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Research paper

Comparative analysis of energy consumption, CO2 emissions and economic growth: evidence for OECD selected countries

Samia Gmidène [1]*, Saida Zaidi [1], Sonia Zouari Ghorbel [2]

[1] *FSEG, Sfax, Tunisia*
[2] *ISAA, Sfax, Tunisia*
**Corresponding author E-mail: Sa2008mia@gmail.com*

Abstract

The main purpose of this study is to investigate the causal relationship among renewable energy, nuclear energy consumption, economic growth, and CO2 emissions for selected OECD countries over the period 1980 to 2013. All variables are found to be cointgrated.
Results of Granger causality show long-run relationship from GDP, renewable energy consumption and nuclear energy consumption to CO2 emissions, from CO2 emissions, GDP, to renewable energy consumption, from emissions, GDP to renewable energy, and from CO2 emissions GDP and nuclear energy consumption.
In short run, results show that there exists bidirectional causality between GDP and CO2 emissions, and unidirectional causality running from renewable energy consumption to GDP. Also unidirectional causality running from renewable energy consumption to CO2 emissions without feedback but no causality running from nuclear energy consumption to CO2 emissions was found. This evidence suggests that renewable energy can help to mitigate CO2 emissions, but so far, nuclear energy consumption has not reached a level where it can CO2 emissions.

Keywords: *Renewable Energy; Nuclear Energy; Economic Growth; CO2 Emissions; Granger Causality Test.*

1. Introduction

It is commonly recognized that CO2 emissions are the main contributor to green-house gas emissions and global warming. This constitutes a threat for all countries all over the world. Their consequences differ among countries and depend on economic, social, and natural characteristics.
Topic of causal relationship among energy consumption, environment, and economic growth is widely studied in the energy economic literature. This literature can be classified into three groups. The first stand interested in the causal relationship between energy consumption and economic growth. The literature review classifies empirical studies that examined the relationship between energy consumption and economic growth in two categories. The first one used the energy demand function, especially Masih and Masih ‘1998), Asafu- Adjaye (2000), Fatai et al., (2004) Oh and Lee (2004), Javid and Qayyum and Bashiri Behmiri(2013) and PiresManso, related to GDP (gross domestic product) and consumer prices index, as an indicator of energy prices, the second one used the production function aggregate considering energy as production factors as well as capital and labor. These include the work of Yu and Choi, (1985) Masih and Masih (1996), Glasure and Lee (1996), Yang, Soytas and Sari(2000),Shiu and Lam (2004), Paul and Bhattacharya (2004), Morimoto and Hope (2004), Lee and Chang (2007), Stern and Enflo (2013) Bloch and et al., (2012).
This latter approach is a revolution compared to Solow traditional growth model. Three types of causalities were shown by various empirical results. Unidirectional causality was found by first one, bidirectional causality and lack of causality. The unidirectional causality can be seen either from energy consumption to economic growth or vice versa. In other words does energy use cause economic growth or does economic growth imply increasing energy consumption?
In the first case, energy saving policy is likely to have a negative impact on economic growth. However, if causality goes from economic growth to energy consumption, the implementation of energy saving policy has no effect on economic growth. The presence of bidirectional causality means that energy consumption and economic growth are complementary and that reducing energy consumption by adopting an energy conservation policy may cause contraction effects. The absence of causality allows energy policy implementation without affecting economic growth (Bozoklu, Yilanci2013), and Mahadevan, AsafuAdjaye (2007).
Table 1 shows a summary of recent studies for energy consumption and economic growth
The second group focuses on the validity of the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis proposes the existence of an inverted U-curve in the relationship between economic development and the environment (Ang, 2007) and Saboori Sulaiman, & Moh (2012). That is, environmental pollution increases as a country’s grow level increases, but begins to decrease as rising incomes pass beyond a turning point. This hypothesis was first proposed and approved by Grossman and Krueger (1991). Dinda (2004) offered extensive review surveys of these studies.

