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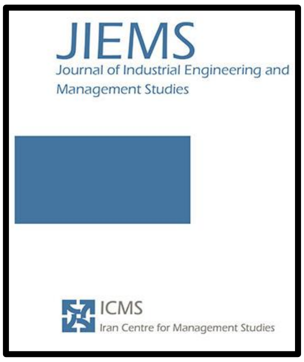

Analysis of the simultaneous effects of renewable energy consumption and GDP, using Dynamic Panel Data

A.M. Kimiagari[1], F. Lotfian Delouyi[1], M. Shabani[1,*]

Abstract
In the recent years, renewable energy sources are an important component of world energy consumption. GDP is one of the main measures of a country's economic activity. Most of the studies examine the impact of renewable energy consumption on GDP with single equation model and the others use dynamic panel data. Since the Granger causality analysis's findings of this paper establish bidirectional causality between GDP and renewable energy consumption, the purpose of this study is to develop a simultaneous-equations model to explore the interaction between GDP and renewable energy consumption in a dynamic panel data. This model uses GDP and renewable energy consumption as endogenous variables and seven factors as exogenous variables. By using a dynamic panel data of 34 OECD countries from 1990 to 2012, the model is estimated by using the two-stage least-squares method. The results confirm the important influence of renewables and non-renewables as well as capital and labor force on GDP in OECD countries. Based on the results, both GDP and real oil price play an important role in renewable energy consumption. Our findings suggest that energy planners and policy makers need to increase renewable energy investment to ensure sustainable economic development in future.

Keywords: Simultaneous Equations, GDP, Renewable energy consumption, Panel Data.

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1. Introduction
Over the recent years, a number of studies have examined the relationship between energy consumption and economic growth. GDP is one of the main measures of macro-economy. Because not only as the most important indicator of economic performance analyzes and assessments used, but many other items that are considered macroeconomic by products measured.

Gross Domestic Product (GDP) is a measure of economic growth. GDP gives us the total market value of all final goods and services produced within a country's borders in a specific time period – monthly, quarterly or annually. The main reasons have compelled government policies to develop low-fossil-fuel economies and improve energy efficiency are fossil-fuel shortage, climate change and global warming.

* Corresponding Author.

[1] Department of Industrial Engineering and Management Systems, Amirkabir University of Technology.

Reduction of energy cost and carbon dioxide emissions (CO_2) are the primary expected achievements of energy efficiency. Therefore renewable energy is becoming an increasingly substantial source of alternative energies. Renewable energies are planned to be the fastest growing source of energy between now and 2030 (Omri & Nguyen 2014).

Solar energy is one of the cleanest renewable energy sources. It was in use much earlier before humans even learn how to light a fire. The other important renewable energy is Wind energy that has least negative impacts on the environment. 'Geo' means Earth and "thermal" means energy. Geothermal energy means energy drawn or harnessed from beneath the earth. It is completely clean and sustainable. Solar energy is produced by sun and wind energy is produced by moving of winds. The heat caused by sun drives the wind. The wind turbines can convert the kinetic energy in the wind into electricity. The energy of the flowing water can be captured and called as hydroelectric power. This is the process by which an alternative energy is generated. The earth grants many power sources. Just like the geothermal and solar energy, which have been used in heating homes and lighting for centuries.

Renewable Energy is a fundamental part of the energy sector and because of benefits provided to the society and economy their role is increasing with reference to data of international Energy agency. Renewable Energy accounted for 13.1% in global total primary energy supply (further in the next TPES, Total Primary Energy Supply) in 2004 and 2009. However, it is expected to increase the share of fossil energy sources such as oil, coal and natural gas (Müller et al. 2011).

Biomass and waste are the noticeable types of Renewable Energy, representing 9.9% in global TPES and 75.9% in global Renewable Energy supply in 2009. However, their share in global Renewable Energy has a decreasing trend. The second largest type of Renewable Energy is Hydro. It accounted for 2.3% in global TPES and 17.7% in global Renewable Energy supply in 2009. This is by 0.1 and 1.0 percentage points less than in 2004. It is expected that during 2009-2035 the volume of hydro power will be increasing by 2.1% a year and will exceed the growth rates of fossil fuel and nuclear energy; however, the share of it will have a tendency to reduce (Müller et al. 2011).

