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Energy Efficiency, Utilization of Renewable Energies, and Carbon Dioxide Emission: Case Study of G20 Countries

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Abstract – *Greenhouse gas emissions highly contribute to the climate change, in which the world pays big concern. The world's 20 largest economies, the G20, supports around 86% of world GDP, 80% of total world trade and two-thirds of the world population, which make it contribute to 85% of the world's energy-related emissions. This high emission level makes the G20 in need to implement a set of policies on energy efficiency and develop the implementation of friendly-renewable energy. This study analyzes the effects of energy efficiency and utilization of renewable energy on CO_2 emissions in the G20 countries, by applying the panel fixed effect model approach of data from 2000 to 2013. The result shows that energy efficiency and renewable energy affect negatively on CO_2 emissions. Implementing renewable energy has a greater effect on reducing CO_2 emissions than applying energy efficiency. The result also shows that population and per capita income affect positively on CO_2 emissions.*

Keywords – CO_2 emission, energy efficiency, G20, panel data, renewable energy.

1. INTRODUCTION

Global warming, one of the causes of climate change, has been the world's issue these days. It appears due to the increased concentrations of greenhouse gases, especially carbon dioxide (CO_2) in the atmosphere, mainly from the use of fossil fuel (oil, coal and gas). Moreover, the current world energy mix is still dominated by fossil fuel (see Figure 1); the use of this fossil fuel is contributed to nearly 70% of the world's greenhouse gases emissions that is dominated by CO_2 emissions (90%) [1].

In 2013 the G20 countries accounted for 85% of total global emissions from energy [2]. Among the G20 countries, four countries become major producers of CO_2 emissions from energy, namely China, The United States, India and Russia (see Figure 2). Since 1980, China recorded having high CO_2 emissions of energy and increased rapidly over the next three decades. The significant growth in emissions was caused by the rapid growth in the Chinese economy, especially in the last decade that reached double digits, around 10%. Although the European Union also has a fairly high level of CO_2 emissions, countries in these regions are able to consistently reduce them in the last two decades. On the other hand, developing countries such as India, Indonesia, South Africa and Brazil are likely to have an increasing trend of CO_2 over the last three decades.

The Organization for Economic Co-operation and Development (OECD) in its report in 2012 predicted that without the appropriate implementation of energy innovation policies, CO_2 emissions from energy use in the world will increase by 70% in 2050, which will be followed by an increase in greenhouse gases by 50% [3]. Specifically, the IEA identifies two strategies for mitigating CO_2 emissions from energy use: energy efficiency and a shift in the structure of energy toward renewable energy sources. Both efforts became the main strategy of the G20 economic group to reduce greenhouse gases emissions and sustainable development. The G20 countries formed G20 clean energy and energy efficiency (CE3) working group as an effort to optimize the energy efficiency policy transition and utilization of new renewable energy (RE).

The energy efficiency is expected to reduce the final demand of energy, save energy costs, and provide benefits in reducing CO_2 emissions. On the other hand, the G20 economic group is encouraging the use of renewable energy that is addressed to reduce its dependence on fossil fuel. The use of renewable energy would reduce CO_2 emissions; since renewable energy is derived from natural materials that are environmentally friendly and most of its compound structure is not easily biodegradable in the combustion process.

Several studies have shown the importance of improving energy efficiency and the use or utilization of renewable energy. The studies that emphasize the importance of using technology to push the increase of energy efficiency are [4]-[8]. These studies argue that the environmental impact of CO_2 emissions can be reduced by using technology in the form of energy efficiency in the production sector and the distribution sector.

Meanwhile, studies show that the use of renewable energy able to reduce the rate of CO_2 emissions can be found in [8],[9]-[13]. These studies explain that the use of renewable energy is expected to be a substitute for fossil-based energy that can reduce CO_2 emissions. This is because most of the renewable energy is not chemically carbon compounds. Hence the use of renewable energy is expected to have negative impacts on CO_2 emissions.

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This study aims to examine the effects of energy efficiency and utilization of renewable energy as an alternative energy to reduce CO_2 emissions in G20 countries. It is non-debatable that energy efficiency and the utilization of renewable energy will reduce CO_2 emissions, but one important aspect is still essential to be analyzed, that is the magnitude of the impact. This study emphasizes the differences in the magnitude of the impact of energy efficiency versus renewable energy on CO_2 emissions. It is expected that the results could give important information to the policy makers in G20 member states to formulate appropriate policies to reduce CO_2 emissions.

