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Analysis of Agronomy and Environmental Impacts of Palm Oil Production: Evidence from Indonesia

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Indonesia relies heavily on palm oil production to meet the expanding demand for inexpensive vegetable oil. Approximately nine percent of the annual rise in palm oil production can be attributed to the rising demand for biofuels. However, the oil palm business has been connected to severe environmental issues, such as peatland mismanagement, biomass burning, and deforestation, which produce carbon dioxide (CO2) and contribute to climate change and global warming. Consequently, the present study aims to empirically examine the effects of palm oil production on environmental pollution, namely CO2 emissions in Indonesia from 1990 to 2020, while controlling for energy consumption, economic growth, and agricultural production. Applying the Quantile Autoregressive Distributed Lag Model (QARDL) for empirical evaluation, this study evaluates the influence of oil output at different quantiles. According to the study, long-term palm oil production has a considerable and favorable effect on CO2 emissions in the lower to middle quantiles (0.05th to 0.7th quantiles). In the short term, the impact of palm oil production is significant and positive across all quantile levels. The post-estimation Wald Test and Granger Causality Test at quantiles suggest that bidirectional causality exists between all of the study variables, confirming the consistency of the parameters. The findings advise the implementation of proper management of the oil palm crop by the Indonesian government. Green management policies and environmental standards are encouraged by the government of Indonesia to have sustainable growth and development of the oil palm sector.

Key words: Palm oil production; CO2 emission; Indonesia; QARDL.

1. INTRODUCTION

Palm oil is the world's most widely used edible oil, and Indonesia is one of its top producers. According to the United States Department of Agriculture, global palm oil production increased from 15 million tons (Mt) to 70 million tons (Mt) between 1995 and 2017, with Indonesia being the largest producer since 2007 and the United States coming in second (Xin et al., 2021). Palm oil positively affects Indonesia's economy, substantially contributing to economic growth and being a leading export commodity. In 2014, palm oil comprised 17% of Indonesia's agricultural Gross National Product (Purnomo et al., 2020). Palm oil's primary agricultural export from Indonesia has evolved into a critical sector for the nation. 2017 palm oil exports were valued at USD 23 billion (Purnomo et al., 2020).

Additionally, palm oil plantations contributed to the growth of rural villages. 50 percent of the palm oil plantations in Indonesia are owned by large corporations with mills, while local farmers own 40 percent. The government of Indonesia owns the remaining 10% of the plantations. According to research, palm oil farmers in rural areas are more successful than farmers of other commodities (Pratama, 2021). Seven point eight million hectares of oil palm were harvested in Indonesia in 2013 (Svatoňová et al., 2015). Figure 1 illustrates the trend of palm oil production in Indonesia during the past three decades.

Besides been criticized for invading villagers' resource rights, exacerbating conflicts with local people, as well as intensifying social inequalities and ecologic inequity (Abram et al., 2017; Inoue et al., 2013; Obidzinski et al., 2014; Sheil et al., 2009), the positive effects of palm oil production on employment and economic development are remarkable. Large-scale oil palm cultivation has increased the living standard and profits of palm oil companies in tropical regions. It is the most economically lucrative and productive oil crop due to its high yield, low costs, and ease of establishment. In 2017, Indonesia's oil palm sector employed 3,8 million people and produced 39 million metric tons of palm oil from 14 million hectares of palm farms (Xin et al., 2021). It is predicted that between 2000 and 2016, oil palm production and cultivation development moved about 2.6 million Indonesian households over the poverty line (Edwards, 2019).

In addition to Indonesia, the worldwide palm oil business is enormous, with annual sales reaching US$ 50 billion (Murphy, 2014). Kernel palm oil is used in detergents, cosmetics, plastics, and chemicals, whereas crude palm oil is generally used to make food and biofuels (Arshad et al., 2022; Evers et al., 2017; Panyasit et al., 2022; Rapankum et al., 2022). However, according to studies, palm oil production is a significant source of CO2 emissions in agricultural production (Khong, 2022; Manning et al., 2019; Nnamchi et al., 2022). The palm oil industry's carbon emissions consist of cultivation- and palm oil-processing-related emissions. The cultivation stage of oil palm contributes the most to global warming, which comprises farming (15%), clearing (17%), and replanting (18%).