The third largest type of Renewable Energy in the world is geothermal energy. It provided 3.9% in global Renewable Energy supply in 2009. This is by 0.7 percentage points more than in 2004. The contribution of wind, solar and tide energies is still minor with respect to data of International Energy Agency. They accounted for 0.3% in world TPES and 2.5% in global Renewable Energy supply. Because of the rapid development of wind, solar and geothermal capacities in future, the share of these types of energies will triple, i.e. will increase till 22.4% (2035) in the structure of global Renewable Energy supply (Müller et al. 2011).

The data provided by the international Energy Agency showed that during 1990-2009 renewable energy sector grew at an average annual rate of 1.8%, which was slightly higher than the growth rate of global TPES (1.7% a year). Growth rates were particularly high for solar photovoltaic (further in the next PV) (43.5% a year) and wind power (25.1% a year). However, this is due to the fact that their bases were very low in 1990. Biogas had the next highest growth rate (14.9%) a year, followed by the liquid biofuels and solar thermal, which both grew at 10.0% a year. Solid biofuels (including charcoal) experienced the lowest growth (1.2% a year) among the Renewable Energy (Müller et al. 2011)

International energy agency expects the renewable energy sector will remain one of the fastest growing energy sectors in the world during the next two decades. It will grow at an average annual growth rate of 2.5% when the world primary energy demand will increase by half as big (by 1.3% a year), and will guarantee for future generations the supply of energy. But seeking that this will be realized additional new investment is required (Müller et al. 2011).

Finally, various studies confirmed the correlation between GDP and consumption of renewable energy. Renewable energy consumption affects GDP and thus GDP affect energy consumption and both of them will have great impact on the economy. In this paper, a two-way communication between GDP and consumption of renewable energy is expected to be examined. The reminder of this article is organized as follows. Section2 presents the Literature review, section 3 reports the data and model designing and section 4 reports methodology and model estimation. Section 5 is about empirical Findings of simultaneous equations model and section 6 concludes the article.

2. Literature Review

The relation between energy and economic growth has been investigated in several studies using diverse approaches. However, there has been a lot of divergence in the results obtained Bash (2015). Zhang and Cheng (2009) analyzed the existence and direction of Granger causality between economic growth, energy consumption, and carbon emissions in china from 1960 to 2007. Their results indicate the existence of a unidirectional Granger causality running from GDP to energy consumption, and a unidirectional Granger causality running from energy consumption to carbon emission in the long run. Which suggest that neither carbon emissions nor energy consumption leads to economic growth.

The hypothesis of causality between energy consumption and economic growth has also demonstrated to be neutral in several studies. Using the same methodology, Yildirim et al. (2014) applied the Toda Yamamoto procedure and bootstrap-corrected causality test in order to analyze the causality between renewable energy and economic growth in the USA. They also found no causality between economic growth and total renewable energy consumption.

Ocal & Aslan (2013) found that renewable energy consumption has a negative impact on economic growth for the case of Turkey. Chang et al. (2009) attempted to investigate the development of renewable energy sector under different economic growth rate regimes by applying panel threshold regression (PTR) model in OECD member-countries. The results showed that countries with high economic growth are able to increase the renewable energy use, while countries with low-economic growth are unable to grow the consumption of renewable energy.

Apergis & Payne (2010a) used panel co-integration and error correction model to study the causality relationship between renewable energy and economic growth for twenty OECD countries. According to their findings, there is a long run equilibrium relationship between real GDP, renewable energy consumption, real gross fixed capital formation and the labor force. They also found bi-directional causality for long and short run between renewable energy and growth. Similar results were found for the case of Eurasia Apergis & Payne (2010c).