Table 1: Summary of Studies for Energy Consumption and Economic Growth

Author	country	Period	methodology	Results
Kraft and Kraft (1978)	USA	1947-1990	Multivariate VAR	GDP EC Long run
Apergis et Payne (2012)	80 countries	1990-2007	Panel cointegration and panel error correction term	EC GDP In both short and long run
Menegaki (2011)	27 European countries	1990-2007	Panel causality tests& one-way random effect model	GDP…. EC
Abalaba et al. (2013)	Nigeria	1971-2010	Granger causality	EC↔GDP
Dogan (2014)	Benin, Congo, Kenya, Zimbabwe	1971-2011	Granger causality	EC→GDP(Kenya) GDP---EC(Benin,Congo, Zimbabwe)

Note: EC→GDP means that the causality runs from energy consumption to economic growth. GDP→EC means that the causality runs from economic growth to energy consumption. EC↔GDP means that bi-directional causality exists between energy consumption and economic growth GDP----EC means that no causality exists between energy consumption and economic growth ED means economic development, REP means renewable energy production EL means electric consumption

Table 2: Summary of Studies for Economic Growth and CO2 Emissions

Authors	Period	Country	Methodology	Results
Fodha and Zaghdoud. (2010)		Tunisia	Cointegration analysis	Co2 GDP
Boopen et al. (2012)	1975-2007	Mauritania		U-shaped
Richmond et al. (2006)	36 countries	1973-1997		No relationship
Sabouri et al. (2012)	Malaysia	1980-2009	EKC hypothesis	Co2 GDP

Note: CO2→GDP means that the causality runs from CO2 emissions to economic growth. GDP→CO2 means that the causality runs from economic growth to CO2 emissions. U-shaped means the existence of EKC

The third stand investigates the interrelation among three variables. (Dinda, 2004; Chontanawat et al., (2008); Payne (2010); Aslanidis and Iranzo, (2009).

Hence, the importance of nuclear and renewable energy consumption as key sources economic growth and mitigating greenhouse gases emission necessitates a research that investigates the comparative performance of these two energy sources on economic growth and CO2 emissions.

2. Data and methods

This investigates the causal relationship between renewable energy, nuclear energy, GD, and CO2 emissions on economic growth for OECD selected countries over the period 1980-2013.

Annual data from 1980 to 2013 were obtained from the World Bank Indicators and the International US Energy Information Administration. General notation of the production modeling framework is as follows:

$$Y_t = \alpha A_i^b K_i^c L_i^d e_i$$

Whereα represents a constant; b, c and d are the exponents of A, K and L, which indicates, respectively, technology elasticity; capital elasticity and labor elasticity is the error term; and t denotes the year. The subscript i illustrates the differences between the quantities Y, A, K, and L and e across observational units.

In this paper, three different models are used to estimate the effects of different variables on CO2 emissions.

First, the relationship among CO2 emissions and renewable and nuclear energy consumption will be investigated. Therefore, T represents renewable energy use and non-renewable energy use as follows:

$$\ln y_{it} = \ln\alpha + b\ln(A_{\underset{t}{it}}) + c\ln K_{it} + \ln L_{it} + \ln e_{it}$$

$$Y_{it} = \alpha_i + \alpha_{1it}\ln REN_{it} + \alpha_{2it}\ln NREN_{it} + \alpha_{3it}\ln GDP_{it} + \alpha_{4it}\ln K_{it} + \alpha_{5it}\ln L_{it} + e_{it}$$

Where α represents a constant; b, c and d are the exponents of P, A and T, which indicate, respectively, the effects of population elasticity, affluence elasticity and technology elasticity; e is the error term; and t denotes the year. The subscript i illustrates the differences between the quantities I, P, A, T and e cross observational units.

2.1. Panel unit root test analysis

To examine the integration among CO2, GDP, NUC, and REN, panel unit root test is used.

Levin Lin and Chu (2002), Im, Pesaran and Shin (2003), Maddala and Wu (1999), Breitung (2000) and Hadri (2000) proposed panel-based methods. Two types of methods are used in this paper in order to test unit root test for panel. The first one has only a constant and no trend and the second has a constant and deterministic trend stationarity.

