responses to shock to goal3. Note: The shaded area is the 90 percent confidence band constructed based on 1000 replications. The vertical axis are the one standard deviation shock and the horizontal axis is period ahead of the response.

Table 3
Forecast Error Variance Decomposition (10th period).

Response	Impulse						
	ResP	Goal7	Goal8G	Goal8W	Goal9	Goal12	Goal13
ResP	34	0	2	4	20	36	4
Goal7	12	27	13	5	12	25	5
Goal8G	2	2	47	0.1	6	37	6
Goal8W	3	3	10	33	26	21	4
Goal9	8	1	35	0	28	20	7
Goal12	1	6	9	1	2	82	1
Goal13	1	9	21	14	7.4	22	26

The impulse-response of SDG 8W (refer to Fig. 3), shows a positive and significant effect up to three periods ahead, but insignificant thereafter. This implies a positive response of unemployment to unexpected increase in climate action via increase in carbon emission per capita.

In the case of SDG 8G, the impulse-response function indicates a negative response of economic growth to unexpected increase in carbon emission per capita in the EU. Fig. 3 further indicates that both SDG 7 and 9 respond negatively to unexpected increase in climate action proxied by carbon emission per capita. In the case of SDG 7 the response is only significant up to two periods, while for SDG 9, the response is significant for three periods. Notice that in all the impulse-response functions discussed above, the longest significant response is 3 periods ahead, suggesting the impact of the shocks are non-permanent, since their significant effect disappear at most in three periods. The effect of the shocks is considered to be short-lived due to the non-permanent nature of the shocks.

5.4. Forecast error variance decomposition

The forecast error variance decomposition (FEVD) for each of the variables in the system is reported in Table 3. We specifically focus our discussion on the three key variables of interest (renewable electricity price, SDG 7 and SDG 13) and what explains their variation. The results indicate that at the end of the period, about 36 percent of the variation in renewable electricity price is explained by SDG 12 (responsible production and consumption), 34 percent is explained by renewable electricity price and 20 percent of the future renewable electricity price is explained by SDG 9 (industry, innovation and infrastructure). The other variables in the system (SDG 7, SDG 8 and SDG 13), explain less than 5 percent of the future renewable electricity price variation.

Furthermore, the FEVD for SDG 7 reveals that SDG 7, SDG 12 and SDG 8G (economic growth) are the three largest contributors to the future variation in SDG 7. Specifically, they explain the variation in SDG 7 by 27, 25 and 13 percent, respectively. While both SDG 9 and renewable electricity price explains about 12 percent each. Climate action and SDG 8W on the other hand explains only 5 percent of the variation in SDG 7.

The results also indicate that SDG 13 (climate action), SDG 12 and SDG 8G are the highest contributors to variation of future climate action, while renewable electricity price least explains the variation in future climate action (only 1 percent) in the EU.

5.5. Discussion

The renewable electricity equation results suggest that an increase in unemployment reduces the renewable electricity price. This may be explained in terms of lack of affordability created by unemployment, which affects the demand for renewable electricity and consequently impacts the renewable electricity price. However, this effect is expected to be small, since the consumers' response to electricity price is generally limited (Eskeland and Mideksa, 2010; Blazquez et al., 2013). Whereas the negative effect of economic growth (SDG 8G) on renewable electricity price, we argue is due to the ability of rich countries to offer significant subsidies during high growth period to support renewable energy deployment, which reduces the cost of renewable electricity generation as done in countries such as Germany, Spain, Netherland etc.

Furthermore, the findings that responsible production and consumption have a negative influence on renewable electricity prices can be explained via demand for renewables. Adopting environmentally friendly process is likely to create less demand for renewable electricity, causing the price of renewable electricity to fall.

Conversely, the positive effect of renewable electricity price on SDG 7 can be explained via the excess demand channel. If the increase in renewable price is due to an increase in demand relative to supply, SDG 7 will increase since access to clean energy sources would have increased via the excess demand. This is a very short-term effect since the increase in price will ultimately affect demand negatively in the medium to long run.

Also, the negative effect of SDG 9 on SDG 7 may be explained by the impact of innovation on jobs, especially low-skilled labor that innovation may displace and consequently cause a lack of affordability of clean energy. Since the key indicators within SDG 9 proxy all forms of innovation, high-tech industry and infrastructure (and not just renewable), their direct effect on renewable electricity price might be minimal. Our results thus suggest that the employment effect might dominate the price effect.

Additionally, the evidence reveals that SDG 8G impacts positively on SDG 13, as proxied by CO2 emission per capita. It is not surprising that we find that as the EU promotes growth, especially growth that depends on greater fossil fuel consumption, CO2 emissions consequently increases. Thus, increasing de-coupling of economic growth from fossil energy is imperative in the EU. Even though much progress has already been made in this region, more progress is still required, especially in the energy intensive industries, where the existing energy policies are less stringent to endanger innovation towards less polluting fuels (Climate Action Network Europe, 2018).

