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Analysis of Existing and Forecasting for Coal and Solar Energy Consumption on Climate Change in Asia Pacific: New Evidence for Sustainable Development Goals

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ABSTRACT

This study aims to identify trends in the role of coal and solar energy consumption on climate change through existing and forecasting analysis as new evidence for the sustainable development goals launched by 2030. This research targets countries in the Asia Pacific, especially coal exporters (Indonesia and Australia) and coal importers (China). The basic model uses panel regression as the existing condition, which covers the period 2008-2023. Meanwhile, the forecasting analysis uses the ARIMA method, which covers the period 2024-2030. The findings of existing conditions include coal energy consumption contributing to increasing climate change. Meanwhile, solar energy consumption can reduce climate change. Furthermore, the forecast findings on average are climate change conditions of 5.237 million tons and coal energy consumption of 33,830 exajoules, but on average the annual growth rate is relatively small (0.91% for climate change and 1.46% for coal energy consumption). Meanwhile, solar energy has also increased with a small quantity of 2.40 exajoules, but the growth rate is relatively high (29.61%). This research recommends that the government massively increase the transition of clean energy consumption towards solar so that the mix can dominate for greater reductions in climate change in achieving sustainable development goals.

Keywords: Coal Energy Consumption, Solar Energy Consumption, Climate Change, Sustainable Development Goals
JEL Classifications: C23, C53, Q47, Q54

1. INTRODUCTION

The issue of climate change is an issue that has a significant impact on the social and ecological life of society. Climate change will cause a widespread and severe socio-ecological crisis throughout the world (Abbass et al., 2022; Keenan, 2015). This problem is becoming increasingly complex because new crises are not occurring evenly and future generations will be more exposed to the risks of climate change than current generations (Raza et al., 2019; Rojas-Downing et al., 2017). This threat needs to be anticipated by prioritizing the issue of climate justice, which is in line with global climate change policies in the Sustainable Development Goals (SDGs) as a commitment to keep the climate below 2°C (Campbell et al., 2018; Morton et al., 2019). The world has agreed to the decision to improve the global climate and is also committed to controlling climate change, in particular reducing carbon emissions through the transition to cleaner energy consumption because one of the factors causing this climate change phenomenon to occur is the high level of accumulation of carbon emissions (Fawzy et al., 2020; Zheng et al., 2019). This condition makes the 13th SDGs goal, namely climate change, important to prioritize.

SDGs priorities are targeted to be achieved by the end of 2030 through increasing resilience capacity to climate change and integrating climate change anticipation actions into policies, strategies and planning (Kelman, 2017; Reckien et al., 2017). Furthermore, the urgency of prioritizing the SDGs agreement is because carbon emissions continue to increase, which are currently 50% higher than the previous three decades (Huang et al., 2018; Solaymani, 2019). Moreover, carbon emissions cause global warming and permanent changes to the global climate system, this problem will become worse for a long period of time unless the government of each country takes steps to realize the direction of sustainable development that is guided by the SDGs (Olabi et al., 2022; Saha et al., 2021). In line with this, policies to address climate change can also be achieved through low-carbon development as a development platform that aims to maintain economic and social growth through activities that maintain emissions from the threat of climate change (Mi et al., 2019; Olivier et al., 2017).

Previous literature studies concluded that efforts to control climate change will result in a reduction in accumulated carbon emissions because carbon emissions are dominated by residual contributions from non-renewable energy sources (Aimon et al., 2023a; Aimon et al., 2023b; Kurniadi et al., 2022), so there is an interest in investigating the cause. Furthermore, this situation arises because non-renewable energy consumption still dominates the current energy market share, especially the use of coal energy (Aimon et al., 2022; Liu et al., 2020; Odhiambo, 2016). This condition is supported by the role of coal energy as the main engine of global warming, which is not only for energy generation but also for cement manufacturing and steel production in various other industries. This situation arises because coal is an important energy source for the world and is used as the main fuel for almost 40% of various global industries (Aimon et al., 2021; Raza and Shah, 2020). In fact, by 2030 global demand for coal will grow to 60% greater than demand for other non-renewable energy (Jiang et al., 2018; Kurniadi et al., 2021; Li et al., 2019). The diversity of uses for coal commodities shows that this energy is a strategic fuel and a very large energy source. Therefore, it is not surprising that coal energy still dominates the global energy mix.

