

# Economic Growth: Is it Green or not? An Application on OECD<sup>1</sup>

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## Abstract

*For climate change mitigation and considering other environmental impacts of traditional energy sources, countries have started to implement energy policies in favor of renewable energy sources. In this way, without any detrimental effect on economic growth, countries can decrease their fossil fuel consumption. However, there is a debate about the direction of causality between renewable energy consumption and economic growth as for the total energy-growth nexus. Moreover, in the literature, the studies focus only on the total or specific type of renewable energy consumption while analyzing the direction of causality. From this point of view, there is a gap in the literature in such a way that there is a need for a comprehensive analysis which compares the existence and direction of causality for different types of renewable energy sources and technologies. Therefore, the main aim of this study is to investigate renewable energy consumption and growth nexus. By using panel data on renewable electricity generation for OECD countries over the years from 2000 to 2016, the causality is tested for different technologies. Moreover, as the economic growth may not correctly measure the overall economic well-being, another measure for welfare is used. Therefore, the main motivation of this study is to include welfare in renewable energy and growth nexus in which different type of technologies for renewable energy are considered.*

<sup>1</sup> The different and draft version of this study was presented at the MIC 2018 Conference Managing Global Diversities held in Bled, Slovenia between May 30- June 2 2018.

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The results for both economic growth and welfare measure show that the existence and direction of causality highly differs among the different technologies. Therefore, technology specific policies should be implemented in order to stimulate the renewable energy investments and consumption.

**Keywords:** Renewable energy consumption, Green growth, Panel data, Causality, Welfare.

**JEL Codes:** Q2, Q43, O44, D60.

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## Özet

### ***Ekonomik Büyüme: Yeşil mi Değil mi? OECD Üzerine bir Uygulama***

İklim değişikliğinin azaltılması için, geleneksel enerji kaynaklarının diğer çevresel etkilerini de dikkate alarak, ülkeler yenilenebilir enerji kaynakları lehine enerji politikaları uygulamaya başlamıştır. Böylelikle ülkeler ekonomik büyüme üzerinde herhangi bir olumsuz etki olmaksızın fosil yakıt tüketimini azaltabilir. Ancak, yenilenebilir enerji tüketimi ile ekonomik büyüme arasındaki nedenselliğin yönü, toplam enerji-büyüme bağlantısında olduğu gibi tartışılmaktadır. Dahası, literatürde çalışmalar nedenselliğin yönünü analiz ederken sadece toplam veya spesifik yenilenebilir enerji tüketimi türüne odaklanmaktadır. Bu açıdan literatürde, farklı türdeki yenilenebilir enerji kaynakları ve teknolojileri için nedenselliğin varlığını ve yönünü karşılaştıran kapsamlı bir analiz konusunda bir boşluk vardır. Bu nedenle, bu çalışmanın temel amacı yenilenebilir enerji tüketimi ve büyüme ilişkisini incelemektir. Bu çalışmada, 2000'den 2016'ya kadar OECD ülkeleri için yenilenebilir elektrik üretimi üzerine panel verileri kullanılarak nedensellik farklı teknolojiler için test edilmektedir. Dahası, ekonomik büyüme genel ekonomik refahı doğru bir şekilde ölçemeyebileceğinden, refah için başka bir ölçü kullanılır. Bu nedenle, bu çalışmanın temel motivasyonu, yenilenebilir enerjiye refahı ve yenilenebilir enerji için farklı tür teknolojilerin dikkate alındığı büyüme ilişkisini dahil etmektir. Hem ekonomik büyüme hem de refah ölçüsü için sonuçlar, nedenselliğin varlığı ve yönünün farklı teknolojiler arasında oldukça farklı olduğunu göstermektedir. Bu nedenle, yenilenebilir enerji yatırımlarını ve tüketimini canlandırmak için teknolojiye özgü politikalar uygulanmalıdır.

**Anahtar Kelimeler:** Yenilenebilir enerji tüketimi, Yeşil büyüme, Panel veri, Nedensellik, Refah.

**JEL Kodları:** Q2, Q43, O44, D60.

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*Economic Growth: Is it Green or not? An Application on OECD*  
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## 1. Introduction

The previous studies have widely studied the energy consumption and economic growth nexus in the literature<sup>4</sup>. As most of the attention was put on the importance of

<sup>4</sup> A literature on energy-growth nexus can be found in Ozturk (2010).

green economy because of various global environmental problems, different environmentally friendly technologies were developed and in this context the renewable term has become to be widely used. This study focuses on renewable energy technologies for electricity production among them and their growth and welfare effects in OECD countries based on data availability. Therefore this introduction part presents aim and scope of the study.