Moreover, the findings also suggest that increase in unemployment causes a decrease in SDG 13, which we interpret to stem from the income effect of unemployment. This leads to a decline in the production and consumption, which directly or indirectly results in carbon emissions reduction.

Impulse-response functions suggest that the unexpected movement in renewable electricity price have no serious significant economic consequences on most of the selected goals, except SDGs 8, 9 and 12. Conversely, economic growth responds negatively to the unexpected increase in carbon emission per capita in the EU. This suggest that, climate action is an important factor for economic growth. Actions that reduces negative climate change tend to promote economic growth, which can be due to a reduction in climate related health problems, improvement in agricultural productivity, cognitive performance (Dell, Jones, & Olken, 2012) and a general improvement in ecosystem services.

The forecast error variance decomposition results as presented in Section 5.4 suggest that the future renewable electricity prices within the EU are more likely to be influenced by responsible production and consumption, renewable electricity price and industry, innovation and infrastructure. These factors are generally responsible for the relatively high penetration of renewables in the electricity generation in the EU, supported by the deliberate policy framework in the region. For instance, most of the EU countries proposed and implemented various financial packages such as subsidies and soft loans for energy efficient investments/ equipment, and fiscal incentives such as subsidies on investment in energy efficient equipment, tax credit among others to promote renewables (EEA, 2017). These measures directly impact the prices of renewables, responsible production and consumption and SDG 9 (industry, innovation and infrastructure).

Our overall findings may be summarized as follows. First, only SDG 8G and SDG 12 are complementary in achieving a lower renewable electricity price as improvements in either of these goals result in lowering renewable electricity prices for the final consumer. SDG 7 has synergies with SDG 13 and 12. Synergies also exist between SDG 12 and 13, SDG 8G and 13, and SDG 9 and 12. We also find a case of trade-offs between SDG 8W and renewable electricity price. Finally, the response to an electricity price shock, SDG 7 and SDG 13, are found to be short-term.

6. Conclusions

The energy union strategy of the EU (COM/2015/080 final), adopted on 25 February 2015, is focused on improving energy security, creating a fully integrated internal energy market, improving energy efficiency, decarbonizing the economy - not least by using more renewable energy - and supporting research, innovation and competitiveness. The 2030 framework for climate and energy sets clear targets for 2030. Amongst other targets[7] it aims to achieve, at least a 32 percent share of renewable energy consumption, with an upward revision clause for 2023. These EU targets are in sync with SDG 7 that aims to achieve affordable and clean energy. However, a silo-based policy approach in meeting this goal (and targets), ignores its synergies and tradeoffs with other goals and sectors of the economy. Our study investigates how adoption of renewable electricity impacts SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 12 (responsible production and consumption) and SDG 13 (climate action), through electricity prices.

Analyzing country level data sourced from Eurostat data base and the World Bank's World Development Indicators (WDI) for the period 2000–2016, we estimate how transformation towards renewable electricity will affect the prices and through prices impact the key SDGs. The analysis is conducted in two steps. We first obtain the response rate of electricity price to renewable electricity demand (consumption) and use it to compute renewable electricity price based on the total electricity price. In step two, we estimate the interlinkages between the renewable energy prices and the selected sustainable development goals using PVAR.

Several interesting findings emerge. First, in general, increase in renewable electricity demand within the EU has a positive effect on electricity prices. We argue that this may be explained by through an increase in the direct generation cost (investment cost), and the indirect cost associated with intermittency of some of the renewables (wind and solar). The cost of balancing requirement imposed by the intermittency on the power system is passed on to the final consumer through higher electricity prices.

Our findings support and extend the earlier research on renewable energy on electricity prices (e.g., Traber and Kemfert (2009), Mulder and Scholtens (2013) at the aggregate EU-level. Furthermore, our study contributes to the prior literature on Renewable Energy Source (RES) impact on electricity prices by providing an empirical evidence on the key factors that are likely to influence the future electricity price movement. Another contribution is the finding that future access to affordable and clean energy in the EU-28 countries is likely to be influenced by economic growth and responsible production and consumption, suggesting the likely synergy effect between SDGs 7, 8 and 12, which corroborate the positive economic effect findings by Mulder and Scholtens (2013).

Our results suggest that by designing policies that integrate the synergies between the different SDGs, policy-makers can be more effective in achieving the targets/goals for 2030. Similarly, adopting and implementing policies in silos may imply counter-intuitive results where policies supporting RES may unintentionally result in unwanted outcomes in other aspects of sustainable development.