Furthermore, previous literature does not deny the impact of using non-renewable energy such as coal which causes various negative externalities, especially for the environment, one of which is that burning coal will emit 66% more carbon emissions per unit of energy compared to other fossil fuels (Shearer et al., 2017; Squalli, 2017). Additionally, around 7% of annual methane emissions also come from coal mines (Arisanti et al., 2018; Mineev et al., 2021). Other research also emphasizes that coal energy consumption will emit a lot of carbon emissions which will create extreme climate changes that have been felt in various countries, such as extreme weather and heat waves in several countries in Asia (Koplitz et al., 2017; Kurniawan and Managi, 2018; Sharvini et al., 2018). Another supporting finding is that the use of coal energy for a long time can cause global warming (Chang et al., 2015; Zhou et al., 2019). Then, subsequent studies also found the same thing that coal is considered a dirty energy source which causes the earth's temperature to increase and contributes to global climate change (Benalcazar et al., 2017; Steckel et al., 2015; Zhao and Alexandroff, 2019). Based on various previous research explanations, the environmental carrying capacity will decrease if countries continue to ignore the negative impacts of using coal energy. Therefore, several countries in the world are starting to focus on switching to environmentally friendly renewable energy such as solar energy to reduce the use of coal energy. This is based on the fact that solar energy is a source of energy that is freely available and effective for achieving climate improvements in creating sustainable development.

Specifically, this research focuses on analyzing several countries in the Asia-Pacific region because this region is the largest producer of carbon emissions at the global level and the main driver of climate change. What's worse is that experts say improving climate change in Asian countries is largely determined by reducing dependence on non-renewable energy sources, including coal energy (Fulton et al., 2017; Gouldson et al., 2016; Wang et al., 2017). In line with this, this research focuses on analyzing several selected countries in the Asia Pacific region, including coal exporting countries consisting of Indonesia and Australia, as well as importing countries such as China. Based on existing conditions, phenomena related to climate change (carbon emissions), average coal and solar consumption for Indonesia, Australia and China as selected countries in Asia Pacific can be seen in Figure 1.

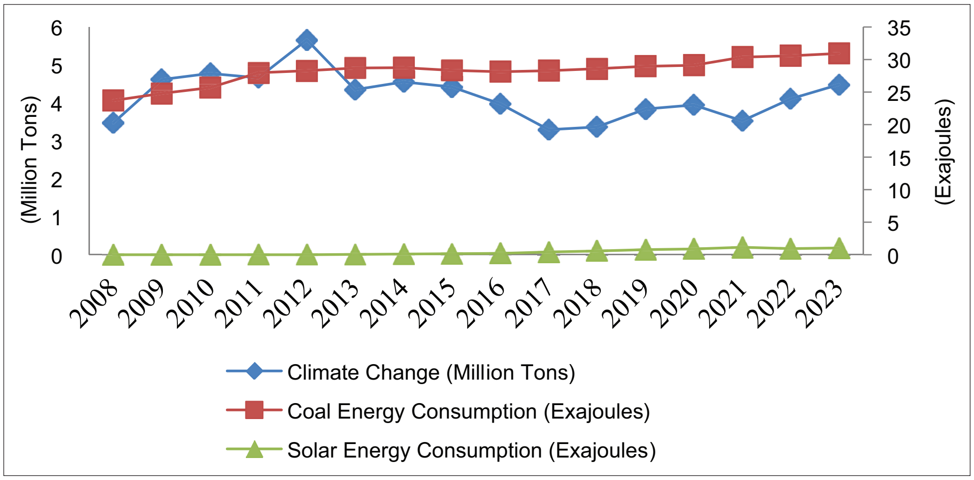
Based on the information in Figure 1, it can be seen that on average over the last 6 years conditions have experienced a sustainable climate improvement as reflected in a positive growth trend, except in 2021 due to COVID-19 which has had an impact on decreasing economic activity, resulting in residues such as emissions carbon also experienced a slowdown. Furthermore, at the same time, increasing climate change is also supported by increased consumption of coal as non-renewable energy. However, on the other hand, there is also an increase in solar consumption as renewable energy, but the accumulation is relatively small, so this condition is believed to not have made a significant contribution to reducing climate change. Based on the various phenomena that have been explained, the main problem that arises as an urgency for this research is the trend conditions that occur when projections are made for climate change, coal and solar consumption as new evidence for the achievement of the SDGs until 2030. To answer the challenges of problems in in this research, it will be discussed in the next section.