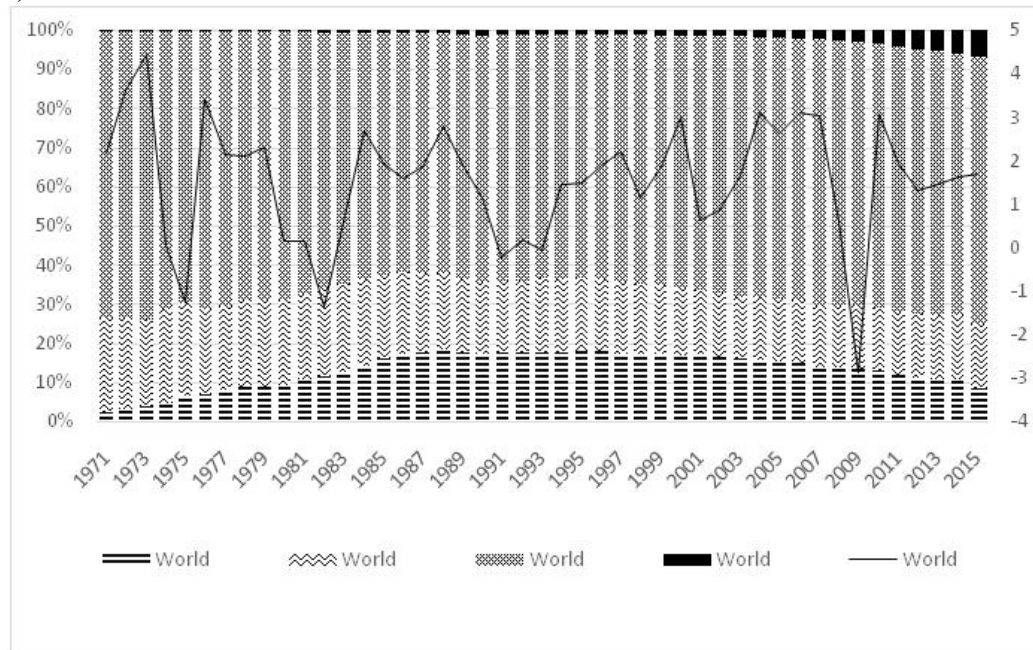
Figure 1 shows that world and OECD countries' electricity production is mostly based on fossil fuels (coal, oil and gas) over the years from 1971 to 2015. For year 2015, 65% of world electricity production is from oil, gas and coal sources and only 6% of it comes from renewables. In OECD countries, these shares are 58% for fossil fuels and 10% for renewables showing the better performance of these countries in shifting to renewable sources from fossil fuels in electricity production compared to world. Moreover, one can see the rapid increase of renewable usage starting in 2000's. Although there is a tremendous decline in economic growth in 2009 as a result of Global Financial Crisis, share of renewables increased in this year also to 3.1% and 4.6% in the world and OECD countries' electricity production. After 2009, this trend has continued. Based on these facts, studies on energy-growth nexus have shifted their attention to renewable energy-growth nexus.

There is a growing literature about the studies that analyze renewable energy and growth nexus. Most of the studies usually focus on total or specific type of renewable energy consumption. The main contribution of this study compared with the literature is to deal with different types of renewable energy sources and technologies by taking into account the welfare effect. For welfare-energy nexus, in addition to a recent study by Azami and Almasi (2020) for Organization of Petroleum Exporting Countries over 1995-2014, Angeliki N. Menegaki and Can Tansel Tugcu (2016a), A. N. Menegaki and C. T. Tugcu (2016b) and Menegaki and Tugcu (2017) have performed an analysis for Sub-Saharan Africa over 1985-2013, for 15 emerging countries over 1995-2013,

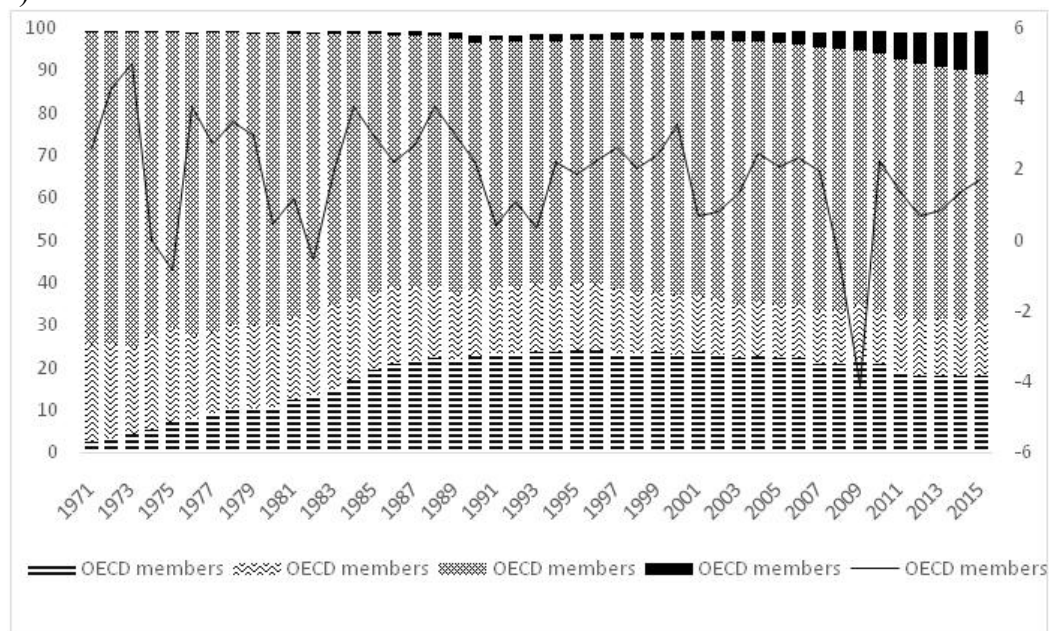
for G-7 countries over 1996-2012, respectively, using a welfare measure proposed by themselves, however, there is not any study specific for renewable energy.