2.2. Panel cointegration test

Pedroni (1999, 2004 developed two sets of panel cointegration tests: The panel tests, based on the within dimension approach: i.e. panel cointegration statistics), and the group tests, based on the between dimension approach: i.e. group mean panel cointegration statistics). Both the panel and group mean panel tests are distributed asymptotically as standard normal. The panel tests include four statistics: panel v, panel ρ, panel PP, and panel ADF statistics. These statistics take into account common time factors and heterogeneity across countries and pool the autoregressive coefficients across different countries for the unit root tests on the estimated residuals. The group tests, based on the between dimension approach include three statistics: group ρ, group PP, and group ADF statistics. These statistics are based on averages of the individual autoregressive coefficients associated with the unit root tests of the residuals for each country in the panel.

2.3. FMOLS and DOLS estimation

This study estimated long-run elasticities with two methods namely fully Modified Ordinary Least square (FMOLS) of Phillips and Hansen (1990) and Dynamic Ordinary Least square (DOLS) developed by Stock and Watson (1993). This study adopted these regression techniques as the variables found co-integrated.

2.4. Panel Granger causality test analysis

Since variables are cointegrated, this indicates the existence of causality between series, but not the direction of causality. To test for Granger causality in the long-run, two-step process is employed. The first one estimates the residuals from the long-run model and the second estimates the residuals a right hand variable in the dynamic error correction model

3. Results and discussions

3.1. Descriptive statistics

Table 3: Descriptive Statistics

	LnCO2	LnNUC	LnGDP	LnREN	LnK	LnL
Mean	2.912894	1.503257	4.463906	1.216595	11.62649	7.576076
Median	2.786824	1.424683	4.473397	1.241041	11.54934	7.499960
Maximum	3.814346	2.283770	4.660000	2.091010	12.48374	8.200540
Minimum	2.320219	0.069668	4.160859	-0.048327	10.98957	7.100000
Std. Dev.	0.401559	0.427281	0.104227	0.556556	0.380944	0.303989
Skewness	1.034865	-0.067999	-0.612385	-0.393590	0.512369	0.541299
Kurtosis	3.259018	2.905316	3.283524	2.411668	2.473959	2.370412
Jarque-Bera	43.14615	0.272315	15.67276	9.577382	13.15751	15.55327
Probability	0.000000	0.872705	0.000395	0.008323	0.001390	0.000419
Sum	693.2688	357.7751	1062.410	289.5497	2767.106	1803.106
Sum Sq. Dev.	38.21613	43.26888	2.574597	73.41192	34.39297	21.90097
Observations	238	238	238	238	238	238

