

Understanding the Causality between Carbon Dioxide Emission, Fossil Energy Consumption and Economic Growth in Developed Countries: An Empirical Study

Bing Xue ^{1,*}, Yong Geng ^{1,†}, Katrin Müller ^{2,†}, Chengpeng Lu ^{1,†} and Wanxia Ren ^{1,†}

¹ Key Laboratory of Pollution Ecology and Environmental Engineering, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China; E-Mails: gengyong@iae.ac.cn (Y.G.); luchp.lzu@gmail.com (C.L.); renwanxia@iae.ac.cn (W.R.)

² Institute for Applied Material Flow Management, University of Applied Sciences Trier, Birkenfeld D-55768, Germany; E-Mail: katrin.mueller@student.unisg.ch

[†] These authors contributed equally to this work.

* Author to whom correspondence should be addressed; E-Mail: xuebing@iae.ac.cn; Tel.: +86-24-8397-0433; Fax: +86-24-8397-0371.

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Abstract: Issues on climate change have been recognized as serious challenges for regional sustainable development both at a global and local level. Given the background that most of the artificial carbon emissions are resulted from the energy consumption sector and the energy is also the key element resource for economic development, this paper investigated the relationship between CO₂ emission, fossil energy consumption, and economic growth in the period 1970–2008 of nine European countries, based on the approach of Granger Causality Test, followed by the risk analysis on impacts of CO₂ reduction to local economic growth classified by the indicator of causality degree. The results show that there are various feedback causal relationships between carbon emission, energy consumption and economic growth, with both unidirectional and dual-directional Granger causality. The impact of reducing CO₂ emission to economic growth varies between countries as well.

Keywords: climate change; carbon reduction; regional disparity; causality test; European countries

1. Introduction

Global climate change has been a hot topic since the end of the 20th century (see, for instance, [1–3]), and it is currently also a major concern and challenge confronting countries in the world [4], for example, the report of IPCC4 pointed that it was very likely (more than 90% of probability) that global warming was related to the increasing of greenhouse gases (GHG) over the past 50 years [5]. Concerning climate change mitigation and adaption, the Kyoto Protocol is a very important step for reducing GHG emissions, and, moreover, broader participation and deeper cuts in GHG emissions are essential for any post-Kyoto agreement [6]. However, the common recognition on reducing GHG emissions from the past several Conferences of Parties (COP) to the United Nations Framework Convention on Climate Change, such as the COP 15 in 2009 of Copenhagen, COP 17 in 2011 of Duban and COP19 in 2013 of Warsaw are not sufficient enough. The key issue for reaching a consensus on GHG emission reduction is the concern on its impact to local economic development [7], either in developed regions or in developing and emerging countries. For example, *van Renssen* explored the worries voiced within industry and argued that Europe must come up with effective climate, environment and energy policies that do not jeopardize economic competitiveness [8], Wang *et al.* [9] stated that China's economic growth and export trade had significantly promoted its carbon emissions, and the rapid economic growth is the main determinant that causes an increase in carbon emissions [10]. Major emitters seem unwilling to accept binding emissions reductions targets as their economies have stagnated [11]. Given the common background that most of the artificial carbon emission results from the energy consumption sector and that energy is also the key element resource for economic development [12], the causal relationship between carbon emission, energy consumption and economic growth should be investigated. This could offer better understanding on the interaction impacts to local sustainable development [13–15].

As for developing and emerging countries, such as China, India and Brazil, the question as to how to delink the energy consumption and carbon emission from the economic growth has been the key issue faced by policy makers and scientific communities. However, currently, in the face of international pressure to curb carbon releases as well as the tight domestic fossil-energy supply [16], relative indicators are usually applied for measuring carbon reduction target in order to avoid the possible negative impacts on local economic development [17]. For example, a case study for Brazil shows that the business-as-usual CO₂ emissions in 2040 from energy use and industrial processes would be almost three times as high as those in 2010, while the current policy aims to lower emissions intensity of the overall economy by 36–39 percent by 2020 [18]. Another analysis on carbon reduction in China indicates that the region with a lower reduction benchmark and higher decoupling elasticity value has more difficulty in achieving the emission reduction targets without powerful relevant policy [19], and a provincial level case study illustrates that with the rapid economic development, CO₂ emission in Jiangsu province rose from $1,88 \times 10^8$ t in 1995 to $5,20 \times 10^4$ t in 2009, with an average annual growth rate of 7.54% [20]. Even the Chinese central government has stated that in 2020 the carbon intensity will be reduced by 40%–45% compared to the 2005 level [21]. An early study that aimed to examine the long-run relationship between output and energy consumption during the period 1971–1999 in Malaysia indicated that energy use was positively related to output in the long-run, and offered strong support for causalities running from economic growth to energy consumption growth