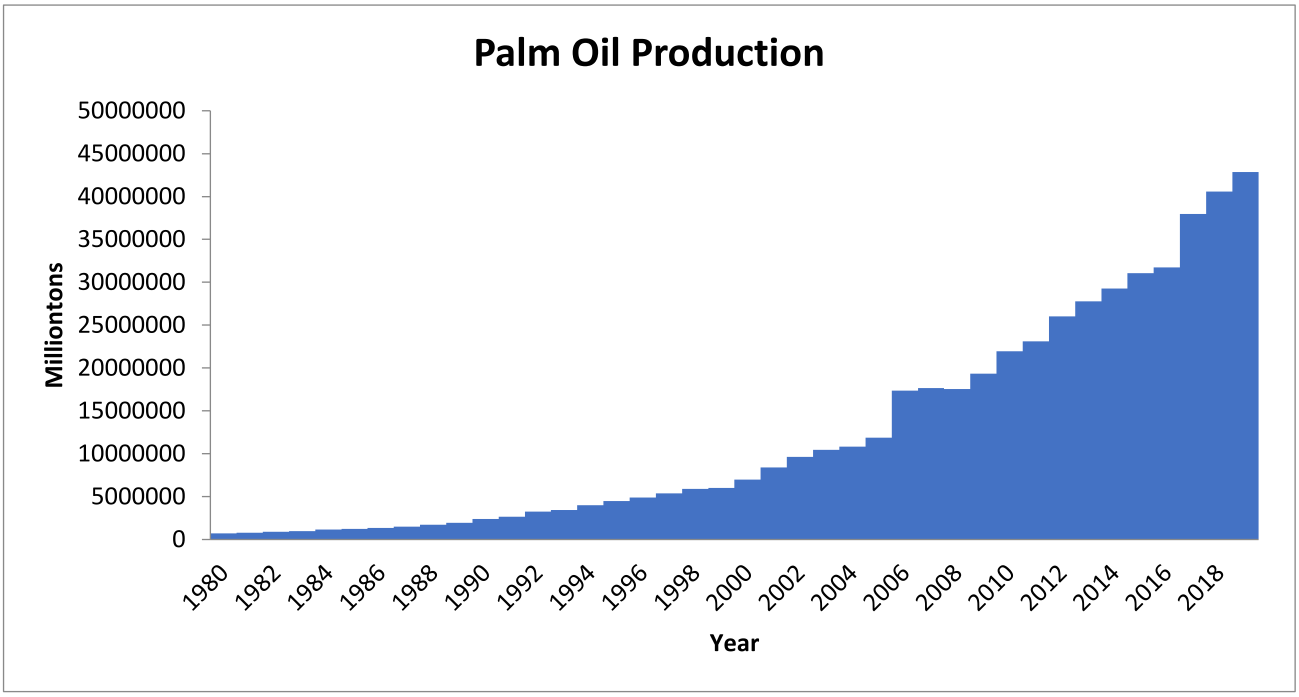

Figure 1. Palm oil production in Indonesia (1980-2019)

Land conversion, specifically for oil palm plantations, is primarily responsible for the increase in CO2 emissions attributable to this crop. In addition, three other inputs utilized in an oil palm plantation, mainly fertilizer, insecticides, and diesel fuel, are also responsible for world pollution. It contains 104.37 kilograms of urea, 109.73 kilograms of phosphate, and 97.92 kilograms of dolomite. The nitrogen content of urea helps plants produce more chlorophyll, a sort of green leaf material (Wahyono et al., 2020). Fertilizer consumption results in emissions that account for more than half of all plantation emissions (Kusin et al., 2015). The expansion of the oil palm business has also been connected to the destruction of forests and peatlands (Purnomo et al., 2020). Deforestation has negative repercussions, such as biodiversity loss and climate change. By emitting CO2 into the atmosphere, deforestation exacerbates the greenhouse impact. Palm oil plantations are the primary drivers of deforestation in Indonesia. The demand for palm oil has greatly increased the quantity of land required to produce it (Lestari et al., 2022; Maheswaranathan et al., 2022; Vijay et al., 2016). Increasing global demand for palm oil compels investors to clear more forests for more extensive plantations (Pratama, 2021). Even worse, it will take decades for nature to replace the carbon stocks lost due to peat forest conversion (Khalid et al., 2022). In Indonesia, oil palm expansion is widely blamed for peatland erosion and deforestation (Koh et al., 2011).

Similarly, palm oil production involves power, diesel, and water. The production of oil palm requires 95.81-kilowatt hours of energy. Diesel fuel drives a 4.9-liter generator and a 2.54-liter 10-ton truck (Siregar et al., 2015). 5.75 cubic meters of water are consumed by the boiler unit (Soraya et al., 2014). Emissions from palm oil extraction influence water and land. The water emissions amount to 3.83 m3 (Soraya et al., 2014), while press cake, shell, kernel, fiber, and ash are discharged into the land, resulting in soil pollution (Egberi, 2022; Le et al., 2022; Ogali, 2022; Wahyono et al., 2020).

Plans to expand oil palm plantations in Indonesia have raised environmental and political concerns. Some believe oil palm can aid in climate change mitigation, offer an alternative energy source, and contribute to rural life and economic development (Obidzinski et al., 2012). Others are concerned with unintended economic, social, and environmental consequences (Colchester, 2011; Fitzherbert et al., 2008; Marti, 2008; Sheil et al., 2009). (Obidzinski et al., 2012). Indonesia, one of the world's leading emitters, has set a target to reduce its emissions by 26 percent below current levels by 2020. However, expanding palm production cannot meet emission reduction goals because peatland destruction accounts for more than 75 percent of Indonesia's CO2-equivalent emissions (Petrenko et al., 2016). In 2017, the European Parliament passed a resolution mandating palm oil consumption restriction by 2021. Unfortunately, this ban is perceived as harmful for nations whose major source of GDP derives from palm oil. The export of palm products and oil is an essential source of revenue for nations such as Indonesia, which have achieved remarkable economic growth to date (Khalid et al., 2022).