Employing similar methodology, Apergis & Payne (2011a) found the existence of unidirectional causality running from economic growth to renewable electricity consumption in the short term and also bidirectional causality between these variables in the long term in emerging economies.

Tugcu et al. (2012a) investigated the relationship between renewable and non-renewable energy consumption and economic growth in the G7 countries. They employed Autoregressive Distributed Lag approach to co-integration and found that both renewable and non-renewable energy are Important for economic growth with bidirectional causality for all G7 countries. Similar results were provided by Pao & Fu (2013) and Ohler & Fetters (2014).

However, Al-Mulali et al. (2014) indicated that renewable electricity consumption is more significant than nonrenewable electricity consumption in promoting economic growth in 18Latin American countries in the long run and the short run. Later, Al-Mulali et al. (2013) studied the case of high income, upper middle income, Lower middle income, and lower income countries by employing the fully modified ordinary least square (FMOLS) method. This study specify along run bidirectional causality between renewable energy and GDP growth for most (79%) of the countries. However, results showed the existence of unidirectional long run relationship from

GDP growth to renewable energy consumption for 2% of the countries, and failed to establish long run relationship between these Variables for 19% of the countries. This study pointed out that the level of significance of the bidirectional long run relationship between the variables is gradually more important while moving from the low Income to the high income countries.

Magnani & Vaona (2013) adopted panel data unit root and co-integration as well as Granger non causality tests based on the system GMM estimator for studying Relation between renewable energy generation and economic growth at regional level in Italy. They found that renewable energy generation has appositive impact on economic growth by reducing constraint on Balance of payments and exposure to the volatility of fossil fuels price.

Sadorsky (2009a) analyzed the relationship between renewable energy and economic growth in emerging countries. He stated that growth in Income has a significant effect on increasing renewable energy consumption. But in the contrary, results from Marques & Fuinhas (2012) suggested negative impact of using renewable energy on economic growth and that in turn, economic growth does not contribute To increased renewable energy consumption. Based on the literature surveyed and to the best of our knowledge, research on the relationship between renewable energy consumption and economic growth is still limited and results provided are not unanimous.

Our objective here is to review the scant literature on the role of renewable energy in explaining sustainable economic growth. A bi-directional causation was established between renewable energy consumption and economic growth by Miech & Papiez, (2014) for emerging economies.

Sadorsky (2009b) reports that in the long run, a 1% increase in real income per capita increased the consumption of renewable energy per capita by approximately 3.5% for these economies.

Payne (2009) analyzed the sectorial causal relationship between renewable and non-renewable energy consumption and Economic growth in the US. Their findings established no causality between renewable energy consumption and real GDP in the commercial and industrial sectors, while positive uni-directional causality exists from residential renewable energy consumption to real GDP. On renewables, there are only a few studies examining the effects of biomass biofuels on the environment with varying results. Bilgili & Ozturk (2015a) reviewed this literature and investigated 51 African countries. They found that a 1% increase in biomass will increase GDP by 0.82% in these countries.

A summary of literature is presented in Table 1 to conserve space. It is noticeable that the findings from the literature are mixed even for the studies where energy-mix is disaggregated. Given that there is currently a worldwide effort to increase the share of renewable sources; a panel study instead of a case study on a single country is considered. The selection of countries following the RECAI index and heterogeneous panel estimation techniques provide new findings in the literature do Valle Costa et al. (2008).

