Carbon dioxide emissions mitigation strategies' performance

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Abstract

The climate change matter is due to Green House Gas Emissions produced essentially by CO_2 emissions. To overcome this problem, decision markers developed several policies among them the adoption of energy efficient measures and the development of renewable energies. Using a panel data analysis, this paper tries to investigate the impact of adoption of such solutions on emissions levels for 161 countries during the period 1985-2014. Estimation results demonstrate that the magnitude of emissions reduction is more important for energy efficiency and that the role of renewable energy still insufficient yet. Furthermore, we proved that non-renewable energy, income per capita and population growth are destructive facts of environmental quality.

Keywords- renewable energy, non-renewable energy, panel data, energy efficiency, carbon dioxide emissions

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1. Introduction

The increased concentrations of Greenhouse Gases causes climate change, which is a problem that affects all countries of the world. Fossil fuels dominates the current energy mix and represents the major contributor in the world's emissions by nearly 70% of the world's greenhouse gas emission. Among fossil fuels: oil, coal and gas. According to the Organization for Economic Cooperation and Development (OECD)'s report published in 2012, if appropriate energy innovation policies have not been implemented CO_2 emissions from global energy consumption would increase by 70% in 2050, resulting in a 50% increase in Greenhouse Gas Emissions.

In this context, two strategies to mitigate CO_2 emissions was identified by the International Energy Agency (IEA) that are energy efficiency and renewable energies. First, energy efficiency will diminish the final energy demand, save energy costs and reduce CO_2 emissions; Second, renewable energies is produced from natural constituents that are ecologically friendly.

The effectiveness of these adopted strategies has been the subject of several studies. Indeed, Shi (2001), Heryadi and Hartono, (2016), Aguir Bargaoui et al., (2014), Mert and Bölük, (2016) and Aguir Bargaoui and Nouri (2017) highlighted the role of technologies to ameliorate energy efficiency in decreasing emissions. Other studies have stressed on the role of the use of renewable energies in reducing the rate of CO_2 emissions, as for example, Apergis N., et al. (2010), Mert and Bölük, (2016) and Ben Mbarek et al. (2016).

A number of researches has been able to verify the contribution of energy efficiency and renewable energies use in emissions reduction. However, an important aspect remains essential to analyze, namely the magnitude of the impact of energy efficiency on the one hand, renewable energy on the other side, but also the extent of the impact of the two measures taken together. In this context, we try to measure the magnitude of the impact of these two strategies for 161countries during the period 1985-2014. The contribution of this work is to try to generalize the findings of Heryadi and Hartono (2016) who studied these relations only for the G20 countries during the period 2000-2013 on one hand, and to shed light on the most appropriate strategy to reduce emissions, on the other hand.

Our research motivated by two central facts. First, the phenomenon of climate change is a problem that will affect all countries that begun to adopt more or less these two strategies. Second, the problem of carbon leakage caused by the transfers of pollutant production from countries with strict environmental requirements to countries without or with less requirements dictated by Kyoto protocol ratifications, thus leading to increase in global emissions. Consequently, we believe that research's outcomes should provide important information not only to decision-makers in different countries, but also to the formulation of suitable programs by the States Member in the programs tracked by the United Nations.

The rest of the paper is organized as follows: Section 2 exposes the used methodology, model specification and data. Section 3 discusses empirical results and Section 4 concludes.

2. Methodology

2.1. Energy efficiency, renewable, nonrenewable energy and carbon dioxide emissions relationship

Some studies including Shi (2001), Li et al. (2012) and Destek et al. (2016) focused on the relationship between energy efficiency and CO_2 emissions and revealed that energy efficiency leads to improve environmental quality. Commonly, two employed indicators to evaluate energy efficiency are current in literature: energy efficiency and energy intensity. Concerning the first indicator, Energy efficiency of an economic activity, is the ratio between real GDP and energy consumption, in local currency per capita by unit of energy use, that is, per capita GDP shared by the total energy used. It shows how much production can be produced from each unit of energy consumed. The higher is the ratio, the more efficient the use of energy by economic activity. On behalf of the second indicator, energy intensity designates the use of energy per unit of GDP. As his value decreases it indicates that less energy is needed to produce a unit of production.