**Figure 1** Electricity production from different energy sources over 1971-2015

a) World



b) OECD countries



**Source:** Authors' own elaboration based on data obtained from The World Bank (2020).

The idea of a more sustainable economy and climate change leads the increasing of green economy discussions as the green economy depends on sustainability. It is first discussed in Stockholm Conference, 1972. Then following remarkable timeline appears in Brundtland Report, 1987; in 1992 Earth Summit and Agenda 21, mostly in 2012 Rio Conference<sup>5</sup> than the Paris Agreement in 2015.

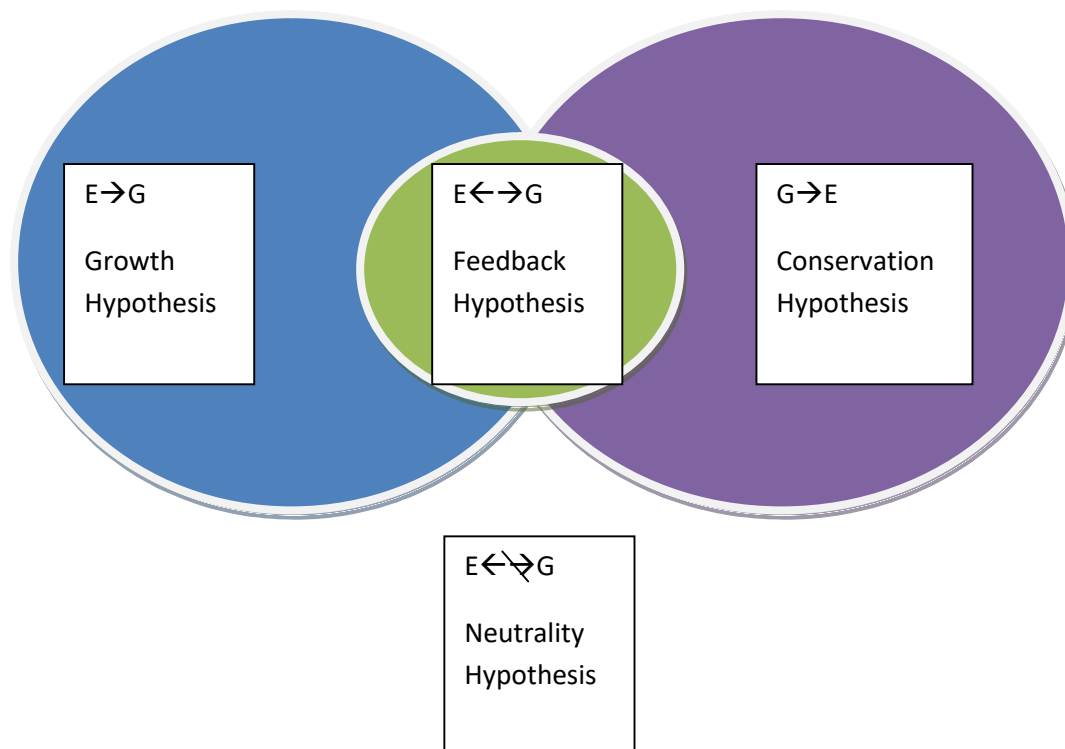
Following this point of view, the main aim of this study is to investigate the causality between renewable energy consumption and welfare in addition to the link between renewable energy consumption and economic growth. Therefore, the main motivation of this study is to include welfare in renewable energy and growth nexus model in which different type of technologies for renewable energy are taken into account. For this purpose, panel Granger causality tests were performed. Results showed that based on technology, the direction and existence of causality may differ. Therefore, technology-specific energy policies should be implemented.

## **2. Theory and the Literature**

According to the following Figure 2, there are 4 types of hypotheses describing the causality between energy and economic growth. If there is bidirectional relationship, this is called as feedback hypothesis. For unidirectional relation, there are two different directions: one is from energy consumption to economic growth hypothesized as growth hypothesis, the other from growth to energy consumption called as conservation hypothesis. If there is not any relation between them, neutrality hypothesis will be valid.