Table 1: Recent researches on Renewable Energy Consumption and GDP

Study	Methodology	Period	Country	Findings
(Sadorsky 2009b)	Panel, FMOLS[1]	1994-2003	18 emerging countries	GDP<>RE*
(Apergis & Payne 2010b)	Panel	1985-2005	20 OECD countries	GDP<>RE
(Apergis & Payne 2010d)	Panel	1992-2007	13 Eurasian countries	GDP<>RE
(Apergis & Payne 2011b)	Panel	1980-2006	6 Central American countries	GDP<>RE
(Menegaki 2011)	Panel, random effect	1997-2007	27 European countries	GDP and RE are neutral to each other
(Fang 2011)	OLS[2]	1978-2008	China	RE>GDP
(Tiwari 2011)	Structural VAR[3]	1960-2009	India	RE>GDP
(Apergis & Payne 2012a)	Panel	1990-2007	80 countries	GDP <> EC (RE, NRE)
(Salim & Rafiq 2012)	Panel	1980-2006	6 major emerging countries	GDP <> RE in the short-run
(Tugcu et al. 2012b)	ARDL[4] approach for co-integration	1980-2009	G7 countries	The relationship is different for countries and varies with specification
al et mulali–Ai	FMOLS	1980-2009	108 countries	79% feedback; 2% conservation; 19% neutrality
(Bilgili & Ozturk 2015a)	Dynamic panel analysis	1980-2009	51 Sub-Sahara African countries	Biomass has positive effect on GDP
(Cho et al. 2015)	Panel vector error correction model	1990-2010	31 OECD and 49 non-OECD countries	GDP > RE** fo developed and GDP <> RE for less-developed countries
Ozturk and Bilgili (Bilgili & Ozturk 2015b)	Panel, DOLS	1980-2009	G7 countries	Biomass has positive effect on GDP

* GDP <> RE Bi-directional relation- ship between GDP and RE.
** GDP > RE Uni-directional causality exists from GDP to RE.

Data in the econometric models include time-series or cross-sectional data separately. It requires the use of time series data at a specific section. Using of panel data was the new method and using conventional methods and systems of equations modeling began.

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[1] Fully Modified Ordinary Least Squares
[2] Ordinary Least Squares
[3] Variance
[4] Autoregressive Distributed Lag

In this paper, Panel data is used in a system equation model, with the case of OECD countries.

3. Data and Model Designing

Taking GDP and renewable energy consumption as two endogenous variables, this work develops a simultaneous-equations model with two linear form equations, including 2 predetermined variables and seven exogenous variables. The selected variables included in the system are based on the economic theory and available empirical evidence.

An increase in GDP may require more energy consumption and probably decrease the environmental quality. Accordingly, the high GDP should lead to a high level of renewable energy consumption under pressure of environmental depreciation. On the one hand some studies including, among others, Refs. Omri & Nguyen (2014), Apergis & Payne (2012b), Sadorsky (2009a) mainly find that the GDP is an important determinant of renewable energy consumption, but on the other hand some studies propose a production function where, along with traditional inputs, renewable and non-renewable sources of energy are used into the production process (Cerdeira Bento et al. 2016), (Bilgili & Ozturk 2015c), (Apergis & Payne 2011c)

Taking the above discussions into account, we develop, in this study, an empirical system equation that is consistent with the broader literature and available empirical evidence. Taking GDP and renewable energy consumption as two endogenous variables, this work develops a simultaneous-equations model with two linear form equations, including two predetermined variables and seven exogenous variables.

The GDP equation contains 3 exogenous variables, and The REC equation contains the lagged endogenous variable GDP (-2) that is multiplied by a dummy variable and three exogenous variables. The specifications of the simultaneous-equations model are as follows:

$$GDPit = C1 + C2*GFCFit + C3*LFit + C4*RECit + C5*NRECit + u_{it} \quad (1)$$

$$RECit = C6 + C7*CO2it + C8*TOit + C9*ROPit + C10*\log(GDPit) + 11*dummy*GDPit(-2) + \varepsilon_{it} \quad (2)$$

The subscripts i (i= 1… N) Denotes the country i in our sample, with N being equal to 34 and t (t = 1, …, T) indicates the time period which T being equal to 23. The error terms, u and $\boldsymbol{\varepsilon}$, are assumed to be independent and identically distributed with a zero mean and constant variance. Real GDP (constant 2005 US$) as a measure of economic output and real gross fixed capital formation (GFCF)(constant 2005 US$) are used as a proxy for the growth of capital stock, total labor force (LF) is used as a measure of all people who supply labor for the production of goods and services during a specified period. CO_2 represents the Carbon dioxide emissions in metric kilo tons. ROP represents the Brent real oil price in metric $/bbl. To represents the trade openness, measured as exports plus imports as a percentage of GDP. The energy sources are used in this model is renewable energy consumption (REC), and non-renewable energy consumption (NREC) in quadrillion Btu units. The required data on oil price is collected from the U.S. Energy Information Administration (EIA, Energy Information Administration, 2013) and the others are obtained from the World Development Indicators (WDI) online database published by the World Bank (various issues). At the end of this part, it is noticed that dummy variable is equal 1 for high income OECD countries and 0 for others.