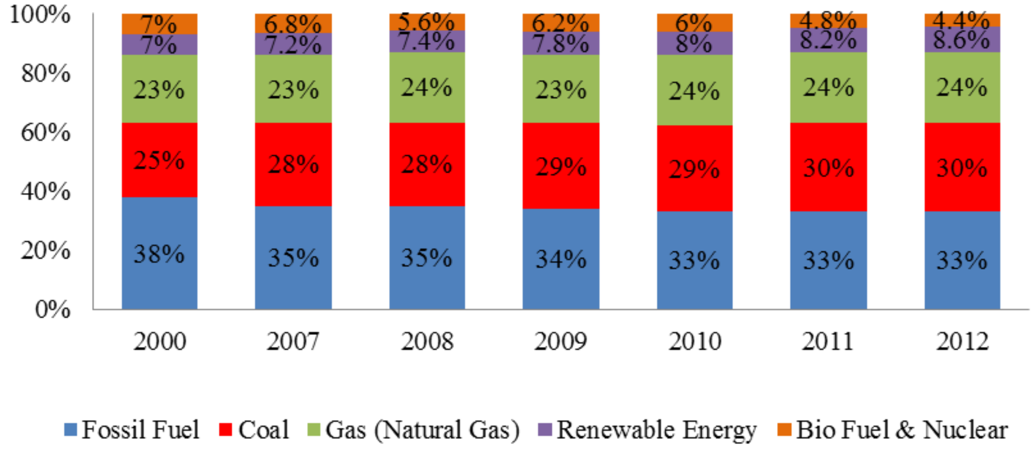

Fig. 1. Structure of world energy mix period 2000-2012 [14].

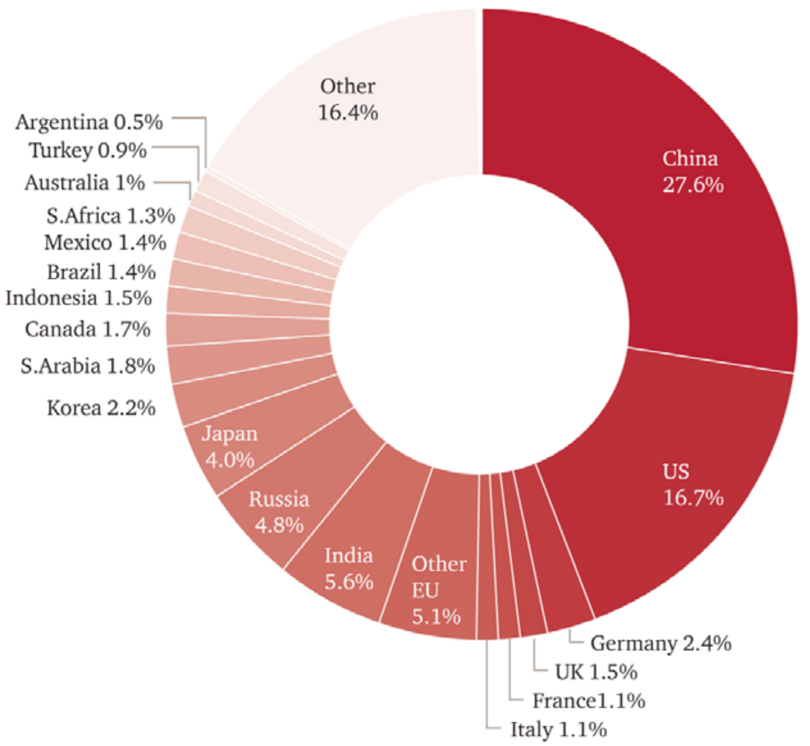

Fig. 2. CO_2 emissions from energy in 2013 [2].