both in the short-run and long-run [22]. Research in the case of South Africa on the effects of economic growth and coal consumption on CO₂ emissions over the period 1965–2008 also shows that a rise in economic growth increases energy emissions, and coal consumption makes a significant contribution to deteriorating the environment [23], which was also verified by Menyah and Wolde-Rufael's research [24]. Under such circumstances, investigation and insights into the relationship between carbon emission, energy consumption and economic growth in developed countries could offer further understanding for developing countries.

As the typical representatives of developed and industrialized countries in this world, Europe plays a leading role in climate change mitigation and adaptation. Thus, investigating the causal relationship between the mentioned elements is significant and could have policy implications for developing countries. Actually, few related studies have been done: *Ang* investigated the dynamic causal relationships between pollutant emissions, energy consumption, and output for France by using co-integration and vector error-correction modeling techniques for the period 1960–2000, and the causality results support the argument that economic growth exerts a causal influence on growth of energy use and growth of pollution in the long run [25]. *Marrero* took the advantage of a panel data set of 24 European countries in the period of 1990–2006 and applied a Dynamic Panel Data framework to examine the relationship of GHG emissions, growth and the energy mix in Europe, and found evidence for the existence of conditional convergence in terms of GHG emissions among the EU27 countries [26]. The change in energy intensity of the main economic activities in period of 1991–2005 of the EU15 countries was also investigated by *Marrero* and *Ramos-Real* in 2013, and the results revealed four different typologies for EU15 countries and showed the importance of identifying those economic activities which are key to reducing energy consumption [27].

Herein, based on the statistical data in the open database of World Bank, nine European countries, namely, Denmark, France, Greece, Italy, Netherlands, Portugal, Spain, Sweden and United Kingdom are selected to investigate the causal relationship between GDP growth, energy consumption and CO₂ emissions in the period of 1970–2008, and followed by the evaluation on the possible impacts of CO₂ emissions reduction to economic development by ranking the classes based on the causality degree results.

2. Methodologies and Results

Selected variables used in this study include: (1) GDP per capita (GDPP) which represents the local economic developmental level of studied countries, (2) CO₂ emissions per capita (PCO₂) which represents the contribution of economic activities to climate change, and (3) Energy Consumption Intensity (ECI) (fossil energy consumption per capita) which represents the fossil energy resources consumption affected by the type of the fossil energy mix and population.

2.1. Unit Root Test

Co-integration analysis introduces the idea that even if underlying time series are non-stationary, linear combinations of these series might be stationary. Therefore it is essential to verify that all variables are integrated of order one in levels before employing panel co-integration techniques. The main idea behind performing a unit root test while using ADF statistics is to ensure that the error term should be

lagged independent [14]. In this method, the unit root test is carried out by means of the following formulation [15].

$$\Delta Y_t = \alpha + \rho Y_{t-1} + \beta T + \sum b_i \Delta Y_{t-i} + \varepsilon_t, i = 1, 2, \dots, n \quad (1)$$

Together with the fixed term regressions with trend, ADF statistics and McKinnon's critical values are derived. Where $\Delta Y_t = Y_t - Y_{t-1}$, α is a drift term, and T is the time trend with the null hypothesis $H_0: \rho = 0$ and H_1 its alternative hypothesis $H_1: \rho \neq 0$, n is the number of lags necessary to obtain white noise, and ε is the error term. Failure in rejecting H_0 implies that the time series is non-stationary. The unit root tests of all the three variables sets mentioned above for the nine countries are tested under differential levels of both first/second differences. From Table 1, we could conclude that most of the unit root hypothesizes have not been rejected when the variables are taken in various levels, but when the first difference was used, most of the hypothesizes of unit root non-stationary are rejected at the level 1% or level 5% of the significance, and few of the hypothesizes of unit root non-stationary are rejected under the second differences at level 1%.

