Effect of Clean Biomass Energy Use on Carbon Dioxide Emissions in ASEAN Countries: An Empirical Investigation

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Abstract. There is growing effort by Association of South East Asian Nations (ASEAN) to increase renewable energy in their energy mix in order to reduce carbon dioxide emissions (CO_2) associated with fossil fuel energy consumption. Biomass energy is one of the renewable energy sources that has the potential to help mitigate carbon dioxide emissions in the ASEAN region considering its abundance and the current rise in its consumption. This study aims to empirically investigate whether the growing consumption of biomass energy contributes to lowering CO_2 emissions in the region. Therefore, this study investigates the impact of biomass energy use on CO_2 emission in ASEAN region over the 1990–2020 period. To achieve this objective, panel fully modified ordinary least squares (FMOLS) was employed and the estimated result revealed that biomass energy use marginally decreases CO_2 emission in the region. This finding implies that increasing and improving supply of clean biomass energy in the region's energy mix can help to mitigate CO_2 emission by significant portion. Consequently, several policy recommendations were suggested, which include advancing the use of technology to increase and improve biomass energy supply to various sectors of the region's economy to substitute significant portion of conventional fuel in productive activities.

1 Introduction

Over the past few decades, the World has witnessed dramatic increase in carbon dioxide (CO_2) emissions. More specifically, global CO_2 emissions rose to 36 mkt in 2013 from 19

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mkt in 1980, an increase of approximately 80 percent [1]. Since 1995, annual conferences have been held by the signatories to the United Nations Framework Convention on Climate Change (UNFCC) in response to the significant increase in emissions, in an effort to manage increasing global emissions and mitigate global warming. This necessitates significant reductions in CO_2 emissions, which can be achieved through significant effort and dedication by participating nations. These efforts led to the Kyoto Protocol which is the consequence of the UNFCCC, in which the participating nations reaffirmed their commitment to slash CO_2 and GHG emissions. Sixty countries ratified the Doha Protocol amendment in February 2016. The UNFCCC held in Paris in 2015 reaffirmed the participant countries' comitment to limit global warming to no more than 2^{o}C above pre-industrial levels.

Global economic growth has significantly increased energy consumption over the past several decades. The increased demand for and consumption of energy has resulted in severe enivironmental consequences which have prompted to need for examine and address the environemntal impact of rapid economic growth and energy consumption [2]. These environmental consequences are however as a result of the rapid use of non-renewables. However, sources of renewable energy such as hydropower, bioenergy, solar energy, geothermal, tide, and wind energy, — are the most effective strategy for addressing environmental issues [3]. Generally, the need to improve economic growth has led to significant increase in CO_2 emissions [4]. Unfortunately, these CO_2 emissions constitute a major portion in greenhouse gas (GHG) emissions and they pose a grave threat to the current state of the world and its future [5]. The growing demand for energy for production activities must be addressed in a way that promotes sustainable economic growth [6].

The most important question is thus how can countries reduce pollution? According to the [7], increasing the proportion of renewables in the energy supply mix is one method to reduce CO_2 emissions. Multiple researches demonstrated that as renewable energy consumption increases, carbon emissions would decrease [8]. More specifically, renewable energy has been proven to be sustainable form of energy for OECD countries [5, 9, 10], North African countries [11], European countries [12], 27 advanced countries [13].

Biomass is a relatively new energy source that will contribute to the global energy sustainability. According to [14], biomass is a source of solar energy that has been stored after being initially gathered by plants during the process of photosynthesis, which involves the collection and conversion of carbon dioxide into plant components, in the form of cellulose, lignin and hemicellulose. Solid wastes such as crop leftovers, forest and wood processing wastes, animal wastes, sewage wastes, human municipal solid trash, and waste from the food industry all make up biomass. This empirical study, which builds on previous research, evaluates the environmental impact of biomass consumption. It is estimated that biomass energy could account for up to 33% of the global energy by 2050. Five variables, according to [14], are responsible for the general tendency towards biomass energy: i) because biomass is easily generated, abundant and renewable, it is a great substitute for oil, lowering countries' reliance on oil importation; ii) it helps to reduce emissions; iii) biomass is easily convertible to electricity; iv) biomass generation is labour intensive; and v) biomass positively contributes to energy security.

Recognising the significance of biomass, we intend to examine the effect and dynamic relationships between its consumption and CO_2 emissions, considering the economic nature of the nations. Most previous studies focused on the impact of renewable energy on the emissions for single or a cross-section-panel of various countries, as opposed to biomass use specifically. In addition, this study selects a panel of countries that have demonstrated a balanced consumption of energy with biomass significantly contributing to the energy mix, as opposed to a generic group of nations. This is done to encourage non-biomass-using countries by demonstrating the reductions in greenhouse gas emissions already accomplished by biomass-using nations. This study assesses the influence of biomass

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consumption on CO_2 emissions in ASEAN nations over the 1990 to 2020 period. This kind of study has received less attention in the recent energy literature [4, 14 - 18]. In this investigation, we selected a panel of ASEAN nations whose energy consumption profiles include contributions from biomass.