However, the reduction of energy consumption in some production processes is not possible. Therefore, it is necessary to invest in energy efficient technology to save energy because it can produce more output for each unit of energy used. As an outcome, the transfer of the resulting energy savings to other production sectors or its use to produce larger quantities to meet the ever-increasing demands of consumers will be possible. In addition, the use of environmentally friendly industrial machines or vehicles allow CO_2 emissions reduction. This fact is supported by several researches including, Mert and Bölük (2016) that demonstrated that the environmental influences of CO_2 emissions could be reduced by using energy efficient technology.

On the other side, Susandi (2008) emphasized the importance and urgency of the development and implementation of renewable energies for two fundamental reasons. First, the importance of the energy supply security to maintain the sustainability of a country's development, especially those with an energy deficit balance. Second, the development of low-emission energy would contribute to mitigating climate change. Therefore, the development of low-emission renewables would be advantageous for both the national economy and the global environment.

Zaekhan (2012) defines renewable energy as a rapidly reproducible energy through natural processes, such as geothermal energy, biomass, water, solar energy and wind energy. The importance of using environmentally friendly energy in mitigating CO_2 emissions has been described by Zaekhan (2012), Shafiei and Salim (2014), and Mert and Bölük (2016), among others. Indeed, renewable energies can be an essential substitute for fossil fuels that could reduce CO_2 emissions because most renewables are not carbon chemicals and usually the conversion of renewable energies are not done by combustion but by a direct transformation. Therefore, the use of renewable energy should have negative impacts on CO_2 emissions. In addition, Apergis et al. (2010) emphasized that the use of renewable energies and nuclear power collectively can play an important role, not only in achieving energy security, but also in reducing CO_2 emissions. Forevermore, Apergis and Payne (2014) indicated that the use of renewable energy would increase if its prices were competitive. Then, if the price of fossil fuels is higher, it could improve the use of renewable energy as an environmentally friendly alternative energy.

2.2. Model specification

This study refers to the STIRPAT model in the form of natural logarithm used in Shafiei and Salim (2014) and Heryadi and Hartono (2016). More specifically, to study the environmental impact of energy efficiency (EFFI), we follow Shi (2001) by translating the technological variable into energy efficiency on economic activities. To explain the economic impact of the use of renewable energies, this study adopts the model of Shafiei and Salim (2014) which defines the technological variable as disaggregated by energy consumption: nonrenewable energy and renewable energies. Next, the current study combines the two models to examine the environmental impact of implementing energy efficiency and the use of renewable energies simultaneously following the study by Heryadi and Hartono (2016).

Some researchers have postulated that population growth; wealth and technology are jointly responsible for the deterioration of environmental quality. The mathematical formalization of this relationship based on the IPAT model (Impact of Population, Affluence and Technology) developed in the works of Ehrlich and Holdren (1971) and Commoner (1972). The results of their researches allowed them to suggest that population growth has a negative and disproportionate impact on the environment and that wealth is one of the main causes of CO_2 emissions. The model formulation is presented as follows:

$$\boldsymbol{I = P \times A \times T} \qquad \textbf{(1)}$$

Where: I: represents environmental impacts; P: Population; A: Affluence and T: Technology.

Dietz and Rosa (1997) refined the model by permitting different weights to different impacts drivers. The expression is presented as follows:

$$\mathbf{I_i = \alpha P_i^{\beta} A_i^{\gamma} T_i^{\delta} \varepsilon_i} \qquad \textbf{(2)}$$

Where: P, A and T respectively represent population, Affluence and Technology. The estimated parameters are: α, β, γ and δ. The error term ε represents all the unexplained variances by the model's specification. i represents the quantities of P, A, T and ε that vary across countries.

To overcome the difference in unit of measure of each variable and to facilitate empirical analysis of tests, Dietz and Rosa (2003) opted for a logarithmic transformation. Their model named "STochastic Impacts on Population, Affluence and Technology" (STIRPAT). The formulation of this model is as follows:

$$lnI_{it} = \alpha_0 + \beta lnP_{it} + \gamma lnA_{it} + \delta lnT_{it} + e_{it}$$

$$\text{With } e_{it} = \ln(\varepsilon_i) \text{ and } \alpha_0 = \ln(\alpha)$$

This model allow to describe the environmental impact I that can be measured by carbon dioxide emissions, level of ecological footprint and levels of different pollutants. The technological variable (T) can take various forms, such as technological innovation, institutions and the use of new renewable or renewable energies.