2. RESEARCH METHODS

2.1 Theoretical Framework

Energy Efficiency

Shi [4] and Li *et al.* [6] defined the energy efficiency of an economic activity as the ratio of real GDP to energy use, in the currency of the country per unit of energy use, *i.e.* GDP per capita divided by the total energy used. It shows how much output can be produced from each unit of energy consumed. The greater the ratio the more efficient the use of energy from economic activity. Furthermore, an efficient energy use can reduce the environmental impact resulting from the economic activity.

In general, the level of efficiency can be assessed by two indicators: energy elasticity and energy intensity. Energy elasticity can be measured by the ratio between the growth rate of energy consumption and the growth rate of economic output or GDP. If the value of the elasticity decreases then it can be inferred that the energy use is more efficient since the less amount of total energy required in raising one percent of output. Meanwhile, energy intensity describes the use of energy per unit of GDP. If the value decreases, it can be inferred that the less amount of energy is required to produce one unit of output.

It is often that energy consumption in the production process could not be reduced. Hence, an energy-efficient technology is needed to save energy as it can produce more output for every unit energy used. In this situation, the resulting energy savings can be transferred to other production sectors. In addition, energy efficiency can also be achieved by the use of technology in industrial machines or vehicles that are environmentally friendly so that CO_2 emissions can be reduced. This is supported by [4],[5],[7] and [8] which stated that the environmental impact of CO_2 emissions can be reduced by using technology in the form of energy efficiency in the production sector and the distribution sector.

Renewable Energy

Zaekhan [10] defines renewable energy as energy which is quickly reproducible through natural processes, such as geothermal energy, biomass, water, solar and wind. According to Shafiei and Salim [11], renewable energy consists of wood, waste, geothermal, wind, photovoltaic cells, water and solar thermal sources.

Zaekhan [10], Shafiei and Salim [11], and Mert and Bölük [8] describe the importance of the use of environmental-friendly energy as the mitigation of CO_2 emissions. This is due to renewable energy can be a critical substitute for fossil fuel that could reduce CO_2 emissions because most of the renewable energy is not chemically carbon compounds. The conversion of renewable energy generally is not through combustion stage but through a direct conversion. Hence, the use of renewable energy is expected to have negative impacts on CO_2 emissions.

Furthermore, by using renewable energy and nuclear collectively can have an important role, not only in meeting the energy security but also in mitigating CO_2 emissions [9]. Moreover, Apergis and Payne [12] indicated that the use of renewable energy used will increase if the price is competitive. If the fossil fuel price is more expensive, it potentially will improve the use of renewable energy as an alternative energy which is environmentally friendly.

Susandi [15] concluded that the development of renewable energy has become a very important and urgent matter to be implemented continuously. In addition to the national energy supply security interest to maintain the sustainability of a country's development, the development of low-emission energy would contribute to the climate change mitigation. Therefore, the development of renewable low-emission energy would be beneficial for both the national economy and the global environment.

Theoretical Model

The environmental impact is an issue that had long been discussed by previous researchers. Among others Ehrlich and Holdren [16] who are the first to declare that population and income as the two main factors affecting environmental. This is then justified in the IPAT (Impact of Population, Affluence and Technology) theory. This theory was formulated as follows:

$$I = P \; x \; A \; x \; T \tag{1}$$

where, I is the environmental impact, P is the population, A (affluence) is the income derived from the economic output which is the GDP per capita, T is the technology factor which covers technology utilization, such as the use of renewable energy resources, or the energy efficiency level.

The IPAT model then was refined by Dietz and Rosa [17] into the following equation:

$$I_i = aP_i^b A_i^c T_i^d e_i \tag{2}$$

where the inclusion of *i* means that the value of each variable varies for each observed units. Coefficient *b*, *c*, and *d* respectively determine the effect of population, income per capita, and technology on environmental impact. Coefficient *a* is a constant and *e* is a residual term.

Furthermore, York, Dietz and Rosa [18] reformulated the Equation 2 into a logarithm form so that regression analysis to investigate the effect of each independent variable could be carried out. This logarithm transformation could overcome the difference in measurement unit of each variables. Hence, the calculation and the empirical testing analysis can be easily carried out. This theory was then named as the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT). The formulation of this model is as follows:

$$\log I_i = a + b \log P_i + c \log A_i + d \log T_i + e_i \tag{3}$$

In the above models, variable *I* depicts various environmental problems that, for instance, could be measured in the form of greenhouse gas emissions, carbon dioxide gas emissions, methanol gas emissions and the levels of pollutants. The technology variable (*T*) could be in various forms, such as technology innovation, social organization, institutions, infrastructure, and the utilization of new renewable energy.