2. METHODOLOGY

2.1. Data and Variables

This research uses a collection of secondary data sourced from various official government agencies at the global level, such as the BP Statistical Review of World Energy and World Bank. Furthermore, this research analyzes a combination of cross section data and time series data, which is referred to as panel data. The cross section data used focuses on the Asia Pacific group

Figure 1: Average conditions for climate change, coal energy consumption and solar energy consumption in Asia Pacific (Indonesia, Australia and China)



Source: BP Statistical Review of World Energy, 2024; World Bank, 2024

of countries using several criteria. The first is the largest coal exporting country, consisting of Indonesia and Australia. Second is the largest coal importing country, namely China. Then, the time series data used is divided into two groups, namely 2008 to 2023 (existing conditions) and 2024 to 2030 (forecasting conditions).

The variables in this research consist of two categories, including the dependent variable, namely climate change, and the independent variable, namely non-renewable and renewable energy consumption. More specifically, the relationship between the variables used in this research can be seen in Figure 2.

Based on Figure 2, it is necessary to determine the definition, units and data source of each variable, which can be seen in Table 1.

2.2. Analysis Model

2.2.1. Existing conditions

The formation of the existing condition analysis model in this research refers to Figure 1. In the initial stage, the analysis applied was panel regression for the respective effects of coal energy consumption and solar energy consumption on climate change during the period 2008 to 2023, which can be seen in equation 1.

$$Y_{it} = \alpha_0 + \alpha_1 X_{1it} + \alpha_2 X_{2it} + \varepsilon_{it} \quad (1)$$

Where, α: parameter, i: cross section (Indonesia, Australia dan China), t: time series (2008-2023), ε: error term.

Panel data regression has three techniques offered, one of which must be selected through a series of tests (Biørn, 2017; Moon and Weidner, 2017). The first is the common effect model (CEM), where this technique combines cross section and time series data as one unit without looking at differences in time and entity and ignoring differences in individual and time dimensions. The second is the fixed effect model (FEM), where this technique assumes that the intercept for each cross section is different while the slope between individuals is constant. The third is the random effect model (REM), where this technique assumes that each

Figure 2: Research framework

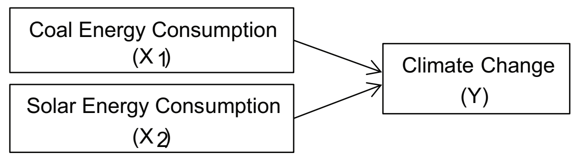


Table 1: Information for research variables

Variable	Description
Climate change (Y)	Total carbon emissions from burning coal energy in million tons sourced from the World Bank
Coal energy consumption (X_1)	Total coal energy consumption for one year in exajoules sourced from BP statistical review of world energy
Solar energy consumption (X_2)	Total solar energy consumption for one year in exajoules sourced from BP statistical review of world energy