Prior research on the relationship between palm oil production and environmental degradation emphasized the review of typical conditions in Indonesia and other countries (Agus et al., 2013; Castanheira et al., 2017; Choo et al., 2011; Lam et al., 2019; Shahputra et al., 2018), but did not consider empirical evaluation of the impact of palm oil production on environmental quality. Therefore, this study's primary purpose is to assess the effects of palm oil production on CO2 emissions in Indonesia over the period 1990-2020. This is the first empirical study to evaluate the consequences of the palm oil industry on CO2 emissions, a topic that requires immediate scholarly attention in light of the European Union parliament's prohibition on palm oil production.

In particular, the study makes a significant contribution to the literature by evaluating the impact of palm oil production on CO2 emissions in the context of Indonesia, one of the world's largest palm-cultivating and palm oil-producing nations, and the absence of any assessment of its high-income palm industry in an environmental context. In addition to its originality, the study's evaluation of the impact of oil production using the QARDL method is particularly noteworthy. QARDL has a significant advantage over linear ARDL estimation because it introduces possible asymmetries under different quantile ranges. Additionally, the QARDL methodology is believed to be better than other linear models in three ways. The first step is to investigate the location-based asymmetry within the conditional distribution. Second, it is advantageous to consider the long- and short-term connections between variables simultaneously. Thirdly, this model allows the cointegration coefficient to vary across quantiles in response to shocks. This method is also helpful in dealing with both short-term and long-term estimations (Sun et al., 2022).

Following this first portion of the introduction, the study is organized as follows: A concise literature overview is presented in Section 2. Variables, data, and approach are discussed in section 3. The fourth section contains empirical studies and associated debates. Section 5 concludes the investigation and makes policy suggestions.

2. LITERATURE REVIEW

Since agriculture has been identified as a source of pollution emissions, researchers have begun investigating the effects of agriculture on pollution emissions (Alam, 2015; Dey, 2022; Doğan, 2019; Gokmenoglu et al., 2018; Karimi Alavijeh et al., 2022; Phiri et al., 2021; Yurtkuran, 2021). However, researchers have not thoroughly examined the influence of agriculture-related products such as oil and palm oil production. Using Methods of Moment Quantile Regression, (Ike et al., 2020) examined the effect of oil production on CO2 emissions in fifteen oil-producing nations. According to the findings, CO2 emissions from oil production increased from the first to sixth quantiles. Using Driscoll-Kraay standard errors, (Mahmood et al., 2019) assessed the effects of oil prices, oil volatility, and economic growth on CO2 emission in EU countries, oil-producing countries, China, and the United States. The authors discovered that oil prices and price volatility considerably impact greenhouse gas emissions in all panels of countries, including China and the United States. Rajaeifar et al. (2014) evaluated the olive oil production life cycle regarding energy consumption and greenhouse gas emissions. The energy consumption and greenhouse gas emissions associated with olive oil production were discovered to be substantial. It was also found that olive oil production's energy use and fertilizer consumption increased GHG emissions. According to Rosa et al. (2017), oil extraction from sand oils necessitated considerable water and deforestation in Canada, resulting in environmental deterioration.

Taking into account research on oil palm agriculture and oil output, (Khalid et al., 2022) for Malaysia investigated the asymmetric and symmetric effects of palm oil production on carbon emissions from 1978 to 2018 using the NARDL method. The scientists found that an increase in palm oil production reduced carbon emissions, whereas a drop in palm oil production increased CO2 emissions. Khalid et al. (2021) In a separate investigation for Malaysia, linear and nonlinear estimation yielded the same results. Saswattecha et al. (2015) investigated the effects of palm oil production on the environment in Thailand and discovered that burning of fiber in boilers, fertilizer use in plantations, wastewater treatment, gasoline used in weed cutters, and glyphosate use for weed control were all the factors that led to environmental degradation in the studied region. (Shahputra et al., 2018) examined the Indonesian palm oil sector.

It was determined that oil palm farming was related to poverty alleviation and an increase in the gross regional product. Still, that palm oil production was also connected with increased carbon emissions. Uning et al. (2020) examined oil palm plantations in the Southeast Asian region focusing on CO2 emission. They discovered that oil palm cultivation activities such as deforestation and peat and biomass reduction produced more CO2 emissions than any other crop in the region. Munar et al. (2022) summarized the findings of studies that estimated the effects of palm oil production on greenhouse gas (GHG) emissions, with a focus on Colombia and concluded that various activities associated with palm cultivation were responsible for GHG emissions. Kusin et al. (2015) assessed the GHG emissions associated with the conversion of rubber plantations to palm plantations in Malaysia's Kempas Estate. The change of crops from rubber to palm boosted the state's total carbon output. Svatoňová et al. (2015) conducted a financial evaluation and sensitivity analysis of palm agriculture in North

Sumatra, a tiny Indonesian state, and discovered that palm cultivation was a successful venture in Indonesia. Assidiq et al. (2021) compared the conflicts of interest between Indonesia Sustainable Palm Oil and Roundtable on Sustainable Palm Oil as the laws aimed at governing peatland use for palm cultivations responsible for GHG emission and discovered that Indonesia Sustainable Palm Oil still permitted the production of palm on peatlands, which was in contrast to the goal of reducing GHG emission by 29% by 2030 in Indonesia.