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<sup>5</sup> Why Green Economy (2020).

**Figure 2** Causal Relation between Renewable Energy and Economic Growth

**Source:** Authors' own elaboration.

The first study in the literature on renewable energy and economic growth according to our knowledge is in 2010 by Apergis, Payne, Menyah and Wolde-Rufael (2010), Apergis and Payne (2010a), Apergis and Payne (2010b) and Apergis and Payne (2010c). Three different valuable contributions to the literature have been made by Apergis and Payne (2010a, 2010b, 2010c). Apergis and Payne (2010a) study Eurasia countries while Apergis and Payne (2010b) analyze the OECD countries and Apergis and Payne (2010c) include eleven countries of the Commonwealth of Independent States. For 19 developed and developing countries over the period 1984-2007, Apergis et al. (2010) analyze the casual dynamics between emissions, nuclear energy, renewable energy, and economic growth employing a panel error correction model. The long-run estimates show statistically significant negative relationship between

nuclear energy consumption and emissions in addition to a statistically significant positive relationship between emissions and renewable energy consumption. Moreover, Apergis and Payne (2011a) examined this relationship for a panel of six Central American Countries while Apergis and Payne (2011b) analyzed for 16 emerging market economies. Apergis and Payne (2012) contributed the literature by their multivariate panel data analysis of 80 countries. They especially used panel approach in their studies and found in almost all of their studies feedback relation between renewable electricity consumption and economic growth in the long run, while the casual relationship was found unidirectional in the short run in some of their studies (Apergis & Payne, 2011b; Apergis & Payne, 2010c). They added non-renewable electricity consumption into this relationship for the studies of Apergis and Payne (2011b and 2012). They found long run and short run bidirectional causality between non-renewable electricity consumption and economic growth. However, they indicated elasticity differences for renewable and non-renewable energy consumption.

In general, studies focus on the sign and direction of the relationship in empirical literature for both country-specific and multi-country approach. They usually analyzed casual dynamics between renewable energy consumption and economic growth. Moreover, most of the studies pointed out positive affect of renewable energy consumption on economic growth. Some of the studies can be shown according to their methodologies, sample periods, countries and results as in the following Table 1. In Table 1, the studies especially searched for the causality between group of countries rather than the single ones by using linear methods. Most of them found bidirectional causal relationship between renewable energy and economic growth.

**Table 1** Literature Review: Renewable energy consumption and economic growth

Author(s)	Sample	Country	Method	Results
Alper and Oguz (2016)	1990-2009	new EU member countries	asymmetric causality/ ARDL	Positive impacts of renewable energy consumption on economic growth but significant effects only for Bulgaria, Estonia, Poland, and Slovenia.

Author(s)	Sample	Country	Method	Results
Apergis et al. (2010)	1984-2007	19 developed and developing countries	panel ECM	Casual relations between emissions, nuclear energy, renewable energy, and economic growth. Short-run emission reduction effect of nuclear energy consumption. No impact of renewable energy consumption on emissions reduction.
Apergis and Payne (2010a)	1992-2007	Eurasia	Panel cointegration	Bidirectional causality in the short-run and in the long-run.
Apergis and Payne (2010b)	1985-2005	OECD	Panel cointegration and ECM	Bidirectional causality in both the short-run and long-run.
Apergis and Payne (2011a)	1980-2006	Central America	Panel cointegration	Bidirectional causality in both the short-run and long-run/
Apergis and Payne (2011b)	1990-2007	Emerging Market Economies (EME)	Panel cointegration	One-way short run causality from economic growth to <b>renewable</b> electricity, but two-way causality for the long-run. Two-way short run and long run causality for <b>nonrenewable</b> electricity consumption.
Apergis and Payne (2012)	1990-2007	80 countries	Panel ECM	Positive long run growth effect of renewable and non-renewable energy consumption. Short-run and long-run feedback relations between renewable and non-renewable energy consumption and economic growth.
Bhattacharya et al. (2016)	1991-2012	Top 38 countries (renewable energy country attractive index)	Panel estimates	For 57% of the selected countries, long-run significant and positive impact of renewable energy consumption on the economic output.
Bloch et al. (2015)		China	ARDL/ VECM	Long-run feedback relation between energy use of three main commodities and economic growth.
Boluk and Mert (2015)	1961-2010	Turkey	ARDL	Negative and significant effect of electricity production from renewable sources in the long run while positive and significant effect for the short run.
Bowden and Payne (2010)	1949-2006	US	Granger causality	Feedback relation between commercial and residential non-renewable energy consumption and real GDP. One-way causality running from residential renewable energy consumption to real GDP.
Chang et al. (2015)	1990-2011	G7	Granger causality	Bidirectional casual relation between economic growth and renewable energy.
Jebli and Youssef (2015)	1980-2009	Tunisia	ARDL/ VECM	Short run unidirectional causality running from GDP and non-renewable energy to renewable energy.
Menegaki (2011)	1997-2007	27 European countries	Random effect model	There is not any causality.
Ocal and Aslan (2013)		Turkey	ARDL	Negative effect of renewable energy consumption on economic growth. One-way causality running from economic growth to renewable energy consumption.
Pao and Fu (2013)	1980-2010	Brazil	Causality test	One-way causal relation from non-renewable energy consumption to economic growth. Two-way causality between economic growth and total renewable energy consumption.
Sebri and Salha (2014)	1971-2010	BRICS	ARDL/ VECM	Bidirectional Granger causality
Tugcu et al. (2012)	1980-2009	G7	ARDL	Bidirectional causality for all countries
Yildirim et al. (2012)		USA	Causality tests	They cannot find any casual relation between real GDP and renewable energy sources.