cross section has a different intercept and also takes into account that errors may be correlated throughout the cross section and time series. A series of tests are carried out to determine the best panel regression technique to use (Croissant and Millo, 2019) is the Chow test to determine which panel data regression model should be used between CEM and FEM (if the probability value of Cross-section F and Cross-section Chi-square is > 0.05 the model chosen is CEM and if < 0.05 the model is chosen is FEM). Next, the Hausman test is used to determine which panel data regression model should be used between FEM and REM (if the probability value of the random cross-section is > 0.05, the model chosen is REM and if < 0.05, the model chosen is FEM). Then, the Lagrange multiplier test is used to determine which panel data regression model should be used between REM and CEM (if the Breusch-food cross section value is > 0.05 then the model chosen is CEM and if < 0.05 the model chosen is REM).

2.2.2. Forecasting conditions

Forecasting is a method that is useful as a tool to find out predictions for the future. Analysis of forecasting conditions for this research uses the Autoregressive Integrated Moving Average (ARIMA) method, which is a medium-term forecasting method that produces quite good forecast values compared to other methods. ARIMA can be interpreted as a combination of two models, namely the Autoregressive (AR) and Moving Average (MA) models. ARIMA assumes there is a combination (p, d, q), where p is the number of AR variables, d is the differencing process so that the data becomes stationary and q is the number of MA variables (Ma et al., 2018; Xue and Hua, 2016). Furthermore, the ARIMA model ignores independent variables in making forecasts. ARIMA uses the past and present values of the dependent variable to produce accurate short-term forecasts through a series of stages (Matyjaszek et al., 2019). First, identify the model, where the ARIMA model can only be applied to stationary time series. Therefore, the first thing that must be done is to investigate whether the data used is stationary or not. If the data is not stationary, what needs to be done is to check the difference between some of the data being stationary, namely determining what the value of d is. Second, determine the ARIMA model for orders p and q from reading the correlogram graph from stationary data results. Reading the graph can be seen from the patterns that appear in the graph. This process can be done using the ACF (Auto Correlation Function) and PACF (Partial Correlation Function) coefficients. Third, estimate the AR and MA parameters included in the model using the automatic ARIMA forecasting method. Fourth, diagnostic checking to find out whether the model specifications are correct or not using residual correlogram graphic analysis. Fifth, carry out forecasting after the best model is obtained.

3. RESULTS AND DISCUSSION

3.1. Existing Conditions

Analysis of existing conditions has been carried out in this research by referring to a series of panel data regression tests, including:

Based on the Chow test results obtained from Table 2, FEM is better than CEM because the Cross-section F and Cross-section Chi-square probability values are smaller than 0.05. The next step is to carry out the Hausman test, which can be seen in Table 3.

Based on the Hausman test results obtained from Table 3, FEM is better than REM because the random cross-section probability value is smaller than 0.05. Furthermore, this research does not proceed to the Lagrange multiplier test because FEM is the best model to be interpreted, meaning that the intercept for each cross section is different while the slope between individuals is constant. Unless the Hausman test results show that REM is the best model, it is necessary to proceed to the Lagrange multiplier test. Based on this explanation, the interpretation of the FEM model as the best panel regression model can be seen in Table 4.

Based on the information in Table 4, equation 1 can be rewritten as equation 2 because the values from the data processing output results have been substituted. The main information from Equation 2 is that each independent variable consisting of coal energy consumption and solar energy consumption has a significant effect on climate change. More specifically, coal energy consumption has a positive effect. On the other hand, solar energy consumption has a negative effect.