Based on the STIRPAT models and its applications in previous studies, we assume in this study that CO_2 emissions are an indicator of environmental impact that is supposed to be influenced by First, population. Second, affluence approximated by GDP per capita as previous studies such as York and Rosa (2003), Asıcı (2011) and Aguir Bargaoui and Nouri (2017). And finaly, the technological variable that will be mmesured by the consumption of non-renewable, renewable energy and energy efficiency as in the previous studies by Mert and Bölük (2016), Ben Mbarek et al. (2016) and Heryadi and Hartono (2016).

Really, the population reflects the size of the country. Thus, the higher the population, the greater the extension the economic activity of this population. In one hand, the increase in economic activity is measured by the national production of a country will cause the increase of emissions due to industrial activity. On the other hand, the growth of national incomes causes the rise of the consumption of goods and services and thus of the demand which will incite the production and consequently the pollution.

Technology variable's proxies are energy efficiency, nonrenewable and renewable energies. Regarding energy efficiency that is measured by the GDP generated by each unit of energy consumed. The higher the value of this ratio, the more efficient will be the use of energy in the economy. In terms of renewable energy, Shafiei and Salim (2014) used the ratio of renewable energy to total energy. As for nonrenewable energy is measured by the share of nonrenewable energy to total energy.

The three models presented in Table 1 concerns a sample of countries i in year t. The error terms e_{it}, correspond to the terms that cover the fact that all the factors influencing country's CO_2 emissions in year t are not explained by all variables of the proposed models.

Model	Specifications
Model 1	$lnCO2_{it} = \propto_0 + \propto_1 lnPOP_{it} + \propto_2 lnGDP_{it} + \propto_3 lnEE_{it} + e_{it}$
Model 2	$lnCO2_{it} = \propto_0 + \propto_1 lnPOP_{it} + \propto_2 lnGDP_{it} + \propto_3 lnRE_{it} + \propto_4 lnNRE_{it} + e_{it}$
Model 3	$lnCO2_{it} = \propto_0 + \propto_1 lnPOP_{it} + \propto_2 lnGDP_{it} + \propto_3 lnEE_{it} + \propto_4 lnRE_{it} + e_{it}$

Table 1. Models specifications

Model 1 used to test the effect of energy efficiency (EE) on CO_2 emissions. Model 2 intended to test the outcome of renewable (RE) and non-renewable (ENR) energies. As for the third model, it tests the influence of renewable energy and energy efficiency on emissions level.

To estimate the above three models, we use the static panel data analysis. For this, we used the estimation of the static fixed-effect panel model and the static variable-effect panel model, and to test the validity of the model and obtain the best estimate, we apply the Hausman test. In fact, the Hausman test check whether the errors are correlated with the explanatory variables. This statistic is asymptotically distributed according to a Chi-two with K freedom degrees which, represents the number of variable factors introduced into the model over time.

Under the null hypothesis of correct specification, if the test is significant (p-value <5%), the estimators of the fixed-effects model are unbiased. The test statistic is presented as follows:

$$H = (\widehat{\beta}_{MEF} - \widehat{\beta}_{MEC})'[\widehat{V}(\widehat{\beta}_{MEF}) - \widehat{V}(\widehat{\beta}_{MEc})]^{-1}(\widehat{\beta}_{MEF} - \widehat{\beta}_{MEC}) \rightarrow \chi^2(k)$$

The used data represents a data set for the majority of countries for which data are available that imply 161 countries for the period 1985-2014. This choice is motivated by the fact that the problem of climate change is a problem that affects all countries of the Earth and therefore it is more useful to detect the impact of each environmental impact factor at the global level in order to be able to quantify this impact given the phenomenon of carbon leakage.

Given the later, we consider the measurement of the impact's intensities of different emissions drivers at a larger scale more suitable to quantify the global effect either of the problems causes or the strategies adopted to resolve them.The definitions and sources of data are explained in Table 2.