3.2. Panel unit root test results

Table 4: Panel Unit Root Test Results

Null: Unit root		LLC test	Breitung t-stat	IPS test	MW(ADF) test	MW-PP test	Hadri Z-stat
				Individual intercept			
Variables							
Level	CO2	0.6539 (0.2566)	-	0.3984 (0.6549)	4.5790 (0.5987)	5.1299 (0.5273)	3.6129 (0.0002)*
	GDP	-3.2861 (0.0005)	-	2.8179 (0.9976)	0.7264 (0.9939)	0.7206 (0.9940)	5.9124 (0.0000)
	NUC	-7.1161 (0.0000)	-	-0.0218 (0.4913)	5.2488 (0.5123)	9.1115 (0.1674)	4.8193 (0.0000)
	REN	3.2222 (0.9994)	-	2.2898 (0.9890)	1.4838 (0.0000)	1.5119 (0.9844)	6.1454 (0.0000)*
				Intercept and trend			
First difference	CO2	-4.0190 (0.0000)*	1.0476 (0.8526)	-6.5984 (0.0000)*	44.1534 (0.0000)*	46.4674 (0.0000)*	1.4280 (0.0766)*
	GDP	-2.0834 (0.0186)*	2.7744 (0.9972)	-6.8854 (0.0000)*	46.2835 (0.0000)*	43.5436 (0.0000)*	1.3313 (0.0915)
	NUC	-1.7735 (0.0381)*	4.1570 (1.0000)	-10.4479 (0.0000)*	71.4172 (0.0000)*	71.7470 (0.0000)*	1.61124 (0.0536)
	REN	-5.7337 (0.0000)	3.4069 (0.9997)	1.3758 (0.9156)	23.3478 (0.0003)	23.4199 (0.0007)	0.2860 (0.3895)
				Indiviudual intercept			
Level	CO2	3.2923 (0.9995)	---	0.0005 (0.5002)	6.8796 (0.3321)	5.8135 (0.4444)	4.01967 (0.0000)*
	GDP	1.5146 (0.9351)	-	-1.46001 (0.0721)	15.2294 (0.0185)	5.9318 (0.4309)	3.1264 (0.0009)
	NUC	-2.9611 (0.0015)	-	-0.8423 (0.1998)	8.5322 (0.2016)	5.1215 (0.5283)	-0.7680 (0.7788)
	REN	0.4682 (0.6802)	-	-3.6847 (0.0002)	1.8687 (0.9314)	2.4940 (0.8691)	1.6734 (0.0471)
				Intercept and trend			
First difference	CO2	-6.5058 (0.0000)*	-3.8410 (0.0001)*	-6.0610 (0.0000)*	36.9091 (0.0000)*	53.8492 (0.0000)*	3.5644 (0.0002)*
	GDP	-1.6892 (0.0456)*	-2.8789 (0.0020)*	-7.4206 (0.0000)*	52.1370 (0.0000)*	53.1700 (0.0000)*	1.0272 (0.0324)
	NUC	-2.0728 (0.0191)*	-2.2797 (0.0113)	-9.4618 (0.0000)*	58.5911 (0.0000)*	58.0701 (0.0000)*	5.2722 (0.0000)*
	REN	-5.2146 (0.0000)	-5.5658 (0.0000)	-2.4783 (0.0066)	16.1418 (0.0093)	16.1864 (0.0128)	2.7319 (0.0031)

Table 4 shows the results of the panel unit root tests from LLC, IPS Hadri, Maddala (1999 &Wu and Hadri (2000) for the level and first differenced series.

For all the three variables in level form, the null hypothesis of unit root cannot be rejected for the IPS, LLC tests, Breitung and Maddala & Wu (2000); but the Hadri test rejects the null hypothesis at the1% significance level for all the variables in level form.

By taking the first difference, the null hypothesis is rejected for all five tests at the 1% level. In both these two series, the first difference gives conclusive evidence of panel unit root. Therefore, it is safe to conclude that at a 1% significance level, the two series in each model have a panel unit root. Overall, all the panel unit test techniques reject the null hypothesis for the differenced series and thus show that renewable energy, nuclear energy, co2 emissions, and economic growth are integrated of order one.

3.3. Panel cointegration results

Panel cointegration test results are reported in table (5) . This table shows that almost test statistics reject the null hypothesis of no cointegration at the 1% and 5% significance level.

To demonstrate the direction of causality flowing from one to the other variables and vice versa or the information content in one variable in correctly predicting another variable, the Granger causality test is used

3.4. FMOLS and DOLS results

Table (6) reports the estimates results. This table shows that the long-run coefficients estimated from OLS and FMOLS techniques are approximately similar and have the same magnitude and produce the same sign. All estimated coefficients are statistically significant except for renewable energy consumption. FMOLS elasticities suggests that a 1% increase in GDP decreases CO2 emissions by 18.48 % increases nuclear energy consumption 25.13 % and renewable energy consumption by 24.26 % a 1% increase in nuclear energy consumption increases CO2 emissions by 26.72 %, a 1% increase in renewable energy consumption decreases CO2 emissions by 11.06 %. Also, a 1% increase in renewable energy consumption decreases GDP by 2.21 %. An increase in CO2 emissions decreases GDP by 18.46 %and a 1% increase in nuclear energy consumption increases GDP by 8.33 %

DOLS estimates indicate that a 1% increase in GDP decreases CO2 emissions by 17.72 % increases nuclear energy consumption by 22.33 % and increases renewable energy consumption by 25.16% and a 1% increase in renewable energy consumption increases GDP by 18.23 % and a 1% increase in nuclear energy consumption increases GDP by 10.56 % and an increase of CO2 emissions decreases GDP by 26.80 %.

