Vector error correction model to analyze energy uses, environmental quality and economic growth during Covid-19 Pandemic

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Abstract. Time series data commonly show are interconnected behaviour and non-stationer interrelated variables, so a model that able to obtain a good forecasting result from a non-stationary multivariate variables time series data are needed. Vector Error Correction Model (VECM) is one of multivariate time series model which is a vector form of Vector Autoregressive Boundary (VAR) for non-stationary time series data and has a cointegration relationship. The purpose of this study is to identify the VECM model in analyzing the relationship between energy use, environmental quality (CO$_2$), and economic growth (GDP) during the Covid-19 pandemic that plagued Indonesia. The results of this study explained energy uses and and environmental quality (CO$_2$) and economic growth (GDP) are interrelated and have a long-term cointegration relationship due to the influence of the Covid-19 pandemic.

1. Introduction

Currently, the world community is being hit by the outbreak of Covid-19 cases which is increasing along with the large number of data showing positive events to date. The total number of new cases and deaths in Indonesia as of the end of May 2021 was 1.76 million cases, 1.62 million recovered, and 48,887 deaths. Meanwhile, the total number of Covid-19 cases worldwide is 166 million cases and the number of deaths is 3.44 million cases. The COVID-19 pandemic has not only changed the way people live in Indonesia but also people around the world. Impact on almost all dimensions, both health, education, tourism, social and economic dimensions. In particular, economic growth in Indonesia during the Covid-19 pandemic experienced a significant decline.

One of the main factors influencing economic growth is energy use. Indonesia is one of the countries that has relatively available reserves of energy resources, but alternative choices of other energy resources are needed considering that oil reserves are the main energy and its supplies are decreasing. Furthermore, energy use must still pay attention to environmental quality to support economic activities. Improving the efficiency of energy use and adopting the use of energy with an environmental concept (green energy) are some of the ways that are known to be effective in overcoming the problem of using environmentally sound energy.

As economic growth increases, the quality and function of the environment also decrease. The decline in environmental quality shows that the amount of available natural resources is decreasing and even experiencing scarcity. The ability of nature to treat the waste produced is decreasing as a result of the capacity of the waste produced exceeding the capacity of the environment itself. Thus, the
environment is not able to pleasure due to natural resources and the environment that have changed functions or increased pollution air. Research about relationship between energy consumption and economic growth began in the 1970s by J.Kraft and A.Kraft [1] and found one-way casual relationship between GNP and energy consumption.

On the other hand, during the Covid 19 pandemic, movement restrictions humans are considered as a step in reducing the spread of the Covid-19 virus which has an impact on economic activity in Indonesia. The implementation of lockdown, work from home and online learning are new activities in controlling the spread. Thus, this indicates a slowdown in the level of carbon dioxide emissions due to a decrease in energy use activities. The Center for Clean Energy and Air Research (CREA) said that the world's carbon emissions based on data decreased by up to 17% due to the Covid-19 quarantine implemented in various countries. Nearly half (43%) of global emission reductions during the peak of lockdowns came from the transportation and industrial sectors, especially motor vehicles and commercial manufacturing plants [2]. Empirical study about the regression model method for instance Ugur Sotya et al [3] studied the Granger Casuality relationship among the US Income, energy consumption, and carbon emissions based on the Vector Autoregression Model (VAR).

During the Covid-19 pandemic, urban air quality has improved. Image from NASA’s Earth Observatory satellite shows NO2 pollution in China’s Wuhan dropping sharply. The level of air pollution in New York was reduced by 50%, air quality in China rose 11.4%, and NO2 emissions also decreased in Italy, Spain, and England [4]. Conditions in Indonesia itself, CREA stated that the maximum reduction in carbon dioxide emissions reached 18.2%. The level of NO2 gas in Jakarta decreased by around 40% from the gas level last year [2].