Author(s)	Sample	Country	Method	Results
Zeb et al. (2014)	1975-2010	SAARC Countries (Bangladesh, India, Nepal, Pakistan and Sri Lanka)	FMOLS	Casual relations between renewable energy and economic growth.

**Source:** Authors' own.

The organization of the paper is as follows. Section 3 overviews methodological issues while Section 4 presents empirical results. Last section, Section 5 concludes the study and discusses the policy implications.

### 3. Methodology

Gross Domestic per capita cannot be a correct measure for welfare as it does not consider some important socio-economic factors and informal sector for example, income inequality, poverty, natural resource depletion and unpaid work. Because of this, this study used another measure along with GDP per capita for comparison purpose. First, the measure for welfare, namely Solid Index for Sustainable Economic Development (SISEW) was calculated based on the following formula in equation (1) which is obtained from Menegaki and Tugcu (2017, p. 895) and was previously proposed by Menegaki and Tsagarakis (2015).

$$SISEW = Economic\ Variables\ (C^w + G^{nd} + K^{net} + B^{UPW}) - Environmental\ Variables\ (Ndepletion) \quad (1)$$

where,  $C^w$ ,  $G^{nd}$ ,  $K^{net}$ ,  $B^{UPW}$  and  $Ndepletion$  are the consumption weighted by Gini coefficient and poverty index, public education and health expenditure excluding defensive spending, net fixed capital formation, benefits obtained from unpaid work and natural depletion (forest, energy, mineral and CO<sub>2</sub> related depletion).

Then, in order to test for the direction of causality between growth/welfare and renewable energy consumption, this study employs panel Granger Causality test.

Detailed information for the test is provided by Lopez and Weber (2017). Test was performed under the assumption of individual coefficients, therefore allowing for heterogeneity across countries. This test was developed by Dumitrescu and Hurlin (2012). Following equations (2) and (3) are considered in testing;

$$GDPpc_{i,t} = \alpha_{1,i} + \sum_{k=1}^K \beta_{1k,i} GDPpc_{i,t-k} + \sum_{k=1}^K \delta_{1k,i} RENpc_{i,t-k}^j + \varepsilon_{1i,t} \quad (2)$$

$$RENpc_{i,t}^j = \alpha_{2,i} + \sum_{k=1}^K \beta_{2k,i} RENpc_{i,t-k}^j + \sum_{k=1}^K \delta_{2k,i} GDPpc_{i,t-k} + \varepsilon_{2i,t} \quad (3)$$

where,  $i=1,2,\dots,26$ ;  $t=2000,2001,\dots,2016$ ;  $j=$  total, hydropower, renewable hydropower, pumped storage, marine, wind, onshore wind energy, offshore wind energy, solar, solar photovoltaic, concentrated solar power, bioenergy, solid biofuels, renewable municipal waste, bagasse, other solid biofuels, liquid biofuels, biogas, geothermal. GDPpc and RENpc stand for real GDP per capita and renewable electricity generation per capita for country  $i$ , technology  $j$  and year  $t$ . One can replace GDPpc with SISEW per capita (SISEWpc) in equations (2) and (3) to test the causality for welfare measure. Similar to economic growth, one expects renewable energy usage to increase the well-being of the country by decreasing environmental degradation, supporting economic growth and employment. But also, as welfare of the country increases, country may give much more importance to environmental quality and employ much more renewables in order to sustain its welfare level. Moreover, causal relation may be bidirectional. However, they may not be any causal relation also. In order to examine direction of causal relations between welfare and renewable energy employment, similar equations were employed. After performing individual F tests for each country  $i$  to test the null hypotheses which are given in equations (4) and (5), in order to test the panel Granger causalities from  $RENpc^j$  to GDPpc (SISEWpc) and from GDPpc (SISEWpc) to  $RENpc^j$ , average Wald statistics is computed as shown in equation (6).