2.1 Literature Gap

From the review of the literature present so far, we concluded that although the association between palm oil production and the environment is theoretically reviewed and discussed by the studies, the effect of palm oil production on the environment is not extensively empirically analyzed by the earlier studies and therefore this issue requires further investigation. Indonesia is one of the world's top producers and exporters of palm oil; therefore, empirical examination of the influence of oil palm cultivation on carbon emissions is lacking in the existing literature and should be explored. In addition, this study makes a novel contribution to the literature by analyzing the impact of palm oil production on carbon emission in Indonesia using the QARDL approach, as opposed to (Khalid et al., 2021, 2022), which enables researchers to test the relationship comprehensively across a wide range of quantiles. By filling these gaps, the present study represents an important contribution in palm oil-environmental quality nexus literature, notably in Indonesia.

2.2 Data and Methodology

The present study examines the influence of palm oil output on CO2 emission in Indonesia from 1980-2020. CO2 emission is the dependent variable for this purpose, while palm oil output is the primary explanatory variable. In addition, economic growth, energy consumption, and agriculture production are introduced as control variables to avoid model misspecification. Table 1 provides the precise measurements and data sources for the study variables.

The model of the study in its functional form is given as follows:

$$CO2 = f\,(POIL, GDP, EC, AGRI) \qquad (1)$$

While the model in its econometric form can be specified as :

$$CO2_t = \beta_0 + \beta_1 POIL_t + \beta_2 GDP_t + \beta_3 EC_t + \beta_4 AGRI_t + \varepsilon_t \qquad (2)$$

Table 1: Variables Description and Data Sources

Variables	Abbreviation	Measurement	Source
CO_2 emission	CO_2	Carbon dioxide emission (kiloton)	World Development Indicators
Palm oil production	POIL	Million tons	Our World in Data
Energy consumption	EC	Energy consumption equivalent of oil per capita	World Development Indicators
Economic Growth	GDP	Gross domestic product (constant US$ 2015)	World Development Indicators
Agriculture production	AGRI	Agriculture value added (% of GDP)	World Development Indicators

This study examines the cointegration of palm oil output, energy consumption, economic growth, and agricultural production using the recently developed QARDL estimation (Cho et al., 2015). This model's strength is its potential to analyze the quantile long-run equilibrium effect of palm oil production, energy consumption, economic growth, and agricultural production on CO2 emissions. We also check the time-varying integrations of the variables using the Wald test, which examines the consistency of the integrating coefficients over quantiles. The conventional ARDL approach for assessing cointegration between variables is as follows:

$$CO2_t = \mu + \sum_{i=1}^{p} \sigma_{CO2i} CO2_{t-1} + \sum_{i=0}^{q} \sigma_{POILi} POIL_{t-i} + \sum_{i=0}^{V} \sigma_{GDPi} GDP_{t-i} + \sum_{i=0}^{r} \sigma_{ECi} EC_{t-i} + \sum_{i=0}^{s} \sigma_{AGRIi} AGRI_{t-i} + \varepsilon_t \qquad (3)$$

Where $CO2_t - E\left[\frac{CO2_t}{w_{t-1}}\right]$ defines the error term ε_t , and w_{t-1} refers to the υ field comprised of $CO2_t$, $POIL_t$, GDP_t, EC_t, $AGRI_t$, $CO2_{t-1}$, GDP_{t-1}, EC_{t-1}, $AGRI_{t-1}$ and $POIL_{t-1}$.

The Schwarz Information Criterion (SIC) is used to figure out the optimal lag orders in the model, which are p,q, v,r, and s. In the preceding equation, 3, $CO2_t$, $POIL_t$, GDP_t, EC_t, and $AGRI_t$ represent the CO2 emission, palm oil production, economic growth, and agriculture production, respectively. Cho et al. (2015) modified and revised the model of the equation no 1 to create the basic version of the QARDL model shown below:

$$Q_{\Delta CO2t} = \mu(\tau) + \sum_{i=1}^{p} \sigma_{CO2i}(\tau)\, CO2_{t-i} + \sum_{i=0}^{q} \sigma_{POILLi}(\tau) POIL_{t-i} + \sum_{i=0}^{r} \sigma_{GDPi}(\tau)\, GDP_{t-i} + \sum_{i=0}^{s} \sigma_{ECi}(\tau) EC_{t-i} + \sum_{i=0}^{u} \sigma_{AGRIi}(\tau) AGRI_{t-i} + \varepsilon_t(\tau) \qquad (4)$$

We refer to quantiles as, $\varepsilon_t(\tau) = CO2_t - Q_{CO2t}\left(\frac{\tau}{\delta_{t-1}}\right)$ (Kim & White, 2003) and (0> τ < 1). This study reframes equation 4 to analyze QARDL as follows:

$$CO2_t = \alpha(\tau) + \sum_{i=1}^{q-1} \Delta POIL_{t-1} + \gamma_{POIL}(\tau) POIL_t + \sum_{i=1}^{r-1} \Delta GDP_{t-1} + \gamma_{GDP}(\tau) GDP_t + \sum_{i=1}^{s-1} \Delta EC_{t-1} + \gamma_{EC}(\tau) EC_t + \sum_{i=1}^{u-1} \Delta AGRI_{t-1} + \gamma_{AGRI}(\tau) AGRI_t + \varepsilon_t(\tau) \qquad (5)$$