The Vector Error Correction Model (VECM) is a model developed by [5] to solve the problems of cointegrating variability. In other words, in time-series data, VECM analysis can be a solution in overcoming the problem of variables that have a long-term equilibrium relationship, but there is no balance in the short term. Shawka Hammoudeh et al [6] utilized VAR and VECM to analyze the short-term dynamic influence of changes in oil prices, coal prices, natural gas prices, electricity prices, and carbon emissions quota on carbon emissions prices. The conclusions found that positive impact of the crude oil price will produce a negative effect on the approved price of carbon emissions. Rajathanam Shantini [7] showed the long term equilibrium relationship between CO2 emissions and GDP using marginal testing method of the autoregressive distributed lag model. Furthermore, it explained that long-term decrease of CO2 emissions was related to price increasing of crude oil and technical progress, despite their small extent.

The VECM model is also referred to as the VAR model which is designed to be used on non-stationary data that is known to have a cointegration relationship. This study focuses on the VECM model to analyze the cointegration relationship between energy use, environmental quality, economic growth, and positive cases of Covid-19 in Indonesia. The purpose of this study is to model the cointegration relationship in providing clarity on the long-term relationship of the impact of the Covid-19 pandemic on energy use, environmental quality, and economic growth in Indonesia.

2. Literature Review

2.1. Vector Error Correction Model (VECM)

Modern Econometricians point out a method to establish the relational model among economic variables in a nonstructural way, they are VAR and vector error correction model (VEC) [8]. Christopher A. Sims in 1980 introduced the Vector Auto Regression (VAR) model as an alternative model in analyzing matters related to macroeconomics [9]. The VAR model has a practical/simple model structure, character with a limited number of variables where all the variables are endogenous variables and the independent variable is lag. The VAR model was created for variables that are stationary or do not contain unit roots and do not have a trend [10].

Time-series data containing stochastic trends indicate that there are long-term and short-run components. The concept of cointegration was first developed by Granger in 1981. Then, together with Engle in 1981, Granger developed the concept of cointegration and error correction. Research on
stochastic trends continues to grow so that in 1990, Johansen and Julius developed the VECM concept which offers an easy working system to separate the long run and short-run components in the data formation process [11],[12]. Therefore, the VAR model has a different concept from the VECM model, where the VECM model can be used to analyze cointegrated and non-stationary time series data.

2.2. Unit Root Test
The requirement to use the VECM model based on the previous discussion is time series data which are cointegrated and non-stationary. To test whether the time series data is stationary or not, a unit-root test is carried out by testing the hypothesis $H_0: \rho = 0$ (containing unit roots) in the regression equation through the Augmented Dicky-Fuller (ADF) test statistic as follows:

$$\Delta y_t = \gamma + \delta_t + \rho y_{t-1} + \sum_{j=1}^{k} \phi_j \Delta y_{t-j} + e_t$$

With, $\Delta y_t = y_t - y_{t-1}$ dan $\rho = \alpha - 1$

The null hypothesis ($H_0$) is rejected at significance level $(1 - \alpha)100\%$ if the ADF test statistic value is less (more negative) than the critical area value. If the null hypothesis is rejected, then the data is stationary [13].

2.3. Johansen Cointegration Test.
Johansen test statistics can be used to see the amount of cointegration contained in the test variables or known as the Johansen cointegration test. In general, the VAR model is unrestricted and has $p$-lags shown as [9]

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + \epsilon_t$$

Where:
$y_t = k$ vector non-stationary variable
$A = \text{parameters matrix}$
$\epsilon_t = \text{error vector}$

The VAR($p$) model (2.2) can be rewritten into VECM model using $y_{t-1}$ (first difference) as shown in the equation (2.3):

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p} \Gamma_i \Delta y_{t-p} + \epsilon_t$$

with,
$\Pi = \sum_{i=1}^{p} A_i - 1, $
$\Gamma_i = - \sum_{j=i+1}^{p} A_j$

where
$\Gamma_i = \text{matrix coefficient} (p x p), j = 1, \ldots, k.$
$\Pi = \text{matrix} (p x r); 0 < r < p,$ and $r$ is the number of linear combinations of $y_t$ elements which is only affected by shock transistor.
$\epsilon = \text{error correction vector}$
$t = \text{number of observations}$