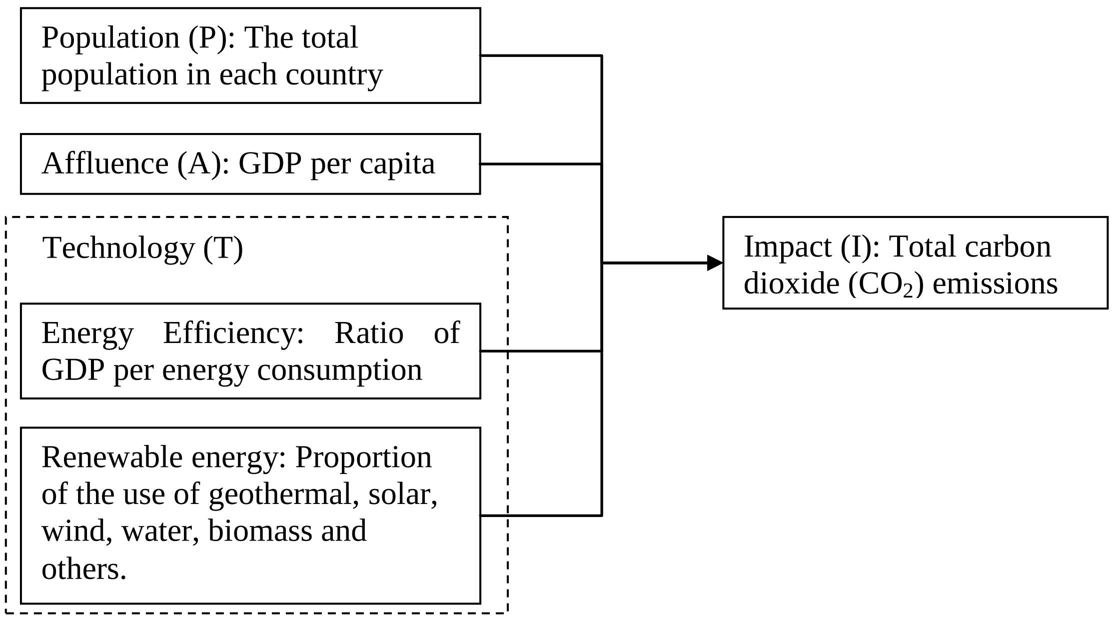

Fig. 3. Conceptual framework.

Based on the above models, and the models built in the studies in [4],[11], the current study assumes CO_2 emission as the proxy for environmental impact. Furthermore, the level of CO_2 emission is assumed to be influenced by population, GDP per capita, and technology variable (see Figure 3). The GDP, population and energy consumption variables in the model to explain the change in CO_2 emissions, supported by several studies such as in [19],[20] were used. Meanwhile, the use of renewable energy consumption variable in the model is supported by several studies [8],[13].

Population, in the model above, is a factor that could explain the size of a country. Shi [4] stated that the bigger the population in a country the greater the economic activities of the people in that country. The use of population variables in the model is also supported by research [21],[22]. The increase in economic activities that are depicted by economic output would then increase the CO_2 emission from energy use. On the other hand, income describes consumption ability of goods and services. The increase in income would trigger the demand in goods and services. Rahmansyah [5] stated that income is the main factor to push the increase in CO_2 emission from energy use.

Lastly, the technology variable is described in the form of energy efficiency and renewable energy. Researches by Shi [4], Rahmansyah [5], Li *et al.* [6] described the technology variable as energy efficiency, that is measured by output ratio or GDP generated from each energy consumption unit. The higher the value of this ratio, the more efficient the energy used in the economy. Hence, the CO_2 emission generated from the energy use could decrease. On the other hand, Shafiei and Salim [11] and Zaekhan [10] translated the technology variable into the proportion of renewable energy to the total energy use.