This period is selected based on availability of data for the balanced panel and because most of the initiatives for renewables have been accomplished during this time. Figure1 presents the share of renewable energy sources in total final energy consumption in 2002 and 2012 in OECD countries.

For the empirical analysis, this paper uses a balanced panel for 34 OECD countries from 1990 to 2012. The countries are: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.

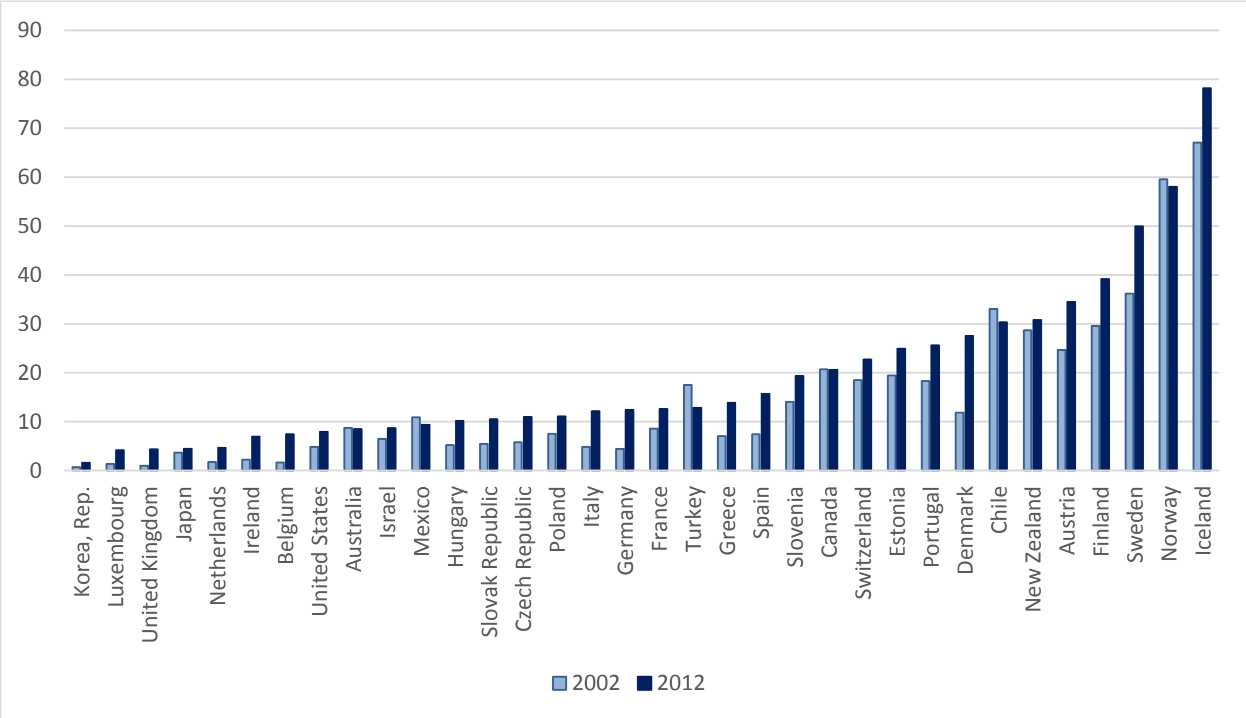

Figure 2: Share of renewable energy sources in total final energy consumption; 2002 and 2012 in OECD countries

Table 2 presents the average of each variable in our model. There was heterogeneity across countries for these statistics. For example, the average annual real GDP was 1.14104E+13 for United States, followed by Japan (4.34864E+12) and Germany (2.75483E+12). While, the average annual real GDP for Estonia was 12089098924. The highest average annual consumption of renewables is recorded for US (531.7066), Canada (264.0997), France (108.3694) and Norway (107.2217). The three countries with highest annual average percentage of renewable energy were Iceland, Sweden and Norway.