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Appendix

Tables A1–A3.

Table A1
Summary statistics.

Variable	Mean	Std. Dev.	N
Electricity price	0.124	0.045	493
Cooling degree days	104.38	172.97	493
Heating degree days	2954.251	1218.28	493
Renewable electricity demand	11387.992	24162.193	493
Non-renewable electricity demand	22152.848	30878.56	493
Goal 7			
Primary energy consumption	57.196	77.667	493
Final energy consumption	36.182	49.458	493
Final energy consumption in households per capita	597.576	207.419	493
Energy productivity	6.496	2.896	493
Share of renewable energy in final energy consumption	17.451	13.778	491
Greenhouse emission intensity	95.935	7.396	464
Goal 8G			
Real GDP per capita	25302.444	17223.201	491
Resource productivity and (DMC)	1.47	0.941	493
Goal 8W			
Young people not in employment, education and training	14.052	5.334	480
Employment rate by sex	69.173	6.257	476
Long-term unemployment rate	3.985	3.043	462
Involuntary temporary employment	6.228	5.162	480
Inactive population due to caring	20.374	12.566	487
Goal 9			
Gross domestic expenditure on R&D by	1.444	0.859	482

(*continued on next page*)

[7] Other targets include: (1) a 40 percent cut in greenhouse gas emissions as compared to 1990 levels; (2) an indicative target for an improvement in energy efficiency at EU level of at least 32.5 percent; (3) following on from the existing 20 percent target for 2020; (4) and support the completion of the internal energy market by achieving the existing electricity interconnection target of 10 percent by 2020, with a view to reaching 15 percent by 2030.

Table A1 (*continued*)

Variable	Mean	Std. Dev.	N
sector			
Employment in high- and medium–high technology	42.826	11.23	493
R&D personnel by sector	0.99	0.505	455
Patent applications	1879.019	4205.444	491
Share of transport modes in passenger land trans	18.967	6.327	432
Share of rail and inland, waterways in freight trans	32.935	15.589	450
Goal 12			
Resource productivity and (DMC)	1.457	0.887	493
Energy productivity	6.496	2.896	493
Goal 13			
CO2 emission per capita	8.021	3.531	435

Table A2
Eigenvalue for stability test.

Real	Imaginary	Modulus
0.985	0.000	0.985
0.923	0.000	0.923
0.825	0.000	0.825
0.754	−0.221	0.786
0.754	0.221	0.786
0.317	0.298	0.435
0.317	−0.298	0.435

Table A3
Summary of Diagnostic tests on individual country VAR model.

Country	Modulus: Model stability	Ljung-Box portmanteau test statistic	Number of parameters	N
Belgium	0.510–1.048	268.858 (0.000)	56	14
Bulgaria	0.019–1.886	255.929 (0.003)	56	14
Czech Republic	0.441–0.867	63.416 (0.081)	56	13
Denmark	0.098–1.011	404.399 (0.000)	56	15
Germany	0.088–1.154	18.867 (1.000)	56	12
Estonia	0.258–0.889	321.084 (0.000)	56	15
Ireland	0.270–1.206	87.267 (0.000)	56	13
Greece	Does not converge		56	13
Spain	0.713–0.869	129–451 (0.000)	56	13
France	Does not converge		56	13
Croatia	0.599–1.001	38.449 (0.861)	56	11
Italy	0.392–0.934	340.314 (0.000)	56	15
Cyprus	Does not converge			13
Latvia	0.510–0.957	82.067 (0.002)	56	13
Lithuania	0.210–0.874	66.438 (0.049)	56	13
Luxembourg	0.324–1.052	43.240 (0.705)	56	12
Hungary	0.270–1.130	373.819 (0.000)	56	15
Malta	Does not converge			13
Netherlands	0.071–0.911	67.573 (0.040)	56	12

Table A3 (*continued*)

Country	Modulus: Model stability	Ljung-Box portmanteau test statistic	Number of parameters	N
Austria	0.776–1.224	5.490 (1.000)	56	13
Poland	0.100–1.058	249.929 (0.006)	56	14
Portugal	0.432–0.831	75.768 (0.008)	56	15
Romania	Does not converge			
Slovenia	0.346–0.956	248.405 (0.007)	56	13
Slovakia	0.001–0.970	81.691 (0.002)	56	14
Finland	0.105–0.779	321.150 (0.000)	56	13
Sweden	0.097–1.192	57.178 (0.198)	56	15
UK	Does not converge		56	13
Norway	0.131–1.237	92.315 (0.000)	56	14

Notes: N stands for number of observations, UK is United Kingdom and "Does not converge" implies that we could not find convergence in the model iterations to be able to produce estimates.

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