2.2 Data and Model

Observational data taken from 2000 to 2013 within the G20 economy nations are used in this research that are derived from the British Petroleum and World Development Indicator (see Table 1) [23]. The G20 economic group is the 20 biggest economy in the world consisting of The United States of America, South Africa, Saudi Arabia, Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Great Britain, Italy, Japan, South Korea, Mexico, Russia, Turkey and the European Union (represented by Netherlands, Spain and Poland). This group accumulates almost 86% of the world's GDP, 80% of the world's total trade and two-thirds of the world’s population that would total 4.56 billion people in 2013. Based these facts, we consider the G20 countries as representing the world economy. This group was formed in 1999 after the Asian and global economic crises as a forum that systematically gather the forces of the developed and developing economies to discuss key issues of the world economy. The objective of the G20 then expanded in discussing environmental issues, such as coordinating efforts to use cleaner energy and low carbon dioxide emission in the future; for example, in September 2009 the G20 leaders committed to gradually end the subsidy of fossil fuels in their countries [24].

Table 1. Data and data source.

Variable	Description	Unit	Source
$CO2_{it}$	Total of carbon dioxide emission from energy consumption	million tonnes of carbon dioxide	British Petroleum statistical review 2013 [22].
POP_{it}	Total population	People	World Development Indicators (WDI) [25].
$GDPcap_{it}$	GDP per capita	Purchasing Power Parity (PPP) (constant 2011 US$)	WDI 2014 [25]
$EFFI_{it}$	Energy efficiency ratio	GDP per unit of energy use (constant 2011 PPP US$ per mtoe)	British Petroleum statistical review 2013 and WDI [22], [25].
RE_{it}	Renewable energy consumption (water, wind, geothermal, solar, biomass, and others)	Million tonnes of oil equivalent	British Petroleum statistical review 2013 [22].
NRE_{it}	Non renewable energy consumption	Million tonnes of oil equivalent	British Petroleum statistical review 2013 [22].
$REpct_{it}$	The proportion of renewable energy consumption (water, wind, geothermal, solar, biomass, and others) from total energy consumption	Percentage (%)	British Petroleum statistical review 2013 [22].

Table 2. Empirical model specification.

Model	Specification
Model 1	$\ln CO2_{it} = \alpha_0 + \alpha_1 \ln POP_{it} + \alpha_2 \ln GDPcap_{it} + \alpha_3 \ln EFFI_{it} + e_{it}$
Model 2	$\ln CO2_{it} = \beta_0 + \beta_1 \ln POP_{it} + \beta_2 \ln GDPcap_{it} + \beta_3 \ln RE_{it} + \beta_4 \ln NRE_{it} + v_{it}$
Model 3	$\ln CO2_{it} = \gamma_0 + \gamma_1 \ln POP_{it} + \gamma_2 \ln GDPcap_{it} + \gamma_3 \ln EFFI_{it} + \gamma_4 REpct_{it} + \varepsilon_{it}$

Model Specifications

The model in this study refers to the model used in [3],[10] that is based on the STIRPAT model in the form of natural logarithm. More specifically, to study the environmental impact from energy efficiency (EFFI), this study follows Shi [3] by translating the technology variable as energy efficiency on the economic activities described by the GDP ratio to energy use. To explain the economic impact from the use of renewable energies, this study adopts the model from [10] which defines the technology variable as disaggregate of energy consumption: non-renewable energy (NRE) and fossil fuel sources and renewable energy (RE).

Next, the current study combines the two models to examine the environmental impact from the implementation of energy efficiency and the utilization of renewable energy. The technology variable in this research consists of energy efficiency (EFFI) and the disaggregation of consumed energy types represented by the ratio of renewable energy (REpct) from the overall total of energy consumption. All variables are presented in natural logarithm (ln), except the REpct variable that is presented in percentage.

The three models above observe samples of country i in year t (see Table 2). The e_{it}, v_{it}, and ε_{it} are error terms that covers the fact that not all factors influencing CO_2 emission of country *i* in year *t* are explained by all variables in the models.

Model 1 is used to test the effect of variable efficiency to the reduction of CO_2 emissions. While the use of model 2 is intended to test the effect of RE and NRE to CO_2 emissions, referring to the model developed in [11]. Finally, model 3 is needed to test the effect of RE and efficiency to the reduction of CO_2 emissions.