Table 2: Chow test results

Effects test	Statistic	d.f.	P
Cross-section F	69.811164	2.43	0.0000
Cross-section χ^2	69.418566	2	0.0000

Table 3: Hausman test result

Test summary	Chi-square statistic	Chi-square d.f	P
Cross-section random	139.622328	2	0.0000

Table 4: Fixed effect model interpretation

Variable	Coefficient	SD	t-statistic	P
C	0.348469	0.286578	1.215967	0.2303
Coal energy consumption (X_1)	0.228762	0.079183	2.889028	0.0059
Solar energy consumption (X_2)	−0.081968	0.036989	−2.216032	0.0318

Sd: Standard deviation

$$Y_{it} = 0.348469 + 0.228762\ X_{1it}^{**} - 0.081968\ X_{2it}^{*} \quad (2)$$

**significant at α = 1%; *significant at α = 5%

In the countries analyzed in this study, coal energy consumption contributes 0.228762% to climate change. Coal energy is a type of non-renewable energy source and its use produces residue in the form of carbon emissions. Most of the world's air pollution comes from incomplete combustion of fossil fuels such as coal. When coal is burned to produce energy, the carbon in the fuel reacts with oxygen to form carbon dioxide gas, much of which is released into the atmosphere and contributes to global warming. Coal mining and coal-fired power plants release heat-trapping greenhouse gases such as carbon dioxide and methane. This means that coal causes more air pollution than other energy sources. Emissions into the atmosphere from burning coal are said to be toxic particles containing sulfur dioxide, nitrogen oxides, lead and other heavy metals, all of which contribute to a decrease in carrying capacity and, in particular, an increase in climate change. The results of this research are also supported by several related studies, including that emissions from coal are one of the largest contributors of greenhouse gases in the world which contribute to climate change, producing one fifth of the world's greenhouse gases which is more than other sources (Bauer et al., 2016; Brown and Spiegel, 2019). This result is also supported by other findings that global warming is one of the biggest impacts of using coal energy because it releases heat-trapping greenhouse gases such as carbon dioxide and methane (Chiu et al., 2021; Curran, 2021). Furthermore, the findings also found that carbon emissions from burning coal contribute to climate change by worsening air quality (Zeng et al., 2022; Zhang et al., 2020).

In the countries analyzed in this study, solar energy consumption contributed 0.081968% to reducing climate change. Solar energy is a type of renewable energy source and because it relies on solar energy, its use tends not to produce residue in the form of carbon emissions. In addition, solar energy is an alternative raw material for coal energy. Harnessing solar energy to generate more electricity to support economic activities will reduce harmful emissions from burning non-renewable energy sources such as coal, because generating electricity from solar panels is less likely to produce harmful emissions. This means fewer emissions and can offset increases in climate change. In addition, when fossil energy sources are increasingly scarce and expensive, the use of solar energy can help reduce dependence on increasingly scarce fossil energy sources. In addition, the use of solar energy helps reduce climate change through reducing emissions and air pollution, making it more environmentally friendly than fossil energy sources. Although the initial investment cost of using solar energy is quite high, it can save you financially in the long run because solar energy is free and sustainable. Another benefit of using solar energy is that it can increase energy independence, especially in areas that are difficult to reach by traditional electricity networks. The results of this research are also supported by several related studies, including that the use of renewable energy is the most important solution to reduce the increase in climate change (Creutzig et al., 2017; Shahsavari and Akbari, 2018). Furthermore, similar findings also state that alternative energy from non-renewable sources needs to be developed to control climate change (Noorollahi et al., 2021; Olabi and Abdelkareem, 2022). Other research also finds that an energy mix dominated by renewable energy will maintain environmental quality, such as controlled climate conditions (Dutta et al., 2022; Ouria and Sevinc, 2018).

Table 5: Stationarity test results

Variable	ADF test		Decision
	Level	First difference	
Climate change (Y)	0.1940	0.0020	Stationer
Coal energy consumption (X1)	0.1519	0.0273	Stationer
Solar energy consumption (X2)	0.0441	-	Stationer

3.2. Forecasting Conditions

Analysis of forecasting conditions has been carried out in this research by referring to a series of ARIMA tests, including checking data stationarity using the ADF test in Table 5.