The coefficients indicated in equation no 3 quantify the short-run dynamics. The long-run relationship between palm oil production, energy consumption, economic growth, and CO_2 emission by rewriting equation 5 as equation 6:

$$QCO2_t = \mu(\tau) + X_t'\beta(\tau) + M_t(\tau) \qquad (6)$$

With X = (POIL, GDP, EC, AGRI) and $\beta_{POIL}(\tau) = \gamma_{POIL}(\tau)\left[1 - \sum_{i=1}^{p} \theta G_i(\tau)\right]$ and $M_t(\tau) = \sum_{j=0}^{\bowtie} \theta POIL_j(\tau)\Delta POIL_{t-1} + \sum_{j=0}^{\bowtie} \theta POIL_j(\tau)\Delta\varepsilon_{t-1}$, with $\mu(\tau) = \alpha(\tau)\left[1 - \sum_{i=1}^{p} \emptyset_i\,(\tau)\right]$ and $\vartheta_j(\tau) = \sum_{i=j+1}^{\bowtie} \pi_1(\tau)$. we calculate all other explanatory variables in the same manner.

We prevent the correlation of error terms by QARDL generalization as follows:

$$Q_{\Delta CO2t} = \mu + \sigma CO2_{t-1} + \pi_{POIL}POIL_{t-1} + \pi_{GDP}GDP_{t-1} + \pi_{EC}EC_{t-1} + \pi_{AGRI}AGR_{t-1} +$$

$$+ \sum_{i=0}^{p} \sigma_{CO2i}\Delta CO2_{t-i} + \sum_{i=0}^{q} \sigma_{POILi}MPOIL_{t-i} + \sum_{i=0}^{r} \sigma_{GDPi}GDP_{t-i} + \sum_{i=0}^{s} \sigma_{ECi}EC_{t-i} \sum_{i=0}^{u} \sigma_{AGRIi}AGRI_{t-i} + \varepsilon_t(\tau) \qquad (7)$$

There is still the likelihood of a contemporary relationship between CO2 and POIL$_t$, GDP$_t$, EC$_t$, and AGRI$_t$. We can prevent past correlations by using CO2 projections on POILt, GDP$_t$, EC$_t$, and AGRI$_t$ of the form CO2 = POIL$_t$ + GDP$_t$, +EC$_t$, and AGRI$_t$. The prior projections are incorporated into equation 5, then generalized into a quantile regression model. Therefore, the QARDL error correction framework takes the following form:

$$Q_{\Delta CO2t} = \mu(\tau)\rho(\tau)(CO2_{t-1}\beta_{POIL}\,(\tau)POIL_{t-1} - (\tau)GDP_{t-1} + \sum_{i=1}^{p} \sigma_{CO2i}\,(\tau)\Delta CO2_{t-i} + \sum_{i=0}^{q} \sigma_{POILi}(\tau)\Delta POIL_{t-i} + \sum_{i=0}^{r} \sigma_{GDPi}(\tau)\Delta GDP_{t-i} + \sum_{i=0}^{s} \sigma_{EC}(\tau)\Delta EC_{t-i} + \sum_{i=0}^{u} \sigma_{AGRIi}(\tau)\Delta AGRI_{t-i} + \varepsilon_t\,(\tau) \qquad (8)$$

We calculate the cumulative effect of prior CO2 on present CO2 in the short run by $\sigma^* = \sum_{i=1}^{p} \sigma_{CO2i}$, we measured the short-run effects of the previous and current levels of POIL, GDP, EC, and AGRI by $\sigma_{POIL} = \sum_{i=1}^{q} \sigma_{POILi}$, $\sigma_{GDP} = \sum_{i=1}^{r} \sigma_{GDPi}$, $\sigma_{EC} \sum_{i=1}^{s} \sigma_{ECi}$, $\sigma_{AGRI} \sum_{i=1}^{u} \sigma_{AGRIi}$. after that, we calculate long-term integrating parameters of all variables as follows:

$$\beta_{POIL^*} = -\frac{\beta POIL}{\rho}, \beta_{GDP^*} = -\frac{\beta GDP}{\rho}, \beta_{GDP^*} = -\frac{\beta EC}{\rho}, \beta_{EC^*} = -\frac{\beta EC}{\rho}, \beta_{AGRI^*} = -\frac{\beta AGRI}{\rho},$$

Furthermore, the cumulative short-run variables and long-term co - integrating variables are calculated using the Delta technique. The error correction coefficient should be significantly negative. The Wald Test is used, which asymptotically reflects the Chi-Squared distribution, to statistically evaluate the long-run and short-run asymmetric and nonlinear impacts of palm oil prices on carbon emission. The Wald Test is used to investigate the alternative and null hypothesis for the following long-run and short-run parameters Ø*, β*, ω*, and ρ*.

$$H_0^{\emptyset} = F\emptyset_*\,(\tau) = f \; verses \; H_1^{\emptyset} : F\,\emptyset_*\,(\tau) \neq f$$
$$H_0^{\emptyset} = S\omega_*\,(\tau) = s \; verses \; H_1^{\emptyset} : S\,\omega_*\,(\tau) \neq s$$
$$H_0^{\emptyset} = S\beta_{i*}\,(\tau) = s \; verses \; H_1^{\emptyset} : S\,\beta_{i*}\,(\tau) \neq s$$
$$H_0^{\emptyset} = S\rho_{i*}\,(\tau) = s \; verses \; H_1^{\emptyset} : S\,\rho_{i*}\,(\tau) \neq s$$

Where f and F are pre-defined matrices *h**l and *h*ps*. S and S are *h*l* and *h*s*, representing a pre-specified matrix with "h" representing the limitations number (Cho et al., 2015) and I representing POIL, GDP, EC, and AGRI, respectively. We investigate non-linearities in the long-run integration parameter and speed of adjustment parameter using the Wald test. We perform 4 tests for every parameter and group.