[8] suggested that in the Johansen test we tested the null hypothesis. There are as many as $r, r = 0,\ldots,k-1$ cointegration equations versus alternative hypotheses. There are $k$ cointegration equations with $k$
representing the number of endogenous variables in the VAR model. So, to test this hypothesis we use the trace test statistics, as follows [11]:

\[
L_{R_{tr}}(r|k) = -T \sum_{t=r+1}^{k} \log(1 - \lambda_t)
\]

(4)

and Max Eigen value statistics test as follows,

\[
L_{R_{mak}}(r) = -T \log(1 - \lambda_{r+1})
\]

\[
= L_{R_{tr}}(r|k) - L_{R_{tr}}(r+1|k)
\]

(5)

\[r = 0, 1, ..., k-1, \] with the hypothesis used is;

\[H_0 = \text{There are } r \text{ cointegration equations at the significance level } (1 - \alpha) \times 100\% , \] 

\[H_0 \text{ accepted if the trace test statistic and the maximum Eigen value are less than the critical value of, or is greater than the significance value [13].}\]

2.4. Procedure

The time-series data in this research, the VECM is applied to monthly data on energy consumption, CO2 emission, Gross Domestic Product (GDP) [15], and positive cases of Covid-19 in Indonesia from January to December 2020 [16].

The procedure in VECM analysis is as follows:

1. Estimation specifications, and model checks by performing:
   a. Unit root test (data stationary test) using Augmented Dicky-Fuller Test (ADF)
   b. Johansen cointegration test to see cointegration between the variables
   c. Model estimation and examination.

2. Structural Analysis.

The results of data processing carried out in this study used statistical software E-VIEWS6.

3. Result and Discussions

In this research, the data used are monthly data on energy consumption, carbon dioxide emissions (CO2), Gross Domestic Product (GDP), and positive cases of Covid-19 in Indonesia. The data were taken for one year namely, 2020, where positive cases of Covid-19 were recorded in Indonesia, namely in March 2020. The first step in this study was to determine the stationary of the data using the Augmented Dickey-Fuller unit root test (ADF) with decision criteria at the significance level \((1 - \alpha) \times 100\% , \) where \(H_0\) is rejected if the \(p\)-value is less than the significance level. The data are presented in Table 1.

| Data               | \(P\)-Value \(1^{st}\) differencing | Conclusion |
|--------------------|------------------------------------|------------|
| Positive Covid-19  | 0.001                              | Stationary |
| Energy Consumption | 0.000                              | Stationary |
| CO2 Emission       | 0.040                              | Stationary |
| GDP                | 0.038                              | Stationary |

Based on table 1 above, it can be seen that after the first differencing, the \(p\)-value for each of the data variables above is smaller than \(\alpha = 5\% . \) It can be concluded that \(H_0\) is rejected, which means that the data does not contain unit roots or is stationary after the first difference is performed.

The next step before estimating using the VECM model, what must be done is to determine the length of the lag. Determination of the optimal lag is important in VECM modeling because it can provide an overview of the number of periods required for a data variable to react to the movement of other variables. Below are the results of determining the optimum leg length in table 2.
Table 2. Optimum Leg Length

| Lag | LogL     | LR       | FPE       | AIC       | SC        |
|-----|----------|----------|-----------|-----------|-----------|
| 0   | -156.1272| NA       | 51.885190 | 29.11404  | 29.25873  |
| 1   | -58.00443 | 107.0430*| 22.60267* | 14.18262* | 14.90607* |

Based on Table 2, it can be seen that the smallest LR, FPE, AIC and SC values are found in Lag 1. Thus, it can be concluded that the optimum lag in the VECM model is the VECM (1) model.

### 3.1. Johansen Cointegration Test

The results of the cointegration test at a maximum of lag 1 using Johansen cointegration test are presented in tables 3 and 4 below.