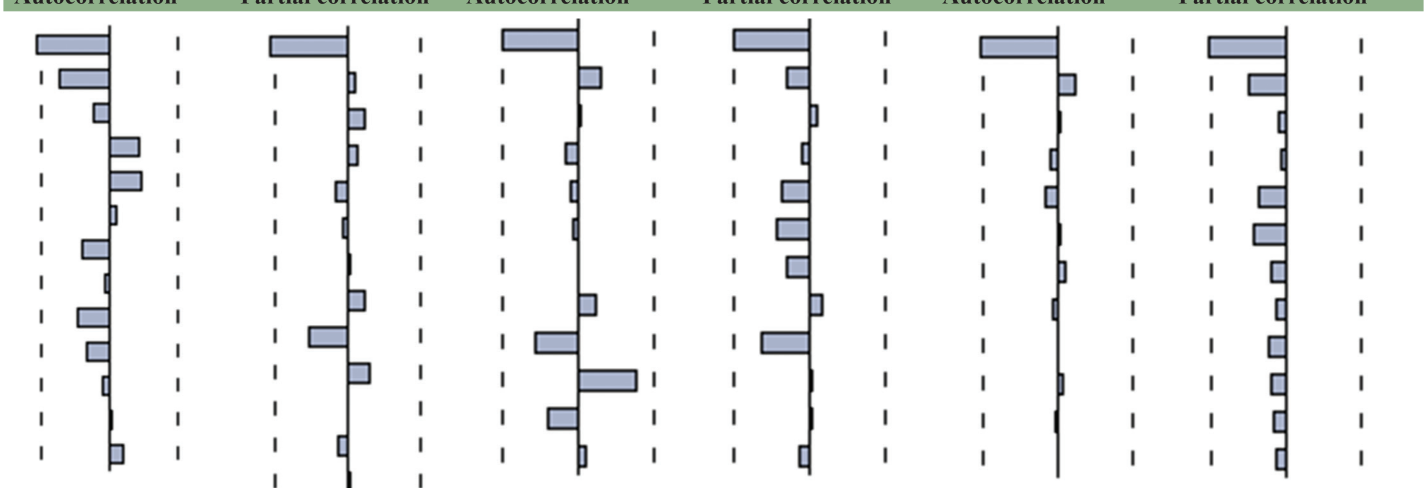
Based on the results of the stationarity test obtained from Table 5, climate change and coal energy consumption are not stationary at level because the probability value is greater than $\alpha = 5\%$, so the stationarity test for these two variables is continued to the first difference stage with the result that the unit root is significant at $\alpha = 1\%$. Meanwhile, solar energy consumption is stationary at the level at $\alpha = 5\%$, so there is no need to proceed to the first difference. Based on the results of the analysis for data stationarity, the d order for climate change and coal energy consumption is 1, while the d order for solar energy consumption is 0. After the data stationarity in this research has been obtained, the next stage is to determine the ARIMA model for the order p and q from reading the data correlogram graph based on the stationarity test, as seen in Table 6.

Based on the information in Table 6, it can be used as a basis for determining ARIMA forecasting using the automatic method in the eviews processing application. Based on the results of the ACF and PACF correlograms (Table 6) and the results of the stationarity test (Table 5), it can be seen that for climate change (Y), coal energy consumption (X1) and solar energy consumption (X2) there is an ACF that is not significant at lag 1st so it is suspected that the data was generated by MA(1) and vice versa, PACF is not significant at the 1st lag so it is suspected that the data was generated by AR(1). Based on the results of this analysis, it is assumed that the initial model obtained for climate change (Y) and coal energy consumption (X1) is the ARIMA model (1,1,1). Meanwhile, solar energy consumption (X2) is the ARIMA model (1, 0, 1) as seen in Table 7.