2.3 Empirical Analysis and Discussions

To begin the empirical analysis, Table 2 provides descriptive statistics for the CO2, POIL, GDP, EC, and AGRI series. With the most significant mean and standard deviation, the variability of POIL is the greatest. In contrast, the GDP has the lowest mean and standard deviation and, hence, the lowest variability among all series. The Jarque-Bera test statistics reveal a considerable deviation of the data from the variables' normal distribution. This indicates that all variables have a sign of non-linearity between them; hence, the QARDL approach is applicable in this circumstance.

Table 2: Descriptive Statistics

Variables	Mean	Min	Max	Std. Dev.	J-B Stats
CO2	352137.2	148540	619840	127108	1.1456***
POIL	12428155	721172	42869845	12532500	6.5170***
GDP	5.00011	1.5811	1.0712	2.7811	4.1165***
EC	631.32	379.52	880.81	168.08	3.105***
AGRI	16.853	12.712	24.452	3.947	5.0767***

Note ***=P<0.05.

Before estimating the QARDL model, the integration order of the time series data is evaluated using a unit root test. The results of the standard ADF and Zivot and Andrews (2000) tests are reported in Table 3.

Table 3: ADF and ZA Results

Variables	ADF	ADF (delta)	ZA	Break Year	ZA (delta)	Break Year
CO2	-2.245	-3.125***	-1.313	1995 Q3	-5.028***	1989 Q1
POIL	-1.255	-2.163***	-1.981	1999 Q1	-3.032***	1995 Q4
GDP	-2.424	-3.497***	-1.219	2000 Q4	-5.099***	2002 Q1
EC	-1.355	-2.131***	-1.244	2004 Q3	-4.932***	2005 Q1
AGRI	-2.516	-3.422***	-2.664	2011 Q1	-3.204***	2018 Q4

The table provides the statistical values of the ZA and ADF test. And ***=P<0.05

According to the results of both unit root tests, the order of variable integration is 1. The variables further enhance the application appropriateness of the QARDL model. Table 4 displays the results of the QARDL estimation in the short run and the long run, employing parameters with quantile values ranging from lower to higher. Findings reveal that the projected adjustment speed coefficient is negative and statistically significant over the long term. More specifically, except for the 0.95th, the values of p are significant from 0.50 quantile through higher quantiles. This finding demonstrated the presence of long-term equilibrium reversal between the variables CO2, POIL, GDP, EC, and AGRI. In addition, Table 3 reveals that POIL has a substantial and favorable impact on CO2 emissions in the Indonesian economy over the study period. However, the effect of POIL on CO2 fluctuated and was determined to be positive between the quantiles of 0.05 and 0.70. Specifically, the estimated influence of POIL on CO2 is more significant for lower-order quantiles than for quantiles of medium order. Carbon emissions from the palm oil business fall into two categories: emissions from deforestation and emissions from palm oil processing. Deforestation reduces carbon reserves by reducing biomass.

Additionally, it releases carbon dioxide from disturbed soils. In addition, reducing carbon inputs from plants and modifying hydrologic cycles affects future carbon sequestration in the environment (Fargione et al., 2008). Palm oil extraction necessitates using fossil fuels for industrial processing, inorganic fertilizers, the transport of goods, and automated plantation equipment. During the processing of palm oil mill waste, large quantities of methane, a potent greenhouse gas, are produced. According to Chase et al. (2010), the second and third most significant sources of greenhouse gas emissions for palm oil production are methane emission from mill effluent and nitrous oxide from fertilizer, respectively. The results are consistent with (Petrenko et al., 2016) and (Chase et al., 2010) but in stark contrast to (Khalid et al., 2021), who discovered that an increase in palm oil production is connected with a decrease in CO2 emissions. Second, the QARDL long-run estimation results reveal that GDP exerts a significant and positive influence on CO2 across the entire range of quantiles, i.e., across all quantiles (0.05-0.95). The use of varied energy sources, including fossil fuels, is necessary for transporting and manufacturing a wide range of goods and services, which helps economic growth. In this regard, more economic growth includes increasing energy consumption, particularly from conventional and nonrenewable sources, exacerbating environmental issues. More economic expansion results in increased energy consumption, mainly from traditional and nonrenewable sources, exacerbating environmental issues. Table 4 demonstrates the relationship between EC and CO2 emissions across all quantile ranges. EC is significantly and negatively connected with carbon emissions in the Indonesian economy, except for the 0.95th order quantile, where a highly significant association is shown. The conclusion is supported by the fact that, like other developing nations, Indonesia is dependent on fossil energy consumption (Sasana et al., 2018), and the use of fossil energy is the primary cause of CO2 emissions in the country. In this regard, the findings of (Hwang et al., 2014; Sasana et al., 2018; Shahbaz et al., 2013), for Indonesia (Khan et al., 2019) for Pakistan, and (Gu et al., 2019) for China corroborate our conclusion that energy consumption has a significant impact on CO2 emission. And finally, the effect of AGRI on CO2 emission is also presented in Table 4 over the whole quantile range. Except for the 0.4 quantiles, the impact of AGRI on CO2 emissions is considerable and positive at all quantiles. This effect is a result of increased agricultural production raising demand for combustible energy sources, which results in the release of emissions into the atmosphere. Agriculture uses fossil fuels for processes such as water pumping, packing, and transporting agricultural products, which increases CO2 emissions. Additionally, certain agricultural operations, such as fermentation in ruminant animals and biomass fuel combustion, may explain how agricultural value addition influences CO2 emissions. Our conclusion is substantially supported by the research of (Karimi Alavijeh et al., 2022), (Eyuboglu et al., 2020), (Adedoyin et al., 2021), and (Yurtkuran, 2021).