Table 1: Average of each variables in the model

Country	GFCF	CO_2	GDP	LF	ROP	NREC	REC
Australia	1.5986E+11	323831.9	6.12518E+11	9989044	42.69522	469.9754	38.73131
Austria	68560500723	64663.88	2.89039E+11	3975778	42.69522	105.4363	37.52256
Belgium	76785380407	110135.7	3.54504E+11	4427912	45.5675	191.2745	8.306535
Canada	2.10187E+11	502872.2	1.02597E+12	16725033	42.69522	956.2315	264.0997
Chile	21943455861	54890.49	1.07266E+11	6428315	42.69522	77.36096	33.20979
Czech Rep	33689271096	121212.1	1.22484E+11	5155806	42.69522	129.7634	9.887032
Denmark	47877781474	53734.38	2.40027E+11	2891447	42.69522	75.0942	10.9696
Estonia	3275787946	17345.83	12089098924	709314	42.69522	2.607581	1.660422
Finland	40460851825	57521.56	1.78686E+11	2614183	42.69522	63.11738	36.9527
France	4.28659E+11	369622.6	2.01732E+12	27789710	42.69522	561.998	108.3694
Germany	5.6188E+11	827600.9	2.75483E+12	40683914	42.69522	1174.487	77.0284
Greece	44517472173	87466.12	2.10609E+11	4780277	42.69522	119.1492	10.69311
Hungary	24893709465	54974.44	1.07909E+11	4261590	61.42846	83.80507	6.953912
Iceland	2903598477	2074.855	14363405837	166902.7	42.69522	3.004786	8.959263
Ireland	39921339502	38518	1.62729E+11	1808241	42.69522	49.7066	1.750126
Israel	30490588286	56578.98	1.25142E+11	2521916	42.69522	74.59874	5.28819
Italy	3.42378E+11	436527.8	1.72726E+12	23812244	42.69522	673.8013	43.88836
Japan	1.05095E+12	1184780	4.34864E+12	66629250	42.69522	1762.338	85.46249
Korea	2.47212E+11	424804.8	7.59671E+11	22811947	42.69522	663.7219	7.497251
Luxembourg	6661766858	9844.895	31673510217	195930.4	42.69522	14.93412	0.546386
Mexico	1.59578E+11	390791	7.87618E+11	41382751	42.69522	547.8645	71.35033
Netherlands	1.30032E+11	169089.5	6.16726E+11	8119803	42.69522	362.8504	8.71451
New Zealand	21066983453	30718.79	98841114400	2018973	42.69522	54.59967	23.73803
Norway	54630271130	39507.76	2.7454E+11	2378712	42.69522	101.4169	107.2217
Poland	53119296241	324943.7	2.73926E+11	17567905	42.69522	364.6104	26.03681
Portugal	40941880490	55405.54	1.80119E+11	5221265	42.69522	79.46604	22.54306
Slovak Rep	15438688456	39101.4	57573276245	2610746	42.69522	57.34404	4.841803
Slovenia	7680914745	15136.83	34035705896	969740.1	42.69522	20.66905	4.195035
Spain	2.60987E+11	281355.4	1.00351E+12	19318081	42.69522	431.4341	52.99811
Sweden	76876049540	51927.72	3.46859E+11	4682662	42.69522	79.03001	86.17323
Switzerland	93275672250	40686.87	3.86821E+11	4124625	42.69522	69.72641	23.83052
Turkey	81373737125	215710.6	4.17047E+11	22205978	42.69522	285.2909	56.65421
UK	3.75793E+11	531349.6	2.12244E+12	30100243	42.69522	833.8354	14.49357
US	2.3528E+12	5394699	1.14104E+13	1.46E+08	42.69522	8102.887	531.7066

Table 3 and Table 4 show the correlations among the variables of the first and second equations, respectively. For the first equation results show that GDP had high correlation with capital formation, labor, non-renewable energy consumption and renewable energy consumption. These findings indicate that all of the variables play an important role in promoting GDP across the countries. For the second equation, REC had higher correlation with CO_2 emission and GDP, and lower correlation with trade openness and real oil price.