As CO_2 emissions continue to rise, there is a massive demand for sustainable energy sources [19]. Although biomass energy is an important contributor to environmental sustainability [20], current findings in the literature regarding its effect on CO_2 emissions is inconclusive [4]. For instance, [5] discovered that biomass energy reduces CO_2 emissions, whereas [21] concluded that biomass energy generates CO_2 emissions similarly to fossil fuels. [22] asserted that biomass consumption promotes the rate of CO_2 emissions, whereas [23] suggested that biomass consumption reduces pollution. [20] noted that biomass energy can contribute to decreasing CO_2 emissions, and [24] investigated the relationship between biomass use and emissions in the BRICS nations. Sulaiman et al. [25] discovered that biomass derived from wood contributes significantly to the reduction of CO_2 emissions in the EU 27. Little has been written about the effect of biomass energy on CO_2 emissions and the results are mix.

However, due to the swiftly evolving production process as a result of technological advancement and fluctuating global economy, Shahbaz et al. [22] argues, that the biomss energy – environmental pollution literature is still insufficient. The emphasis on sustainable development and environmentally energy resources has recently reignited the conversation. According to [26], this body of research has evolved towards a more in-depth examination of the relationship by classifying energy into its various forms. This involves recognising the dissimilar character of the energy types and their impact on the economy, as well as the distinct policy approaches that must be taken.

The connection between renewable energy and environmental contamination dates to [27]. The investigation deduced that the utilisation of renewables would not hinder economic growth. Byrne et al. [28] examined the energy supply composition and policy decisions in China and concluded that the adoption of solar energy can impact economic growth positively. This study relies predominantly on the Environmental Kuznets Curve (EKC) model in order to investigate the impact of biomass energy consumption on CO_2 emissions. This model assumes that, up to a certain point, the level of carbon emissions increases as the level of real income (GDP) increases; after this point, the level of carbon emissions decreases with real income [29-30]. In addition, trade openness and urbanisation were used as control variables in this study to investigate the effect of biomass energy consumption on environmental pollution. Given the multicollinearity issue observed with the quadratic EKC model, the linearized EKC model was chosen for this investigation.

The structure of the paper is as follows: Section 2 describes the study's methodology and data, while Section 3 presents the empirical findings. The final section concludes by discussing the possible policy recommendations of the findings.

2 Material and Methods

2.1 Empirical model and data

The study extends the traditional EKC model by including energy consumption into the quadratic function where CO_2 emissions is the dependent variable, while income and its squared value are independent variables [20], [30]. The logarithmic form of the EKC model is presented as:

$$\ln \frac{CO2}{P}_{it} = \pi_i + \gamma_t + ln\varphi \frac{GDP}{P}_{it} + ln\varphi \frac{GDP^2}{P}_{it} \tag{1}$$

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where $\frac{CO2}{P}$ is emissions per capita, and $\frac{GDP}{P}$ represents income per capita. The terms π_i and γ_t are the country (i)specific and time (t) effects.

Empirically, we use a model that segregate energy consumption into fossil fuels and biomass energy consumption, therefore we modify the EKC model by introducing energy consumption, urbanisation, and trade openness as control variables. The augmented EKC model is expressed as:

$$\ln \frac{CO2}{P}_{it} = \pi_i + \gamma_t + \varphi_1 ln\frac{GDP}{P}_{it} + \varphi_2 ln\frac{GDP^2}{P}_{it} + \varphi_3 lnFEC_{it} + \varphi_4 lnBEC_{it} + \varphi_5 lnT_{it} + \varphi_6 lnURB_{it} + \varepsilon \quad (2)$$

where FEC is fossil fuel consumption, BEC represents biomass energy consumption, T denotes trade openness, URB is urbanisation and ε is white noise error term; φ_1, φ_2, φ_3, φ_4, φ_5, and φ_6 are the coefficients of $\frac{GDP}{P}$, $\frac{GDP^2}{P}$, fossil fuels and biomass energy consumption, urbanization and trade openness. The EKC hypothesis postulates that φ_1 should be positive ($\varphi_1 > 0$) and significant, while φ_2 must be negative ($\varphi_2 < 0$) and significant. In addition, we expect φ_3 to be positive while φ_4, is expected to be negative. However, there are mixed findings regarding the impacts of trade openness and urbanisation on emission.

The major set back of the EKC model is that it suffers from extreme multicollinearity due to GDP and its squared component. Therefore, the squared term is omitted following Bah et al. (2020).

$$\ln \frac{CO2}{P}_{it} = \pi_i + \gamma_t + \varphi_1 ln\frac{GDP}{P}_{it} + \varphi_2 lnFEC_{it} + \varphi_3 lnBEC_{it} + \varphi_4 lnT_{it} + \varphi_5 lnURB_{it} + \varepsilon \quad (3)$$

The data on all the variables for ASEAN countries including Philippines, Cambodia, Singapore, Malaysia, Thailand, Indonesia, Laos, Vietnam, Myanmar, and Brunei are obtained from the World Development Indicators (WDI) for the 1990 to 2020 period. Fossil fuel is included in the model because it is an important fract ion of total energy consumption, and it dominates the energy mix in ASEAN countries.