The models in the current study are then estimated by panel analysis. There are at least three approaches on the panel analysis, namely Random Effects Model (REM), Fixed Effects Model (FEM) and Pooled Least Square (PLS). To test the validity of the model and obtain the best estimation, the LM test and the Hausman test is conducted. The LM test is used to choose between the PLS model and the model of REM. While, the Hausman test is used to choose between models of REM and FE models. The Hausman test can be conducted when the results of the LM test indicated that the RE model is better to use than the PLS model.

3. RESULTS AND DISCUSSION

This section presents and discusses the results of the analyses carried out on the factors influencing CO_2 emissions in the G20 countries. It includes the descriptive statistics of the variables used in this study: CO_2 emission, population, GDP per capita, energy efficiency, and the renewable energy utilization. It also describes the results of the panel regression analysis of impacts of energy efficiency and the use of renewable energy on CO_2 emission.

3.1 *Descriptive Analysis*

In general, the G20 countries contribute 78.69% to the world's total CO_2 emission or around 27,614 MT CO_2 (the world's total CO_2 emission is 35,094 MT CO_2). China, United States of America and Russia has the highest annual per capita of CO_2 emissions: 6,258.50, 6,232.88 and 1,634.17 MT CO_2; while Argentina, Turkey and Australia are the lowest: 159.03, 267.44 and 379.05 of MT CO_2.

Compare to other countries that belong to G20, developed countries such as European Union countries (Netherlands, Poland and Spain), USA, and Australia have the largest GDP per capita that ranges between 35,137 US$ and 82,397 US$. Those are almost 10 to 15 times bigger than those of developing countries, such as China, Indonesia and India, GDP per capita that ranges between 3,533 US$ and to 6,613 US$.

The total population of G20 countries in 2013 reached 4.56 billion people or approximately two thirds of the world's population. The most populated countries are China, India and The USA. While the least populated G20 countries are Australia, Saudi Arabia and Canada.

Among G20 countries, Australia, the European Union (Netherlands, Poland, and Spain), Saudi Arabia and Argentina have the best energy efficiency level. The average energy efficiency of those three countries ranges between 177.89 US$/mtoe and 295.61 US$/mtoe. This suggests that the countries have succeeded in holding down the growth in energy consumption while increasing their GDP per capita. The G20 members with the smallest annual energy efficiency ratio are China (3.49 US$/mtoe), India (8.24 US$/mtoe), and USA (19.99 US$/mtoe).

Countries with the highest averages of annual renewable energy utilization are USA, Germany and the European Union, which respectively stands at 73.95, 29.92 and 22.23 mtoe. This shows that these three countries have succeeded in utilizing their technology and natural resources to develop alternative energy sources as a substitute for fossil fuels. Meanwhile, Saudi Arabia is the only G20 country that has not utilized renewable energy. This finding is quite reasonable, knowing that Saudi Arabia is the main producer of oil with abundant stock of oil, and the country has less incentive to develop renewable energy compared to other countries with limited fossil fuel resources. South Africa, Russia and South Korea are countries that utilize the renewable energy the least – the annual average stands at 0.19, 0.15 and 0.81 mtoes.

3.2 *Panel Analysis*

The panel analysis model is used to examine the relationship between energy efficiency and RE towards CO_2 emissions. The LM test and the Hausman test have been conducted to estimate the three models. The Hausman test was conducted to determine the most appropriate panel analysis method. The result of Hausman test suggested that the fixed effect is the best estimation method.

Table 3. The estimation results of energy efficiency and RE on CO_2 emissions.

Variable	Model 1 Energy Efficiency	Model 2 RE and Non RE	Model 3 Energy Efficiency and RE Proportion
Constants	-8.4563***	-9.0799***	-10.9711***
	(2.3854)	(2.2821)	(2.1524)
LnPOP	0.5906***	0.6006***	0.7017***
	(0.1394)	(0.1327)	(0.1252)
LnGDPcap	0.5920***	0.2379***	0.6058***
	(0.0348)	(0.0399)	(0.0312)
LnEFFI	-0.3989***		-0.3097***
	(0.0369)		(0.0347)
LnRE		-0.0106*	
		(0.0099)	
LnNRE		0.4016***	
		(0.0334)	
REpct			-0.0171***
			(0.0021)
R^2	0.994	0.9945	0.9952
Adjust R^2	0.9935	0.9941	0.9948
Prob > chibar2	0.0000	0.0000	0.0000
Prob > chi2	0.0000	0.0000	0.0000

Notes: All the equations estimated by FE model. *, **, and *** are 10%, 5%, and 1% significant, respectively.
Number in ( ) is the standard error.