Table 2: Correlation for the first equation's variables

	GDP	REC	NREC	LF	GFCF
GDP	1	0.85295	0.966448	0.964654	0.992541
REC		1	0.872465	0.812007	0.833573
NREC			1	0.944675	0.954225
LF				1	0.960510
GFCF					1

Table 4: Correlation for the second equation's variables

	REC	CO_2	TO	ROP	GDP
REC	1	0.862108	-0.294932	0.086112	0.85295
CO_2		1	-0.294319	0.007578	0.966605
TO			1	0.288377	-0.317158
ROP				1	0.053070
GDP					1

4. Methodology and Model Estimation

In this section, appropriate econometric methodology is described and applies these for our balanced panel.

Panel unit root test

Our analysis is continued by performing the panel unit root test proposed by Levin et al. (2002). The objective is to decide which variables should enter the empirical model in their first-order differential form and which variables should be in their level form. The result of unit root test is summarized in Table 5 for all of panels, which show that all of the variables were integrated of same order, i.e., I (1). It finds that all of the variables are non-stationary at levels, and stationary at their first-order differentials.

Table5: results of unit root test for all the variables.

	Level		First difference	
	Statistic	Prob.	Statistic	Prob.
CO_2	-2.19493	0.0141	-5.72442	0.0000
GDP	-1.95779	0.0251	-9.92140	0.0000
GFCF	-1.51763	0.0646	-10.1776	0.0000
LF	0.76940	0.7792	-4.77599	0.0000
REC	9.16300	1.0000	-4.92639	0.0000
ROP	12.8634	1.0000	-15.9564	0.0000
TO	-2.79416	0.0026	-14.0323	0.0000

Panel co-integration test

In the subsequent step, the existence of a long-run equilibrium relationship between the variables is examined. Each of our variables is integrated of order one, panel co-integration test developed by Pedroni (1999a) is conducted. The proposed test statistics are: the panel v-statistic, panel rho-statistic, panel PP-statistic, panel ADF-statistic, group rho-statistic, group PP-statistic and group ADF-statistic.

Table 6 and table 7 present the findings. Out of seven test statistics in the first equation, four confirm the presence of co-integration among the variables. Therefore, it is concluded that real GDP, gross fixed capital formation, labor force, renewable consumption and non-renewable consumption series shared a long-run equilibrium relationship.

In second equation, six test statistics confirm the presence of co-integration among the variables. Therefore, it is concluded that renewable energy consumption, real GDP, real oil price, trade openness series shared a long-run equilibrium relationship.

Table6: Pedroni panel co-integration test results (First equation)

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	1.936535	0.0264***	-0.019438	0.5078
Panel rho-Statistic	3.923795	1.0000	3.726857	0.9999
Panel PP-Statistic	-0.715114	0.2373	-1.703163	0.0443***
Panel ADF-Statistic	-4.616071	0.0000***	-1.891643	0.0293***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	6.344991	1.0000		
Group PP-Statistic	-2.276050	0.0114***		
Group ADF-Statistic	-1.982716	0.0237***		

Notes: Variables: GDP, GFCF, LF, REC & NREC.
Trend assumption: No deterministic trend.
Lag selection: 1.
*** Denote rejection of null hypothesis of no co-integration at 0.5% significance level.