3.5. Granger causality results

Table 5: Panel Cointegration Results

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	0.128469	0.4489	-0.328382	0.6287
Panel rho-Statistic	0.314338	0.6234	0.410903	0.6594
Panel PP-Statistic	-1.721221	0.0426	-1.892451	0.0292
Panel ADF-Statistic	-1.748565	0.0402	-2.031620	0.0211
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	1.355275	0.9123		
Group PP-Statistic	-2.723558	0.0032		
Group ADF-Statistic	-2.941859	0.0016		

Table 6: FMOLS and DOLS Results

	FMOLS Dependent variable CO2			DOLS		
Independent variables	GDP -1.8482 (0.0003)	NUC 0.2672 (0.0000)	REN -1.1065 0.0252	GDP -1.7728 0.0051	NUC 0.2321 0.0004	REN -1.1060 0.0826
Dependent variable GDP						
Independent variables	CO2 -0.2680 (0.0008)	NUC 0.1056 (0.0000)	REN -0.0333 (0.1170)	CO2 -0.1846 0.0186	NUC 0.0833 0.0003	REN -0.0221 0.3694
Dependent variable NUC						
Independent variables	CO2 1.2331 0.0032	GDP 2.5132 0.0000	REN 0.1057 0.0980	CO2 1.7483 0.0401	GDP 2.2331 0.0018	REN 0.2207 0.0383
Dependent variable REN						
Independent variables	CO2 0.05326 0.9496	GDP 2.4667 0.0365	NUC -0.1973 0.552	CO2 0.2677 0.2263	GDP 2.5162 0.0945	NUC -0.2829 0.3038

Table 7: Granger Causality Results

Dependent vbles	Short-run D(lnCO2)	D(lnGDP)	D(lnNUC)	D(lnREN)	Long-run	D(lnCO2)	Joint(short-run/long-run) D(lnGDP)	D(lnNUC)	D(lnREN)
D(lnCO2)	-	4.9500 (0.08421)	0.5505 (0.7786)	7.3878 (0.0249)	3.5201 (0.0006)	-	-0.0686 (0.0145)	0.0558 (0.0370)	-0.0361 (0.0274)
D(lnGDP)	1.5920 (0.4511)	-	1.7350 (0.4200)	0.7405 (0.6905)	1.0120 (0.00092)*	-0.0230 (0.0140)	-	-0.3387 (0.0718)	0.1511 (0.0536)
D(lnNUC)	1.3847 (5004)	8.1878 (0.0167)	-	0.3211 (0.8516)	2.5092 (0.0019)	0.0044 (0.0038)	0.0073 (0.0088)	-	-0.0237 (0.0147)
D(lnREN)	2.2908 (0.3181)	13.4364 (0.0012)	7.0561 (0.0294)	-	-4.1646 (0.0014)	0.0037 (0.0021)	-0.0031 (0.0048)	00079 (0.0108)	-

Table 7 reports the short- and the long-run relationship among CO2 emissions, economic growth, nuclear energy, and renewable energy consumption. The pairwise Granger causality results show that there is bidirectional causality between emissions and economic growth; unidirectional causality running from CO2 emissions to renewable energy consumption without feedback; and unidirectional causality from renewable energy consumption to economic growth and unidirectional causality running from nuclear energy consumption to economic growth in the short-run.

However, there is no evidence of short-run causality links between nuclear energy consumption and emissions or between renewable energy consumption and economic growth.