Table 1. Results of the unit root test in first difference.

Countries	Variables' series	t-Statistic	Probability	1% level
France	PCO ₂	−7.1534	0.0000	−3.6267
	ECI	−6.8673	0.0000	−3.6267
	GDPP	−4.0121	0.0037	−3.6267
United Kingdom	PCO ₂	−7.3724	0.0000	−3.6267
	ECI	−6.2971	0.0000	−3.6267
	GDPP	−4.5310	0.0009	−3.6267
Italy	PCO ₂	−6.0026	0.0000	−3.6267
	ECI	−5.9801	0.0000	−3.6267
	GDPP	−4.2535	0.0019	−3.6267
Spain	PCO ₂	−5.1532	0.0002	−3.6267
	ECI	−4.2121	0.0021	−3.6267
	GDPP	−3.3031	0.0221	−2.9458 ^a
Sweden	PCO ₂	−7.5831	0.0000	−3.6267
	ECI	−6.7491	0.0000	−3.6267
	GDPP	−4.3146	0.0016	−3.6267
Portugal	PCO ₂	−10.130 ^b	0.0000	−3.6394
	ECI	−5.7287	0.0000	−3.6267
	GDPP	−3.8520	0.0056	−3.6267
Netherlands	PCO ₂	−6.0089	0.0000	−3.6267
	ECI	−2.9170 ^c	0.0530	−3.6210
	GDPP	−3.4434	0.0158	−3.6267
Greece	PCO ₂	−6.8068	0.0000	−3.6267
	ECI	−5.7685	0.0000	−3.6267
	GDPP	−5.4214 ^b	0.0001	−3.6463
Denmark	PCO ₂	−2.6389 ^c	0.0945	−3.6210
	ECI	−3.4166	0.0166	−3.6210
	GDPP	−3.7237	0.0078	−3.6268

^a at level 5%; ^b tested in level 10%; ^c tested in 2nd difference.

2.2. Co-Integration Test

The co-integration test was employed in order to determine whether there exists a co-integration between the studied series. The aim of co-integration analysis is to model and estimate the long term correlation-ship among non-stationary time series. Herein, the Johansen co-integration procedure was performed for determining whether the co-integration exists. The first step in Johansen procedure is to determine the lag order. In this study, the significant and right lag period is finally selected after the numbers test from lag 1 to lag 10 and followed by the trace statistic and the maximum Eigen-value statistic (see the supplementary materials). The result shows that causality exists among the selected variables series; however, the co-integration test cannot tell the direction of the causal relationship. Thus, the following multivariate Granger-causality test based on the VECM was carried out to investigate both short-run and long-run causality.

2.3. Granger Causality

If the series X and Y are individually $I(1)$ and co-integrated as well, then the Granger causality tests could use $I(1)$ data because of the super consistency properties of estimation, whereas u_t and v_t are zero-mean, serially uncorrelated, random disturbances. The optimum lag lengths m , n , q and r are determined on the basis of Schwarz Bayesian and/or log-likelihood ratio test criterion:

$$X_t = a_0 + \sum_{i=1}^m a_{1i} X_{t-i} + \sum_{i=1}^n a_{2i} Y_{t-i} + u_t \quad (2)$$

In the above equation, Y Granger causes X if $H_0: a_{21} = a_{22} = \dots a_{2n} = 0$ is rejected, and $H1$: at least on $a_{2i} \neq 0$, $i = 1, 2, 3, \dots, n$. and, correspondingly, in the following equation, X Granger causes Y if $H_0: b_{21} = b_{22} = \dots b_{2n} = 0$ is rejected, and $H1$: at least on $b_{2i} \neq 0$, $i = 1, 2, 3, \dots, r$:

$$Y_t = b_0 + \sum_{i=1}^q b_{1i} Y_{t-i} + \sum_{i=1}^r b_{2i} X_{t-i} + v_t \quad (3)$$