Table7: Pedroni panel co-integration test results (Second equation)

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	-0.451879	0.6743	2.372282	0.0088***
Panel rho-Statistic	0.111223	0.5443	-1.730976	0.0417***
Panel PP-Statistic	-9.743146	0.0000***	-6.641572	0.0000***
Panel ADF-Statistic	-12.00596	0.0000***	-4.346187	0.0000***
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	-0.244304	0.4035		
Group PP-Statistic	-7.735082	0.0000***		
Group ADF-Statistic	-3.145035	0.0008***		

Notes: Variables: REC, GDP, TO & ROP.
Trend assumption: No deterministic trend.
Lag selection: 1.
*** Denote rejection of null hypothesis of no cointegration at 0.5% significance level.

Panel causality analysis

The existence of co-integration between variables confirms that there ought to be at least, one causal relationship, but it fails to give its direction. Hence, the procedure from Engle and Granger (1987) to examine the short-run as well as the long-run causal dynamics between the competing variables is followed. This test requires variables to be stationary; therefore is applied on the first difference of the series. The findings established bidirectional causality between GDP and renewable energy consumption in the short-run. (See table8).

Table 8: Granger causality analysis

Null Hypothesis:	Obs.	F-Statistics	Prob.
D (REC) does not Granger Cause D(GDP)☆	662	7.91088	0.0004
D (GDP) does not Granger Cause D(REC)☆		36.1025	1.E-15

☆ Denote rejection of null hypothesis at 1% significance levels.

5. Empirical Findings of Simultaneous Equations Model

Model estimation

As two equations in this paper are over-identified, 2SLS can be used to estimate the simultaneous equations model. In the table 9 the estimation of the model is presented. The findings on long-run suggest that along with traditional inputs such as capital and labor, both renewables and non-renewables play a significant role in the process of economic development in the OECD countries. Based on these results, it is argued that renewable energy consumption plays a bigger role in GDP. The findings of the second equation show that both GDP and real oil price play an important role in renewable energy consumption in the selected countries. As a result, to ensure sustainable economic development in future, policy makers need to promote the production and consumption of renewable energy.

Table 9: Estimation of the model

		Coefficient	Std. Error	t-Statistic	Prob.
GDP	REC	3.45E+09	5.69E+08	6.055891	0.0000
	GFCF	3.301246	0.087369	37.78512	0.0000
	NREC	81285827	42196409	1.926368	0.0543
	LF	8166.803	1308.187	6.242841	0.0000
	R-Squared	0.986408			
REC	TO	-8.349877	5.3774460	-1.553622	0.1205
	ROP	0.163681	0.069853	2.343212	0.0193
	GDP(-2)*dummy	3.10E-11	4.57e-12	6.784243	0.0000
	Log(GDP)	8.167862	2.656910	3.074196	0.0022
	CO_2	2.43E-05	9.57e-06	2.541856	0.0111
	R-Squared	0.782887			

6. Conclusion

With the rapid development of global economy, the consumption of fossil fuel energy has been growing fast. In response to worldwide attention towards sustainable development, renewable energy as the major alternative energy for achieving that has been widely concerned.

A simultaneous equations model is used to explore the interaction between GDP and renewable energy consumption. It was established a dynamic panel data of 34 OECD countries from 1990 to 2012. The model was estimated by using the two-stage least-squares method. The findings on long-run suggested that capital, labor and both renewables and non-renewables played a significant role in the process of economic development in the OECD countries. Based on these results, it is argued that renewable energy consumption plays a bigger role in GDP. The findings of the second equation show that both GDP and real oil price play an important role in renewable energy consumption in the selected countries.

There are some studies that investigate the impact of renewable energy consumption on GDP with single equation model and the others use dynamic panel data. With Comprehensive research, dynamic panel data in a system equation model is applied to describe two side effect of renewable energy consumption on GDP, for the first time.

One of the limitations of our model was that disaggregated data within the renewables (i.e. bio-mass, solar, wind and hydroelectricity) due to unavailability of data for the selected period, could not investigate.

Developing human expertise, using high technologies, removing financial and political barriers, feed-in tariffs and credit incentives for green energy are major instruments for increasing the production and consumption of renewable energy. For the further research using the mentioned items is suggested.

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