Table 3 shows the estimation results of fixed effect panel model on the impact of energy efficiency and RE on CO_2 in G20 countries in 2000-2013. The estimation results shows that the energy efficiency variable coefficient in model 1 is negative; the renewable energy variable coefficient in model 2 is negative, and in model 3 in which the variables of efficiency and renewable energy are combined in one model shows that the two coefficient are both negative. The other variables on those three models – income (GDP per capita) and population generate positive coefficients. NRE variable (fossil fuel) in model 2 also generates positive coefficient. In general, the whole estimation results correspond to the preliminary hypothesis in this study.

In model 1, as proposed by Shi (2001), income and population would influence the increase in CO_2 emission in the same way as in model 2 and model 3. The energy efficiency is supportive to the decrease of CO_2 emission. In model 2, which is based on [10] that examined the influence of renewable energy and fossil-based energies (non renewable) on the environment impact, it appears that the use of renewable energies contribute to the decrease in CO_2 emission while the use of fossil-fuel energies contribute to the increase in CO_2 emission. Next, model 3, which is developed in this study, shows that the two main variables (energy efficiency and renewable energies) influence the decrease in CO_2 emission.

The analysis discussion will then focus on model 3 which contains two main variables – energy efficiency and renewable energy – to analyze the differences in the magnitude of the influence of these two variables on CO_2 emissions in the G20 countries.

Based on the model 3 estimation results displayed on Table 3, more details can be explained as follows. First, GDP per capita (income) has a statistically significant positive influence on the CO_2 emissions. This means that the CO_2 emissions pollution levels will increase along with the increase in GDP per capita. Second, the population variable has a statistically significant positive effect on the CO_2 emissions. This indicates that the increase in a country's population would increase the CO_2 emission. This is obvious as the growing population might increase the pressure on natural resources and the environment and the use of energy and hence the demand for energy or economic activity on production, distribution and consumption activities would increase significantly.

Third, the energy efficiency variable has a statistically significant negative effect on the CO_2 emissions. This can be explained that when a country experiences an increase in GDP per capita and on the other hand is able to maintain or even to decrease its energy consumption for economic activity then this country has successfully carried out energy efficiency. Furthermore, this energy efficiency would eventually lower CO_2 emissions. Fourth, the renewable energy variable has a statistically significant negative on the CO_2 emissions. This result is correlated with the initial hypothesis. It can also be the basis for increasing the world's awareness towards the use of renewable energy and to encourage the governments for conducting energy policies to reduce fossil fuel consumption and replace it with a more environmentally friendly energy (RE).

3.3 Interpretation of Model 3 Results Estimation

The following equation is obtained based on the model 3 regression estimation results:

$$\ln CO2_{it} = \text{-}10.9711 + 0.7017 \ln POP_{it} + 0.6058 \ln PDB_{it} - 0.3097 \ln EFI_{it} - 0.0171 PROPEBT_{it}$$
$$\qquad (2.1524) \qquad (0.1252) \qquad (0.0312) \qquad (0.0347) \qquad (0.0021)$$

Population coefficient of 0.7017 means that an increase of 1% of population in any G20 country would increase the CO_2 emission in that country by 0.70% with the assumption that other determinants are considered fixed (ceteris paribus). The estimation results are consistent with basic IPAT theory proposed by [16] regarding the role of the population as one of the main driving factors of carbon dioxide emissions. These results are also consistent with the studies conducted by [4],[10],[11]. Increase in population would raise energy demand for each resident to undertake economic activity so that energy consumption increases.

Income (GDP per capita) has a positive relationship with carbon dioxide emission from significant energy use. Increase of GDP per capita by 1% would raise carbon dioxide emission by 0.61% on average, ceteris paribus. These results are also consistent with the studies conducted by [4],[5],[10],[11]. The increase of per capita income of a country would be followed by an increase in energy demand for economic activities such as production, distribution and consumption. In other words, any increase in GDP per capita will be followed by a rise in energy consumption.