In addition, the results of the short-term evaluation are presented in Table 4, and it is seen that the primary cause of present and lag CO2 values is lag CO2 values. Therefore, Indonesia's CO2 emissions contribute to recent changes in CO2 concentration. In addition, preceding and lagging POIL values apply enormous pressure on Indonesia to increase its presence and lagging CO2 levels. The results below the 0.60, 0.80, and 0.90 quantiles are statistically significant, and this effect is evident from the middle to the upper quantiles. In addition, it is known that preceding and lagging GDP numbers are a leading predictor of growing CO2 concentrations. Last but not least, it is observed that, similar to the long-term estimate, previous and lagging EC scores contribute to environmental pollution growth. Nonetheless, the variable AGRI produces insignificant results when projecting CO2 based on its historical and lagged values.

Following the execution of QARDL, the Wald test is used to assess all variables and their associated associations for asymmetries. Despite the absence of an accurate asymptotic probability, this test may disclose the uncertainty of all parameters, including intercepts, in the short and long runs. In addition, whether a structural break is known or not, this test can help identify it. The results are symmetrical, given that the dependent variable, CO2, is statistically significant. Table 5 displays the outcomes overall.

Table 4: CO2 Emission QARDL Estimations

Quintiles	**Constant**	**Error Correction Model**		**Long Run Findings**			**Short Run Findings**				
(τ)	**$\alpha_*(\tau)$**	**$\rho_*(\tau)$**	**$B_{POIL}(\tau)$**	**$B_{GDP}(\tau)$**	**$B_{EC}(\tau)$**	**$B_{AGRI}(\tau)$**	**$\varphi_1(\tau)$**	**$\omega_0(\tau)$**	**$\lambda_0(\tau)$**	**$\theta_0(\tau)$**	**$\acute{\varepsilon}_0(\tau)$**
0.05	0.035	-0.432***	0.032***	0.455***	0.331***	0.159***	0.143***	0.312**	0.138***	0.567***	0.049
	(0.055)	(-4.341)	(2.801)	(3.234)	(3.348)	(2.421)	(3.521)	(2.242)	(2.735)	(4.315)	(0.044)
0.1	0.056	-0.324***	0.440***	0.438***	0.223***	0.156***	0.215***	0.313**	0.349***	0.361**	0.456
	(0.044)	(-2.786)	(2.332)	(2.592)	(3.456)	(3.432)	(2.612)	(2.423)	(2.146)	(2.428)	(0.375)
0.2	0.033	-0.351***	0.408***	0.498***	0.367***	0.275***	0.124***	0.233**	0.435***	0.854***	0.222
	(0.036)	(-3.087)	(3.382)	(4.985)	(2.697)	(3.143)	(2.913)	(2.463)	(2.457)	(2.025)	(0.099)
0.3	0.014	-0.341***	0.361**	1.372***	0.234***	0.225***	0.340***	0.333**	0.284***	0.114***	0.560
	(0.017)	(-3.093)	(2.485)	(2.380)	(3.099)	(4.413)	(4.343)	(2.343)	(2.073)	(3.031)	(0.078)
0.4	0.040	-0.135***	0.313**	0.488*	0.137***	0.244	0.243***	0.153**	0.253***	0.442***	0.093
	(0.069)	(-2.426)	(2.451)	(3.362)	(4.454)	(0.049)	(3.349)	(3.435)	(3.452)	(3.424)	(1.356)
0.5	0.028	-0.284***	0.922**	0.276**	0.254**	0.354***	0.234***	0.149**	0.504***	0.431**	0.489
	(0.070)	(-2.433)	(4.094)	(2.992)	(2.432)	(3.546)	(3.285)	(2.628)	(3.345)	(2.445)	(0.035)
0.6	0.055	-0.138***	0.384**	0.654**	0.164***	0.143**	0.154***	0.253**	0.240***	0.435***	0.265
	(0.059)	(-3.263)	(3.299)	(3.433)	(2.313)	(2.033)	(2.343)	(2.294)	(3.448)	(2.340)	(0.301)
0.7	0.091	-0.273***	0.284**	0.532***	0.456***	0.233***	0.130***	0.459**	0.453***	0.363***	0.308
	(0.058)	(-3.453)	(3.345)	(3.987)	(2.259)	(2.545)	(3.424)	(4.926)	(3.432)	(2.345)	(0.028)
0.8	0.011	-0.545**	0.498	0.420***	0.141***	0.121***	0.167***	0.485***	0.254***	0.476***	0.821
	(0.003)	(-4.333)	(0.119)	(3.775)	(2.340)	(2.235)	(3.567)	(3.467)	(4.147)	(3.478)	(0.027)
0.9	0.039	-0.254**	0.124	0.245***	0.647***	0.341***	0.027***	0.354***	0.256***	0.244***	0.6784
	(0.005)	(-2.487)	(0.580)	(3.990)	(3.344)	(3.133)	(4.341)	(4.704)	(3.356)	(3.432)	(0.067)
0.95	0.029	-0.026	0.097	0.419***	0.0136	0.354***	0.347***	0.357***	0.343***	0.451***	0.656
	(0.007)	(-0.114)	(0.283)	(3.752)	(0.0987)	(3.349)	(2.341)	(2.494)	(2.415)	(2.453)	(1.049)