Results of the Granger-causality test for the 9 countries show that there are various feedback causal relationships between carbon emission, energy consumption and economic growth, with both unidirectional and dual-directional causalities (Table 2, and supplementary materials). In conclusion, (1) Granger Causality between energy consumption and CO₂ emissions: the null hypothesis of “ECI does not Granger Cause PCO₂” and “PCO₂ does not Granger Cause ECI” are rejected in countries of France, Spain and Sweden, but accepted in countries of United Kingdom, Italy, Portugal and Greece; while in Denmark, the null hypothesis of “ECI does not Granger Cause PCO₂” is rejected but that of “PCO₂ does not Granger Cause ECI” is accepted; (2) Granger Causality between economic growth and CO₂ emissions, the null hypothesis of “GDPP does not Granger Cause PCO₂” and “PCO₂ does not Granger Cause GDPP” are all accepted for most of the countries includes France, Italy, Spain, Sweden, Portugal, Netherlands and Greece; while for United Kingdom, the null hypothesis of “GDPP does not Granger Cause PCO₂” is rejected but that of “PCO₂ does not Granger Cause GDPP” is accepted; however, the situation in Denmark is opposite than that in the United Kingdom.

Comparing the differences based on the long term, conclusions are summarized as follows: (1) for France, Spain and Sweden, the causality relationship between ECI and PCO₂ is reciprocal relation,

but has no causality relationship between GDPP and PCO₂; (2) for the United Kingdom, there exist non-causality relationship between ECI and PCO₂, and GDPP is the Granger causality to PCO₂ while PCO₂ is not the Granger causality to GDPP; (3) for Italy, Portugal and Greece, there no causality exists between ECI and PCO₂, and between GDPP and PCO₂. (4) for the Netherlands, ECI is not the Granger Cause to PCO₂, but PCO₂ is the granger cause to ECI; in addition, there exists a non-causality relationship between GDPP and PCO₂; (5) for Denmark, ECI is the Granger Cause to PCO₂, but PCO₂ is not the granger cause to ECI; also the same situation exists between GDPP and PCO₂.

Table 2. Granger-causality test results for nine countries from 1970–2008.

Countries	Null Hypothesis	Obs	Lag	F-Statistic	Probability	Result (1%)
France	ECI does not Granger Cause PCO ₂	33	5	6.65201	0.00065	Reject
	PCO ₂ does not Granger Cause ECI			2.82848	0.04043	Reject
	GDPP does not Granger Cause CO ₂	33	5	0.92345	0.48451	Accept
	CO ₂ does not Granger Cause GDPP			0.52934	0.75166	Accept
United Kingdom	ECI does not Granger Cause PCO ₂	37	1	2.82977	0.10170	Accept
	PCO ₂ does not Granger Cause ECI			0.01032	0.91968	Accept
	GDPP does not Granger Cause CO ₂	37	1	7.00927	0.01220	Reject
	CO ₂ does not Granger Cause GDPP			0.00292	0.95720	Accept
Italy	ECI does not Granger Cause PCO ₂	35	3	0.91294	0.44730	Accept
	PCO ₂ does not Granger Cause ECI			1.34415	0.28009	Accept
	GDPP does not Granger Cause CO ₂	35	3	0.46991	0.70566	Accept
	CO ₂ does not Granger Cause GDPP			1.29007	0.29716	Accept
Spain	ECI does not Granger Cause PCO ₂	37	1	10.4269	0.00275	Reject
	PCO ₂ does not Granger Cause ECI			13.7206	0.00075	Reject
	GDPP does not Granger Cause CO ₂	37	1	0.00693	0.93415	Accept
	CO ₂ does not Granger Cause GDPP			0.01997	0.88845	Accept
Sweden	ECI does not Granger Cause PCO ₂	37	1	5.16707	0.02946	Reject
	PCO ₂ does not Granger Cause ECI			7.32624	0.01055	Reject
	GDPP does not Granger Cause CO ₂	37	1	2.80925	0.10290	Accept
	CO ₂ does not Granger Cause GDPP			8.4×10^{-7}	0.99928	Accept
Portugal	ECI does not Granger Cause PCO ₂	33	5	2.05856	0.10960	Accept
	PCO ₂ does not Granger Cause ECI			1.50857	0.22773	Accept
	GDPP does not Granger Cause CO ₂	33	5	1.99719	0.11887	Accept
	CO ₂ does not Granger Cause GDPP			1.08321	0.39693	Accept
Netherlands	ECI does not Granger Cause PCO ₂	37	1	0.47594	0.49495	Accept
	PCO ₂ does not Granger Cause ECI			3.02977	0.09079	Reject
	GDPP does not Granger Cause CO ₂	37	1	1.12933	0.29541	Accept
	CO ₂ does not Granger Cause GDPP			0.29590	0.59001	Accept
Greece	ECI does not Granger Cause PCO ₂	37	1	0.09839	0.75569	Accept
	PCO ₂ does not Granger Cause ECI			0.77782	0.38400	Accept
	GDPP does not Granger Cause CO ₂	37	1	0.00297	0.95684	Accept
	CO ₂ does not Granger Cause GDPP			0.24599	0.62311	Accept
Denmark	ECI does not Granger Cause PCO ₂	37	1	4.89681	0.03372	Reject
	PCO ₂ does not Granger Cause ECI			0.09204	0.76345	Accept
	GDPP does not Granger Cause CO ₂	37	1	6.99012	0.01231	Reject
	CO ₂ does not Granger Cause GDPP			0.03004	0.86342	Accept