In the long-run, the error correction term is statistically significant. However, there is a long-run relationship (1) from GDP, renewable energy consumption and nuclear energy consumption to CO2 emissions (figure 1), (2) from CO2 emissions, GDP, to renewable energy consumption (figure 2), (3) from missions, GDP to renewable energy, (4) from CO2 emissions GDP and nuclear energy consumption.

4. Conclusion

This paper uses panel cointegration techniques to investigate the long-run relationship among nuclear energy consumption, renewable energy consumption, CO_2 emissions, and economic growth for a panel of selected OECD countries over the period 1980-2013. All variables are found to be cointegrated.
FMOLS elasticities reveals that a 1% increase in GDP decreases CO_2 emissions by 18.48 % increases nuclear energy consumption 25.13 % and renewable energy consumption by 24.26% a 1% increase in nuclear energy consumption increases CO_2 emissions by 26.72 %a 1% increase in renewable energy consumption decreases CO_2 emissions by 11.06 % also, a 1% increase in renewable energy consumption decreases GDP by 2.21 % .An increase in CO_2 emissions decreases GDP by 18.46 and a 1% increase in nuclear energy consumption increases GDP by 8.33%
DOLS estimates indicate that a 1% increase in GDP decreases CO_2 emissions by 17.72 % increases nuclear energy consumption by 22.33 and increases renewable energy consumption by 25.16 % and a 1% increase in renewable energy consumption increases GDP by 18, 23 % and a 1% increase in nuclear energy consumption increases GDP by 10.56 % and an increase of CO_2 emissions decreases GDP by 26.80%.
Results of Granger causality show a long-run relationship (1) from GDP, renewable energy consumption and nuclear energy consumption to CO_2 emissions, (2) from CO_2 emissions, GDP, to renewable energy consumption, (3) from emissions, GDP to renewable energy, (4) from CO_2 emissions GDP and nuclear energy consumption.
Summary of main results:
Figure 1: source of causation between nuclear energy, economic growth and CO_2 emissions

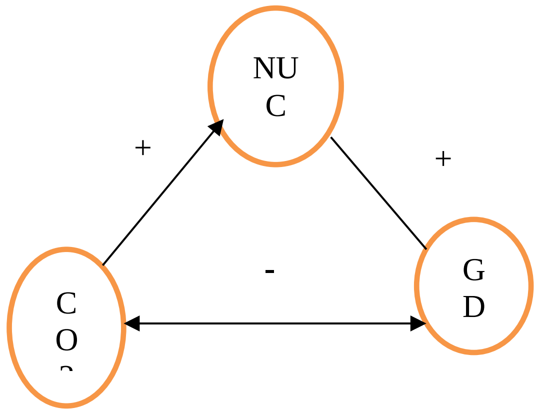

Fig. 1: Source of Causation between Nuclear Energy, Economic Growth and CO_2 Emissions.

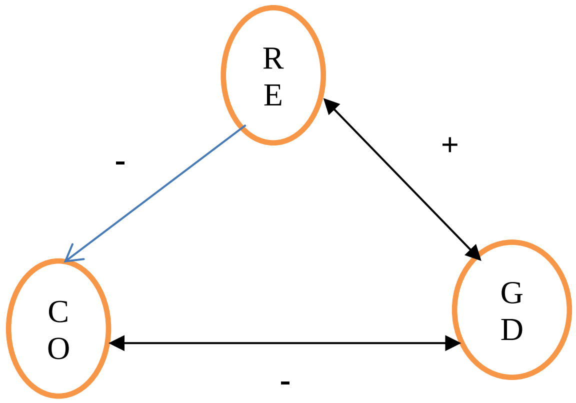

Fig. 2: Source of Causation between Renewable Energy, Economic Growth and CO_2 Emissions.

5. Policy implications

Policy implications are summarized on the fact that authorities ought to adopt new policies oriented on the augmentation of the share of renewable energies in order to reduce CO_2 emissions. Therefore, this study reveals that the share of nuclear energy consumption must be decreased because of its negative impact on environment and replaced by clean energies. These policies are important for the achievement of sustainable development.

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