$$H_{01} : \delta_{11,i} = \dots = \delta_{1k,i} = 0 \tag{4}$$

$$H_{02} : \delta_{21,i} = \dots = \delta_{2k,i} = 0 \tag{5}$$

$$\bar{Wald} = \frac{1}{N} \sum_{i=1}^N Wald_i, \tag{6}$$

where  $i=1, \dots, N$ .  $N$  and  $Wald_i$  are number of countries and the country-specific Wald statistic. Null hypotheses in (4) and (5) are tested based on standardized statistics,  $\bar{Z}$  and  $\tilde{Z}$ , given in (7) and (8) which are asymptotically standard normal distributed assuming that  $Wald_i$ s are identically and independently distributed across countries.

$$\bar{Z} = \sqrt{\frac{N}{2K}} (\bar{W} - K) \sim N(0,1) \text{ as } T, N \rightarrow \infty \tag{7}$$

$$\tilde{Z} = \sqrt{\frac{N}{2K} \times \frac{T-3K-5}{T-2K-3}} \left\{ \frac{T-3K-3}{T-3K-1} \times (\bar{W} - K) \right\} \sim N(0,1) \tag{8}$$

as  $N \rightarrow \infty$  and fixed  $T > 5 + 3K$

For large  $N$  and small  $T$ ,  $\tilde{Z}$  statistic performs better (Lopez & Weber, 2017). Rejection of null hypothesis indicates the presence of panel causality.

## 4. Data and Causality Test Results

### 4.1. Data

Based on the availability of all the data, the analysis is only restricted to the 26 OECD countries<sup>6</sup>, between the years 2000 and 2016.<sup>7</sup> In order to calculate SISEW, various

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<sup>6</sup> Countries include Australia, Belgium, Canada, Chile, Costa Rica, Czech Republic, Estonia, France, Greece, Hungary, Ireland, Israel, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Turkey, United Kingdom, and United States.

<sup>7</sup> For example, the data for minimum wage is only available for 28 OECD countries and 4 more countries.

variables are used. These variables and data sources are presented in Table 2. Interpolation method was employed to deal with missing values in the data.

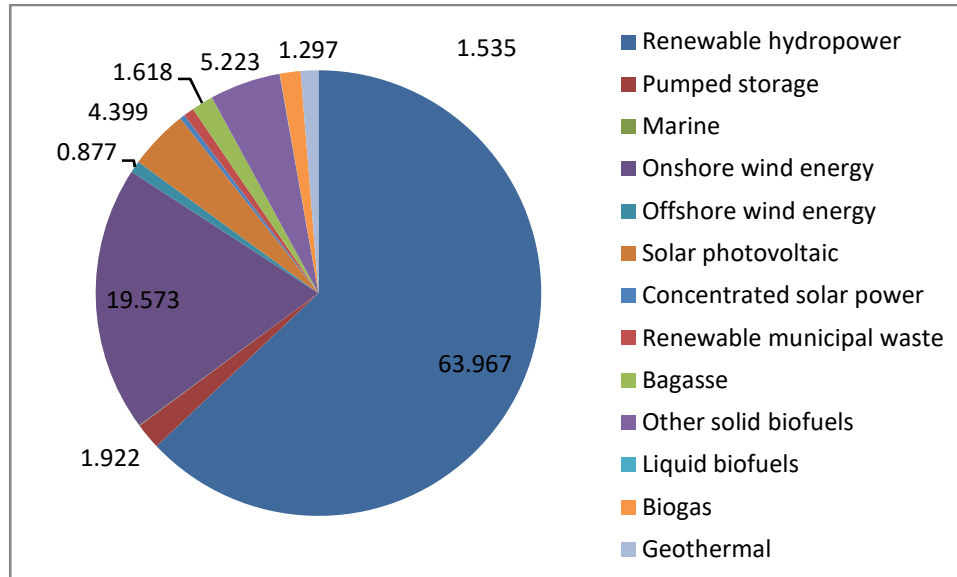
**Table 2** Variables and Data Sources for SISEW calculation