Indicator	Definition	Source
CO_2 emissions (kt)	Carbon dioxide emissions come from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during the consumption of solid, liquid and gaseous fuels and gas flaring.	Carbon Dioxide Information Analysis Center, United States.
Total population	The total population is based on the definition of population, which includes all residents regardless of legal status or citizenship.	(1) United Nations Population Division (2) Census reports and other statistical publications from national statistical offices, (3) Eurostat(4) United Nations Statistical Division, (5) U.S. Census Bureau and (6) Secretariat of the Pacific Community
GDP per capita, PPP (2011 constant international dollars)	GDP per capita based on Purchasing Power Parity (PPP)	World Bank, International Comparison Program database.
Fossil energy consumption (% of total final energy)	Fossil fuels include coal, oil, petroleum and natural gas products.	IEA Statistics © OECD/IEA 2014
Renewable energy consumption (% of total final energy consumption)	Renewable energy consumption is the share of renewable energy in total final energy consumption.	World Bank, Sustainable Energy for All database jointly by the World Bank, International Energy Agency, and the Energy Sector Management Assistance Program.
GDP per unit of energy use (constant 2011 PPI per kg of oil equivalent)	The GDP per unit of energy use is the PPP GDP per kilogram of oil equivalent of energy consumption.	IEA Statistics © OECD/IEA 2014

Table 2. Data and sources

3. Results Discussion

The descriptive statistics of studied variables show a shift in CO_2 emissions. Indeed, the maximum emissions are 10291926.878 (KT) in 2014 for China. Regarding the distribution of energy consumption between fossil fuel energy and renewable energy we find that on average the use of renewable energy constitutes 34.53% against 67.23% for fossil fuels. This reveals the predominance of polluting energies over clean energies. We use the static panel analysis to examine the relationship between energy efficiency, renewable energies, nonrenewable energies and CO_2 emissions. The Hausman test was conducted to determine the most appropriate panel analysis method. The result of the Hausman test suggested that the fixed effect is the most appropriate estimation method. Table 3 presents the results of the estimation of fixed effect panel models.

	Model 1	Model 2	Model 3
Population	1.08086 (47.54)***	1.022038 (41.92)***	1.107057 (44.77)***
GDP/capita	1.03803 (55.71)***	0.4537143 (34.92)***	0.9579506 (50.03)***
Energy efficiency	-0.788286 (-38.68)***		-0.6612401 (-30.23)***
Non Renewable Energy		0.5802496 (30.64)***	
Renewable Energy		-0.2097622 (-22.90)***	-0.1139366 (-13.97)***
Constant	-15.28377 (-44.76)***	-12.35765 (-33.68)***	-14.94933 (-39.94)***
R^2	0.7257	0.7573	0.7360
F	2777.38	2275.76	2116.20
Prob>F	0,0000	0.0000	0.0000
Observations	3313	3053	3198
Nations	161	131	158

Students-T are provided between brackets: ***, **and * represent the statistic signification at 1%, 5% et 10%, respectively.

Table 3. Model Estimations

In general, the overall results of the estimates of the different models correspond to the preliminary hypotheses of this study. In Model 1, proposed by Shi (2001) and Heryadi and Hartono (2016), income and population contribute to the rise in CO_2 emissions similarly for models 2 and 3 as demonstrated by their positive and statistically significant coefficients.

Energy efficiency is related significantly to carbon dioxide emissions with a coefficient of -0.788. This means that a growth in energy efficiency of 1% leads to a reduction in carbon dioxide emissions by 0.788%, all other things being equal. Thus, more efficient energy consumption will reduce emissions.

Model 2, based on the study of Shafiei and Salim (2014) that examined the influence of renewable and non-renewable energies on the environmental impact, it appears that renewable energies adoption contributes to CO_2 emissions decline while the use of nonrenewable energies contributes to the increase of CO_2 emissions. Our results are consistent with those of Shafiei and Salim (2014) who estimated this model for OECD countries during the period 1980-2011 using the Augmented Mean Group (AMG) estimator. The difference lies in the magnitude of the impact of the different used variables. Indeed, the population coefficient is 1.02, which means that a 1% increase in the population would intensify CO_2 emissions by 1.02% assuming that everything is equal otherwise.

The results of the estimation are consistent with the basic STIRPAT theory proposed by York et al. (2003) concerning the role of the population as one of the main drivers of carbon dioxide emissions (coefficient 1.019). A rise in GDP per capita of 1% would increase carbon dioxide emissions by an average of 0.45%, all other things being equal. These results are also in agreement with the studies conducted by Shi (2001), Shafiei and Salim (2014) and Heryadi and Hartono (2016). In fact, the increase in a country's per capita income would be followed by an increase in energy demand for economic activities of production and consumption that will cause an increase in energy consumption.