Energy efficiency is negatively related to carbon dioxide emissions significantly with a coefficient of -0.3097. This means that if an increase in energy efficiency by 1% then the carbon dioxide emissions will be reduced by 0.31%, ceteris paribus. These results are consistent with [4] and [8] that the use of technology in the process of production and distribution has the potential to encourage the use of more efficient energy consumption. Subsequently, the more efficient energy consumption will reduce CO_2 emissions.

Lastly, renewable energies are negatively and significantly related to carbon dioxide emissions with a coefficient of -0.0171. This means that an increase in the proportion of renewable energy relative to total energy consumption by 1%, the carbon dioxide emissions will be reduced by 1.7%, ceteris paribus. This shows that the impact of renewable energy is substantially larger (five times larger) than energy efficiency. In other words, the mitigation policy to reduce CO_2 emissions is much more effective via renewable energy. However, one should also consider the variety of the structure of economy across G20 Member States. This finding is consistent with Mert and Boluk [8], Zaekhan [10], Shafiei and Salem [11], Mbarek, Saidi and Feki [13] that the use of renewable energy contributes to reduce the CO_2 emissions**.**

4. CONCLUSION

Based on the research result and previous discussion, it can be concluded that energy efficiency and renewable energy, individually and collectively, affect negatively on the level of CO_2 emission levels. This is consistent with the initial hypothesis where both variables can contribute positively to the efforts in reducing the rate of CO_2 emissions. Furthermore, compared to the energy efficiency, the use of renewable energy has a greater effect on reducing CO_2 emissions.

This finding is supported by the fact that the decrease in the rate of CO_2 emission in the European continent, especially some European G20 members in the last two decades is mainly due to the successful implementation of energy efficiency and renewable energy policies. The efforts of energy efficiency are carried out by the use of energy-efficient and environmental-friendly technology in the production and distribution sectors. These efforts, on one hand have successfully increased economic output and on the other hand have reduced the energy consumption used as well as lowered CO_2 emission. Although the proportion of renewable energy relative to total energy consumption in G20 Member States is still relatively small, but there are some G20 Member States that have been succesfully implementing renewable energy policy. The larger coefficient of renewable energy relative to energy efficiency implies that the mitigation policy should be focused on the development of renewable energy. Thus, G20 Member States should consider a joint program between G20 Member States that have been succesfully developing renewable energy and other G20 Member States that are still in the early stage in the development of renewable energy.

Thus, this study concludes and shows that the economic and population growth are two potential factors which lead to the increase of CO_2 emissions. Therefore, it is important that in the high economic growth, there should be some efforts to improve energy efficiency levels, both in the production process in some sectors as well as in the behavior of energy consumption by the public. In addition to the improvement of energy efficiency, the use of renewable energy needs to be more massive to reduce the use of fossil energy. Both of these (energy efficiency and renewable energy use) can not be separated if we want to achieve specific targets in reducing CO_2 emissions.

Suggestions

To lower CO_2 emissions, G20 policy on efficient allocation of energy subsidies should be accompanied by a policy of energy efficiency, especially in the production sector to maximize the output of the economy in the form of an increase in GDP per capita and energy savings. G20 members, including Indonesia, should maximize the utilization of renewable energies, such as geothermal energy, biofuel, water energy, wind and solar energies as alternative energies that are environmental-friendly. For example, geothermal energy, water energy and solar energy can be used as energy resources to generate power in the production process. Furthermore, better efforts are needed to gradually substitute fossil fuels to renewable energies; so that the quality of the environment can be maintained and CO_2 emissions can be reduced.

To induce greater energy efficiency, it is necessary to consider the more tight restrictions to suppress the CO_2 emissions, especially in the developing countries of the G20 members. Energy efficiency is expected to give only limited contribution in reducing the growth of CO_2 emissions. This is due to the rapid growth of the use of energy in most of developing countries, particularly the use of fossil-fuel energy in the industrial sector, electricity and transport. Therefore, the contribution and the appropriate policies are needed to address the increase in global CO_2 emissions. In this case, in addition to energy efficiency, the utilization of renewable energy as an alternative to fossil energy sources is also needed.

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