#### Tabel 3. Johansen Cointegration Rank Test (Trace)

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob.** |
|---------------------------|------------|----------------|---------------------|--------|
| None *                    | 1.000000   | 236.0602       | 47.85613            | 0.0001 |
| At most 1*                | 0.988186   | 59.98928       | 29.79707            | 0.0000 |
| At most 2                 | 0.624065   | 11.16601       | 15.49471            | 0.2015 |
| At most 3                 | 0.036086   | 0.404282       | 3.841466            | 0.5249 |

The cointegration test found that there is cointegration between research variables. It is shown that when \( r = 0 \) and \( r = 1 \) the trace statistic and Max-Eigenvalue are greater than the critical value of 5%. As for the other \( r \) values, the critical value is greater than the trace statistic and max-eigenvalue. Therefore, it can be concluded that there is at least one form of cointegration equation which shows that the variables have a balanced relationship and movement similarity in the long run.

#### Tabel 4. Johansen Cointegration Rank Test (Maximum Eigenvalue)

| Hypothesized No. of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 Critical Value | Prob.** |
|---------------------------|------------|---------------------|---------------------|--------|
| None *                    | 1.000000   | 176.0709            | 27.58434            | 0.0001 |
| At most 1*                | 0.988186   | 48.82327            | 21.13162            | 0.0000 |
| At most 2                 | 0.624065   | 10.76173            | 14.26460            | 0.1666 |
| At most 3                 | 0.036086   | 0.404282            | 3.841466            | 0.5249 |

3.2. VECM Estimation

#### 3.2.1. Impulse Respond Analysis

After conducting the cointegration test and it was found that the research data were cointegrated, the next research step was to estimate the VECM model. This is reinforced by Enders, 2015, which states that if there is a cointegration relationship between the research variables, then the estimation is done using the VECM model. On the other hand, if there is no cointegration between the research variables, then the estimation can be done using the VAR model.

The impulse response analysis presented in Figure 1 below will explain the response of a variable that will occur due to a shock of 1 standard deviation from either the variable itself or other variables.
search variable shocks make an important contribution in explaining changes in a variable. VD explains which random innovation is, relative to changes in the variables in the VECM. Briefly, VD explains which research variable shocks make an important contribution in explaining changes in a variable.

Figure 1 above shows that during the Covid-19 pandemic that plagued Indonesia during 2020, it gave a shock that caused various responses from research variables. It can be seen that the response to carbon dioxide (CO2) emissions to positive cases of Covid-19 did not provide significant movement and remained close to the value 0. Meanwhile, the response given by the variable energy use and economic growth (GDP) to positive cases of Covid-19 showed a negative response starting from approaching the third month to the end of the year.

3.3. Variance Decompositions
Variance decomposition (VD) is the next step in the VECM model. VD serves to provide information on how important the change in each random innovation is, relative to changes in the variables in the VECM. Briefly, VD explains which research variable shocks make an important contribution in explaining changes in a variable.
Based on figure 2 above, it can be seen that there is no cross over the dominance of each research variable. So, it can be concluded that energy use, carbon emissions, economic growth, and positive cases of Covid-19 are caused by the movement of the research variables themselves.

4. Conclusion
The results of calculations using VECM (1) show that energy use, environmental quality (CO2) are interrelated and have a long-term cointegration relationship. Not only that, the optimum lag for 1 period shows that a shock on certain variables will have an impact on the next period. The results of the analysis also illustrate that a shock that occurs by one standard deviation in positive cases of COVID-19 will result in a decrease in the variability of energy use and GDP. This is reinforced by the fact that during the Covid-19 pandemic, global energy demand decreased, which was largely driven by the drop in world oil consumption. Meanwhile, environmental quality does not respond to significant movements but tends to be constant and close to 0.

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Acknowledgement
The author would like to thank the research funding support provided by the Faculty of Engineering, Bangka Belitung University, Indonesia.