Author calculations

Table 5: Wald Test Results

Series	Wald-stat [Prob-Value]
P	5.345*** [0.000]
B_{POIL}	7.929*** [0.000]
B_{GDP}	8.512*** [0.000]
B_{EC}	3.777*** [0.000]
B_{AGRI}	9.112*** [0.000]
φ_1	2.022*** [0.004]
ω_0	8.416*** [0.000]
λ_0	13.400*** [0.000]
θ_0	1.987*** [0.000]
$ƿ_1$	14.321*** [0.000]
∂_0	9.128*** [0.000]

Table 5 presents the results of the Wald test in quantiles for the research series. It is discovered that the variables in every model have a bidirectional causal relationship for all quantiles from 0.05 to 0.95. It is noteworthy that the causality is constant across all quantiles.

Table 6: Quantile Granger Causality Test

Quantiles	**$\Delta CO2_t$ ↓ $\Delta POIL_t$**	**$\Delta POIL_t$ ↓ $\Delta CO2_t$**	**$\Delta CO2_t$ ↓ ΔGDP_t**	**ΔGDP_t ↓ $\Delta CO2_t$**	**$\Delta CO2_t$ ↓ ΔEC_t**	**ΔEC_t ↓ $\Delta CO2_t$**	**$\Delta CO2_t$ ↓ $\Delta AGRI_t$**	**$\Delta AGRI_t$ ↓ $\Delta CO2_t$**	**ΔANS_t ↓ ΔINF_t**
[0.05-0.95]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Authors Estimation

3. CONCLUSION AND POLICY IMPLICATIONS

Palm oil plantations negatively influence natural resources, climate change, and biodiversity. Every information readily available points to significant carbon losses, dangers to rare and endangered species, and water and air pollution (Dadi, 2021). Most indigenous Indonesians do not gain from palm oil extraction; they suffer immensely. In addition to the loss of people's rights to their ancestral lands and the destruction of the natural resources they rely on for survival, chemical pollution and fires pose significant health risks. Keeping these factors in mind, this study aims to evaluate the impact of agronomy and palm oil output on CO2 emissions in Indonesia over the 1990-2020 timeframe, adjusting for agricultural productivity, energy consumption, and economic growth. The QARDL approach of (Cho et al., 2015) is utilized since it is highly advantageous to determine if the range of quantiles for palm oil, economic growth, agriculture production, and energy consumption during the study period affects carbon emission. Utilizing the Granger-Causality test, this study also considers the quantiles causality. The QARDL estimation results confirmed that the error correction estimator value is statistically significant and has the expected quantile coefficient. It explains why long-term correlations between palm oil production, economic growth, energy consumption, agricultural production, and CO2 emissions in Indonesia are weakening. Long-term palm oil production, energy consumption, economic growth, and agriculture production all have a beneficial impact on CO2 emissions; however, the relative importance of each variable varies within quantile ranges. The short-term findings of the QARDL are comparable to those of the long-term, except for agricultural production, which has a negligible impact on CO2 emissions in the short term. According to the Granger causality test results and the Wald test, bidirectional causality exists between variables at all quantiles.

The results apply to policy recommendations. As the global demand for palm oil is likely to expand, it is crucial to address the industry's harmful effects on society and the environment. It suggests that a consistent and strategic direction must support decisions made in the palm oil business for government decisions. While steps can be taken to conserve some species, delaying or halting tropical deforestation in Indonesia is the most efficient strategy to prevent both reductions of biodiversity and loss of carbon. Many other green activities tied to palm oil production must be precisely calculated and reported. Suppose Indonesia wishes to continue the long-term expansion of the palm oil sector. In that case, it must increase the sustainability of production activities in light of the global shift toward more ecologically friendly and sustainable alternatives to oil palm products. Creating and sustaining environmental standards is vital for successfully managing the sustainable expansion of the palm oil sector. In determining the prospective impact of new development, third-party organizations must be consulted, and the environmental implications of novel development should be thoroughly examined.

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