Based on the results of the automatic ARIMA test in Table 7 using the eviews program, it can be seen that for all variables in this study it is recommended to use AR(1), while MA(0). Based on these recommendations, it is necessary to carry out the next stage of testing, namely diagnostic checking to find out whether the

Table 6: Correlogram test results

Climate change (Y)		Coal energy consumption (X_1)		Solar energy consumption (X_2)	
Autocorrelation	Partial correlation	Autocorrelation	Partial correlation	Autocorrelation	Partial correlation



model specifications are good using residual correlogram analysis based on the results of the recommended automatic ARIMA model. The results of the diagnostic checking test are shown in Table 8.

Based on the diagnostic test results in Table 8, the residual correlogram for all variables is distributed randomly, which results are confirmed by the ACF and PACF values which cross the specified limit line. This condition indicates that the recommended model specifications are in the good category. After the diagnostic test results show a good category, the next step is to forecast until 2030 in Table 9.

Based on the forecast test results in Table 9, climate change conditions have increased for each forecasting period ending with the highest level of climate change in 2030 amounting to 5.378 million tons with growth of 0.89%, which is the finding of this research in line with previous research that is predicted to occur an increase in temperature of 2°C in 2050 which will impact the risk of famine due to shocks to the agricultural sector due to the worsening climate (Yerlikaya et al., 2020). The findings of this research also reveal that the increase in climate change is also supported by an increase in coal energy consumption for each forecast period ending with the highest level of coal energy consumption in 2030 of 35,305 exajoules with growth of 1.41%. On the other hand, solar energy consumption also increased for each forecast period ending with the highest level of solar energy consumption in 2030 of 4,953 exajoules with growth of 37.71%. Based on the forecast explanation, it implicitly implies that increasing solar energy consumption has not contributed to reducing the accumulation of climate change because the proportion of coal energy consumption still dominates in very large quantities. Furthermore, the results of this research found that although in terms of quantity there has been an increase in forecasts of climate change and coal energy consumption, the growth rate tends to decrease. The results of this research are supported by previous studies that predict there will also be a decline in coal consumption growth from 2016 to 2030 (Jiang et al., 2018). Another interesting thing about the increase in the quantity of solar energy consumption is that it has experienced a very high increase in growth when compared to the other two variables, so it is necessary to focus the attention of governments in Asia Pacific in developing solar energy in the future to substitute coal energy. These findings are also supported by previous findings, where recent progress shows the potential for large improvements in the future estimates of renewable energy such as solar energy (Sweeney et al., 2020). Based on these various explanations, it can be seen that the average climate change condition each year during the forecasting period is 5.237 million tons with a growth rate of

Table 7: Automatic autoregressive integrated moving average model results

Variable	Selected ARIMA model
Climate change (Y)	(1,0)(0,0)
Coal energy consumption (X_1)	(1,0)(0,0)
Solar energy consumption (X_2)	(1,0)(0,0)