Data Series	Series Code	Data Sources
Household final consumption expenditure, etc. (current US\$)	NE.CON.PETC.CD	The World Bank, World Development Indicators (WDI)
Population, total	SP.POP.TOTL	The World Bank, WDI
Poverty headcount ratio at \$1.90 a day (2011 PPP) (% of population)	SI.POV.DDAY	The World Bank, WDI
Adjusted savings: carbon dioxide damage (current US\$)	NY.ADJ.DCO2.CD	The World Bank, WDI
Adjusted savings: consumption of fixed capital (current US\$)	NY.ADJ.DKAP.CD	The World Bank, WDI
Adjusted savings: energy depletion (current US\$)	NY.ADJ.DNGY.CD	The World Bank, WDI
Adjusted savings: net forest depletion (current US\$)	NY.ADJ.DFOR.CD	The World Bank, WDI
Adjusted savings: mineral depletion (current US\$)	NY.ADJ.DMIN.CD	The World Bank, WDI
Wage and salaried workers, total (% of total employment) (modeled ILO estimate)	SL.EMP.WORK.ZS	The World Bank, WDI
Employment to population ratio, 15+, total (%) (modeled ILO estimate)	SL.EMP.TOTL.SP.ZS	The World Bank, WDI
Labor force, total	SL.TLF.TOTL.IN	The World Bank, WDI
Gross fixed capital formation (current US\$)	NE.GDI.FTOT.CD	The World Bank, WDI
Government expenditure on education, total (% of GDP)	SE.XPD.TOTL.GD.ZS	The World Bank, WDI
Domestic general government health expenditure per capita (current US\$)	SH.XPD.GHED.PC.CD	The World Bank, WDI
GDP (current US\$)	NY.GDP.MKTP.CD	The World Bank, WDI
GDP (constant 2010 US\$)	NY.GDP.MKTP.KD	The World Bank, WDI
Consumer price index (2010 = 100)	FP.CPI.TOTL	The World Bank, WDI
Gini index estimate (equivalized household disposable income inequality)	gini_disp	Solt (2019)
Real minimum wages		Organization for Economic Co-operation and Development Statistics database

**Source:** Authors' own.

Detailed calculation for SISEW can be found in Menegaki and Tugcu (2017). The data for renewable electricity generation (kWh) were taken from The International Renewable Energy Agency Data and Statistics. For causality test, per capita values of all variables were considered. As shown in Figure 3, the electricity generation from renewables is mostly based on renewable hydropower and onshore wind energy accounting for nearly 84% of electricity generated by renewable energy in OECD countries for year 2016.

**Figure 3** Share of different renewable energy technologies in electricity generation from renewables for year 2016 (%)



**Source:** Authors’ own elaboration based on data from the The International Renewable Energy Agency (IRENA) Data and Statistics (2019).

Figure 4 illustrates both SISEWpc and GDPpc for 26 OECD countries over the period from 2000 to 2016. For all countries, SISEWpc is lower than GDPpc. In Luxembourg, there is a huge difference between them throughout the whole period. All these call for further analysis to investigate the reason behind this which out of scope of this study. Table 3 shows the time averages of SISEWpc, GDPpc and per capita electricity generation from total renewable energy ( $RENpc^{total}$ ) for all the countries under investigation. The countries are ordered according to the GDPpc. Although Costa Rica has the lowest GDPpc and lower SISEWpc, its  $RENpc^{total}$  is higher than the average of OECD countries. Slovenia is the country which has SISEWpc value below the average and records the highest  $RENpc^{total}$ , however, its GDPpc is lower than the average GDPpc of OECD countries. On the other hand, Luxembourg with the highest GDPpc and SISEWpc is below the average per capita total renewable energy usage in the electricity generation. Lastly, the country with the lowest SISEWpc is Chile which has below average GDPpc but above average  $RENpc^{total}$ . It is difficult to reach a

conclusion for the relations between GDPpc, SISEWpc and  $RENpc^{total}$  using the time averages of these variables, therefore, further analysis based on Granger causality tests aims to show causal relations among  $RENpc^{total}$  and GDPpc as well as  $RENpc^{total}$  and SISEWpc by also considering different renewable energy resources.

**Figure 4** Country by country comparison of SISEWpc and GDPpc over 2000-2016



**Source:** Authors' own elaboration based on the data from The International Renewable Energy Agency (IRENA) Data and Statistics (2019).

**Table 3** Time Averages of SISEWpc, GDPpc and  $RENpc^{total}$

Country	SISEWpc	GDPpc	$RENpc^{total}$
Costa Rica	-3592.27	7745.923	1899.511
Mexico	-13417.3	9450.164	365.9226
Turkey	402.424	10635.48	684.0112
Latvia	-1199.44	11491.13	1453.461
Poland	1656.811	11601.92	257.373

Lithuania	-2656.4	11770.37	280.7192
Chile	-4020.59	12269.42	1599.23
Hungary	4471.363	13038.73	196.7029
Estonia	978.7276	15023.49	473.3328
Slovakia	4912.781	15101.51	963.7114
Czech Republic	7602.387	18783.86	504.0152
Korea	7668.157	20522.08	128.5373
Portugal	5900.946	21997.79	1861.757
Slovenia	10671.02	22437.6	<b>2098.286</b>
Greece	4670.68	25645.77	752.4822
Israel	8593.644	29766.51	50.68924
Spain	4196.681	30446.89	1568.448
United Kingdom	14136.93	39439.23	505.1107
France	17733.96	40513.27	1169.397
Belgium	17301.31	43424.61	545.8843
Canada	15609.46	47523.97	11502.06
United States	2958.025	48545.69	1422.576
Netherlands	18921.33	49881.05	535.2231
Australia	10559.9	50606.09	1097.927
Ireland	15113.83	51538.24	818.2719
Luxembourg	<b>26577.43</b>	<b>102849.5</b>	529.7536
<b>Average</b>	6759.684	29309.63	1279.399

Source: Authors' own.