Based on the long-run causality tests among PCO_2 , ECI and GDPP in the nine countries, we can establish an evaluation matrix to identify the differences of the possible impacts resulted from reducing CO_2 emission to energy consumption and economic growth. Herein, we defined the risk as six levels: (1) Remote—Probability of less than 10%; (2) Highly Unlikely—Probability between 10% and 35%; (3) Possible—Probability between 36% and 50%; (4) Probable—Probability between 51% and 75%; (5) Highly Likely—Probability 76% and 90%; and (6) Certain—Probability above 90%. The assessment result is shown in Table 3. The results show that the impact of reducing CO_2 emissions on economic growth for different countries varies. In general, reducing CO_2 emission has more negative impacts on the economic growth of Italy, followed by Portugal, and has the lowest impacts on the United Kingdom and Sweden.

Table 3. Risk assessment based on the causality analysis.

Causality	Remote (<10%)	Highly Unlikely (10%–35%)	Possible (36%–50%)	Probable (51%–75%)	Highly Likely (76%–90%)	Certain (>90%)
PCO_2 does not Granger Cause ECI	France; Spain; Sweden; Denmark	United Kingdom; Portugal;	Italy; Netherlands		Greece	
ECI does not Granger Cause PCO_2	France; Spain; Sweden; Netherlands	Italy; Portugal;	Greece	Denmark		United Kingdom
GDPP does not Granger Cause PCO_2	Denmark	United Kingdom; Sweden; Portugal; Netherlands	France	Italy		Spain; Greece
PCO_2 does not Granger Cause GDPP		Italy	Portugal	France; Netherlands; Greece	Spain; Denmark	United Kingdom; Sweden

3. Conclusions

Issues on climate change have been recognized as a serious challenge for addressing regional sustainable development at both a global and local level. This paper examined the relationship among CO_2 emission, fossil energy consumption, and economic growth in period 1970–2008 of nine European countries, by employing the Granger Causality Test, followed by the impacts analysis of carbon reduction to local economic growth. The results show that there are both unidirectional and dual-directional Granger causality existing in the nine countries. However, given the background of the environmental industries' development in European countries, reducing carbon emissions would have short-term throes to economic development, because, in the long-term scenario, the reduction of carbon emission also could accelerate the development of renewable energies, such as in Germany [28].

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Supplementary Materials

Supplementary materials can be accessed at: <http://www.mdpi.com/2071-1050/6/2/1037/s1>.

Author Contributions

Bing Xue conducted the research, contributed to data analysis and paper-wrote; Yong Geng, Katrin Müller, Chengpeng Lu and Wanxia Ren contributed to data analysis and revision.

Conflicts of Interest

The authors declare no conflict of interest.

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