On the other hand, growing the use of fossil fuels by 1% would rise carbon dioxide emissions by 0.45%, ceteris paribus. These results are in agreement with those of Heryadi and Hartono (2016) except that the intensity of the impact is less important for the G20 countries (0.40%), which have measured emission level obligations and are outsourcing their productions to developing countries to reduce their local emissions.

Finally, renewable energies are negatively and significantly related to carbon dioxide emissions with a coefficient of -0.209. This means that an increase in the share of renewable energy compared to total energy consumption of 1%, carbon dioxide emissions will drop by 0.209%, ceteris paribus. This shows that the impact of renewable energy is less important than energy efficiency. In other words, the mitigation policy to reduce CO_2 emissions is much more efficient through energy efficiency (diminishes emissions by 0.788%) than renewable energy.

These results are in contradiction with those of Heryadi and Hartono (2016) who concluded that the impact of renewable energies is more important than that of energy efficiency on the reduction of emissions. This can be explained by the fact that the G20 countries are developed and are using renewable energies on one side and in the other, they are developing clean technologies that they are spreading not only in their countries but also in developing countries in application of the Clean Development Mechanism resulting from the Kyoto Protocol.

Therefore, we can conclude that an additional effort must be made to highlight the widespread use of environmentally friendly energies around the world in order to amplify its reducing emissions impact.

Model 3 developed in Heryadi and Hartono (2016), shows that energy efficiency and renewable energies reduce CO_2 emissions. First, income has a statistically significant positive influence on CO_2 emissions. This means that the level of CO_2 emissions will increase with the rise in GDP per capita.

Second, the population variable has a statistically significant positive effect on CO_2 emissions. This indicates that a growth in a country's population will increase CO_2 emissions. This is obvious because the growing population will increase economic activity based on production, distribution and consumption activities, which could increase the pressure on natural resources, the environment and the use of energy.

Third, the energy efficiency variable has a statistically significant negative effect on CO_2 emissions. This can be explained by the fact that a country may experience an increase in GDP per capita while being able to maintain or even reduce its energy consumption for the realization of its growing economic activity.

Fourth, the renewable energy variable has a statistically significant impact on CO_2 emissions. These results are consistent with those of Shafiei and Salim (2013) and of Heryadi and Hartono (2016) who studied the impact of these variables using the same methodology for the G20 countries during the period 2000-2013. Thus, we can generalize their findings and conclude that for most countries of the world the increase in the population, the wealth of a nation increases the level of emissions that can be reduced by the use of renewable energies and energy and energy efficient technologies. Except the fact that the intensity of the impact differs according to the variables introduced in the model. Indeed, the impact intensity of the population is highest for model 3 (the coefficient is 1.107 against 1.022 for model 2).

Similarly for the estimated coefficients of GDP per capita or the coefficient of this variable is the highest for the first model is the lowest for the second model. This result can be explained by the introduction of the nonrenewable energy variable and so it is the use of fossil fuels that is partly responsible for the CO_2 emissions with a proportion of 0.58 of the CO_2 increase and 0.45 which is due to national income otherwise known as production. In addition, comparing Model 1 and Model 3, we note that energy efficiency is able to reduce emissions more than renewable energy.

4. Conclusion

Based on the results previously discussed, we can conclude that economic and demographic growth are two potential factors that lead to increased CO_2 emissions. Therefore, it is important to think seriously about energy efficiency and the use of renewable energy as a solution to the problem of carbon dioxide emissions. With regard to the first strategy, it improves energy usage, both in the production process in certain sectors and in the behavior of energy consumption by households. As for the second, it must be implemented in a more massive way to reduce the use of fossil fuels.

Indeed, at the end of this study, we were able to demonstrate that energy efficiency and renewable energies, individually and collectively, reduce carbon dioxide emissions levels. This is consistent with the initial hypothesis that both variables can contribute positively to efforts to reduce the CO_2 emissions rate. In addition, compared with renewable energies, energy efficiency has a greater effect on reducing CO_2 emissions.

We have been able to explain these results by the fact that, on the one hand, the developed countries are developing and using renewable energies and the use of these energies remains modest in both developed and developing countries. On the other hand, the developed countries are developing clean technologies that they are spreading not only in their countries but also in developing countries in application of the Clean Development Mechanism derived from the Kyoto protocol.

Therefore, we can conclude that an additional effort must be made to highlight the widespread use of environmentally friendly energies around the world, particularly through subsidizing developing countries allowing them to purchase and implement technologies to produce this alternative energy sources in order to amplify its emission reducing impact.

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