## 4.2. Empirical Results

This section presents the Granger Causality test results only related to conservation hypothesis as only for this hypothesis, significant results were found. This result is in line with the findings of Apergis and Payne (2011b), Jebli and Youssef (2015) and Ocal and Aslan (2013). Results are given in Table 4 and Table 5 for GDPpc and SISEWpc, respectively. There is evidence of causality from welfare/income to renewable energy consumption (RENpc<sup>i</sup>). Results differ between two measures except for bioenergy, solid biofuels and biogas. Although the results indicate the presence of Granger causality running from GDP per capita to per capita total renewable and hydropower energy usage, there is not any evidence of causal relation

for SISEW per capita. However, for wind and onshore wind technologies, conservation hypothesis was found to be valid only when SISEWpc was considered instead of GDPpc. Therefore, the results are very sensitive to the measures of economic well-being which can be a sign that GDP per capita cannot be considered as a true measure of welfare.

**Table 4** Results in line with Conservation Hypothesis (2000-2016) (GDPpc->RENpc<sup>j</sup>)

Technology (j)	$\bar{W}$	$\bar{Z}$		$\tilde{Z}$	
<b>Total</b>	3.013	7.2579*	(0.0870)	4.8381*	(0.0870)
<b>Hydropower</b>	2.3478	4.8595*	(0.0990)	3.0806*	(0.0990)
<b>Bioenergy</b>	3.9626	10.6818***	(0.0090)	7.3471***	(0.0090)
<b>Solid Biofuels</b>	3.2471	8.102**	(0.0320)	5.4567**	(0.0320)
<b>Biogas</b>	8.2276	10.8821*	(0.0720)	3.6673*	(0.0720)

Source: Authors' own.

**Note:** In all the analyses, lag length was chosen based on BIC taking maximum lag as 3 and tests were performed considering heterogeneity among countries. Bootstrapped p-values are given in parentheses to account for cross-sectional dependency. Bootstrap number is 1000. \*, \*\*, \*\*\* show the statistical significance at 10%, 5%, and 1% statistical significance level.

**Table 5** Results in line with Conservation Hypothesis (2000-2016) (SISEWpc->RENpc<sup>j</sup>)

Technology (j)	$\bar{W}$	$\bar{Z}$		$\tilde{Z}$	
<b>Wind</b>	2.3185	4.7538*	(0.0530)	3.0031*	(0.0530)
<b>On-shore wind</b>	7.2424	8.8312**	(0.0470)	2.7702**	(0.0470)
<b>Bioenergy</b>	4.5962	6.619*	(0.0940)	3.3117*	(0.0940)
<b>Solid Biofuels</b>	7.7613	9.9114**	(0.0400)	3.2427**	(0.0400)
<b>Biogas</b>	5.152	8.0361**	(0.0500)	4.1899**	(0.0500)

Source: Authors' own.

**Note:** In all the analyses, lag length was chosen based on BIC taking maximum lag as 3 and tests were performed considering heterogeneity among countries. Bootstrapped p-values are given in parentheses to account for cross-sectional dependency. Bootstrap number is 1000. \*, \*\*, \*\*\* show the statistical significance at 10%, 5%, and 1% statistical significance level.

For renewable hydropower, results indicate the validity of neutrality hypothesis for both GDPpc and SISEWpc. Findings of Menegaki (2011) and Yildirim et al. (2012) also supported the neutrality hypothesis. Moreover, due to lack of sufficient observations, analysis cannot be performed for pumped storage, marine, offshore wind energy, solar, solar photovoltaic, concentrated solar power, renewable municipal waste, bagasse, other solid biofuels, liquid biofuels, and geothermal.

## **5. Conclusion**

This study aims to analyze the causal relations between renewable energy consumption and economic growth as well as between renewable energy consumption and welfare, separately. The renewable energy and economic growth nexus is being studied in the last decade. As economic growth may not cover the economic well-being, welfare is used as another measure. For the test of the causal relations, due to data unavailability for all countries, the analysis is restricted to OECD countries over the period from 2000 to 2016. Results show that for different technologies, the direction of causality differs. There is evidence of causality from welfare/income to renewable energy consumption as well as evidence of causality from GDP per capita to per capita total renewable and hydropower energy usage. However, evidence shows the validity of conservation hypothesis and neutrality hypothesis, i.e., the decrease in the renewable energy consumption may not be detrimental to economic growth. In other words, investment in these technologies may not have positive growth and welfare increasing effects. But because of global warming and to meet the energy requirements, for renewables, technology-specific support mechanisms should be implemented and much more global funds should be provided to help the country's transition to sustainable energy systems. The former one was also previously suggested by Polzin et al. (2015). As a future study, the analysis can be extended to cover all the countries and using recent data. Also, conventional energy sources can be included into the analysis in order to compare the results.

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