ARIMA: Autoregressive Integrated Moving Average

Table 8: Diagnostic test results

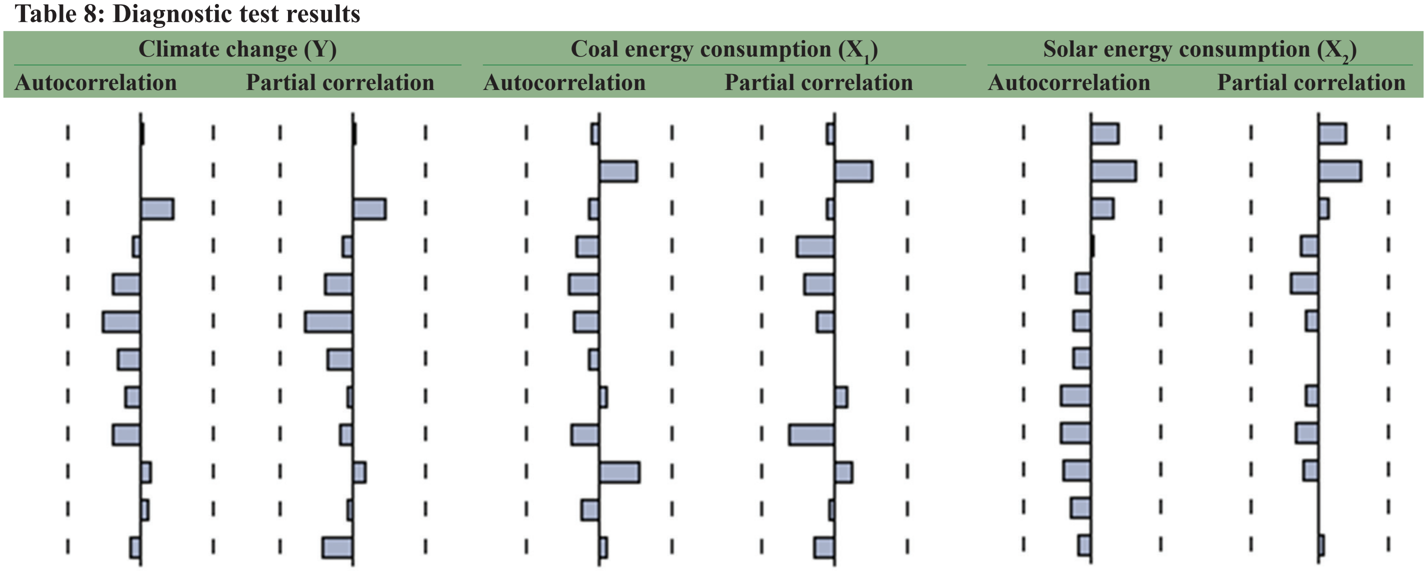


Table 9: Forecasting results

Period	Climate change (Y)		Coal energy consumption (X_1)		Solar energy consumption (X_2)	
	Million tons	Percentage	Exajoules	Percentage	Exajoules	Percentage
2024	5.095	-	32.356	-	1.065	-
2025	5.142	0.93	32.847	1.52	1.157	8.63
2026	5.190	0.92	33.339	1.50	1.464	26.47
2027	5.237	0.91	33.831	1.47	1.933	32.03
2028	5.284	0.90	34.322	1.45	2.616	35.37
2029	5.331	0.89	34.814	1.43	3.596	37.47
2030	5.378	0.89	35.305	1.41	4.953	37.71

0.91%. Then, the amount of coal energy consumption each year during the forecasting period is 33,830 exajoules with a growth rate of 1.46%. Furthermore, the amount of solar energy consumption each year during the forecasting period is 2.40 exajoules with a growth rate of 29.61%.

4. CONCLUSION

This research concludes that an analysis based on existing needs needs to be carried out to control climate change through a transition from coal energy consumption to solar energy. This means that it is necessary to substitute coal energy with solar energy to achieve the SDGs targets set for 2030. Meanwhile, based on forecasting analysis, it is necessary to increase the quantity of solar energy used in larger quantities in order to replace the dominance of coal energy as an effort to reduce climate change. This means that it is necessary to develop the potential of solar energy for future energy to ensure energy needs, desires and control climate change.

Based on these findings, it is recommended that governments in the Asia-Pacific region, especially Indonesia, Australia and China switch to solar energy because it is a clean energy source with minimal emissions and is environmentally friendly. A possible action is to encourage and accelerate the development of rooftop solar power plants in residential buildings, public buildings, government offices, commercial buildings and industrial areas to encourage the growth of a competitive solar power system industry, including the movement of a million rooftop solar power plants. This realization also needs to be supported by a competitive attitude, encouraging and mobilizing community participation to reduce greenhouse gas emissions and the threat of climate change. Additionally, feed-in tariffs, which provide financial incentives for renewable energy projects that include solar panels, could also be implemented to encourage investment in solar panels. Furthermore, the government should also create tax incentives for the purchase of solar panels and create financing options for renewable energy that provide low-interest financing specifically for solar panels.

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