3 Estimation Technique and Results

The general strategy to our inquiry includes first checking for potential dependency between countries via multiple routes such as technology, trade, among others [31], then for the existence of cointegration [32 – 34], and finally, long-and short-run parameters are estimated. To accomplish this, this study employs Pesaran's CD-test [31] to determine whether cross-sectional dependence exists within each data panel. As presented in Table 1, the test indicates that the null hypothesis of no cross-sectional independence should be rejected. This result suggests that we should consider the variables used in the sample to be cross-sectionally dependent.

Table 1. Results from cross-sectional independence test.

	CO_2	GDP	FEC	BIO	TO	URB
CD-test	25.33***	66.31***	31.82***	43.52***	64.33***	53.78***
p-value	0.00	0.00	0.00	0.00	0.00	0.00

Note: ***denotes the statistical significance at 1% level.

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3.1 Panel cointegration tests

This study applies Pedroni [32, 34] cointegration test, which is applicable to heterogeneous panels. It is typically used to examine the long-run relationships among carbon emissions, real income, and energy consumption. In as much as it implies cross-sectional independence, the Pedroni panel cointegration test has limitations. Although it takes the panel's diversity into account. Therefore, we employ the LM bootstrap panel cointegration test created by [35], which is robust to cross-sectional dependence. Table 2 displays the results of the LM bootstrap panel cointegration test, which indicate that there is insufficient evidence to reject the null hypothesis of cointegration at the 1% level. These findings bolster those of [18] for the United States, [16] for Latin American countries, [36] for a panel of European countries, [37] for a group of transition economies, and [20] for a panel of biomass-consuming countries.

Table 2. Results of the LM bootstrap panel cointegration test.

Test	Model 1		Model 2	
	Statistic	Bootstrap p-value	Statistic	Bootstrap p-value
LM Bootstrap	2.18	1.00	2.89	1.00

Note: The bootstrap test statistics are computed by using 5000 replications, with a null hypothesis of the existence of cointegration in the panel, while the alternative hypothesis states that there is no cointegration at least for one cross-sectional unit.

3.2 Panel long run estimator

According to Pedroni [32], if heterogeneity exists, the estimators of group-mean can produce consistent estimates. The group-mean of FMOLS [32, 33] is used to get consistent reliable results. In addition, this study further applied the PDOLS following [38]. Generally, the estimation of vectors of cointegration using FMOLS and DOLS is consistent and efficient. Furthermore, These estimators can also handle the problem of endogeneity in the explanatory variables and vividly depict the characteristic of the time series, taking into account the series' co-integration and integration order. Table 3 displays the cointegration results between the variables. At the 1% significance level, the finding verifies the presence of a long-run link between the variables. The FMOLS and DOLS coefficients are presented in Table 3 as components of the cointegrating vectors for the non-uniform cointegrated cross-sections of the panels proposed by [33]. These two estimators of cointegrating vectors are dependable, consistent, and efficient. Other than that, estimators preserve the consistency of the long-term paths. In addition, they evaluate endogeneity issues in regressors as well as the nature of the data, level of variable integration, and cointegration.

The estimation is separated into two models. Model 1 examined the impacts of real income, fossil fuels, and biomass energy consumption on carbon emissions (the base model), while Model 2 presents the results of the base model, including trade openness and urbanisation as control variables. The results in both Model 1 and Model 2 show that income significantly increases the rate of carbon emissions. The finding is consistent across the two estimators (FMOLS and DOLS). This implies that income is a significant determinant of environmental pollution in ASEAN countries. The results also lend support to previous studies such as [6] for sub-Saharan Africa and [24] for BRICS countries.

The impact of biomass energy is negative, which implies that the higher the biomass use in the ASEAN region, the lower would be the level of CO_2 emissions. Although the magnitude of the impact of biomass energy consumption is relatively small as compared to the impact of fossil fuels, this is mainly because fossil fuels dominate energy consumption in the region. This finding further buttresses the prospects and commitment of the ASEAN countries to reduce overall emissions through the development and encouragement of biomass energy consumption. Therefore, the increase in biomass consumption is essential for the reduction of carbon emissions in the region [20, 24, 25]. On the other hand, fossil fuel enters the model with positive and significant coefficient. This finding is in tandem with several studies, including [25, 39 – 41]. Specifically, the results show that a 1% increase in fossil fuel consumption would increase carbon emissions by 0.834%. This implies that the continuous consumption of fossil fuels in the ASEAN region would further aggravate environmental pollution in the region.

Model 2 was estimated mainly to ascertain that the impact of energy consumption on environmental outcomes does not change significantly with other specifications; hence, we employed urbanisation and trade openness as control variables. The results suggest that real income and fossil fuels significantly increase carbon emissions, while biomass consumption appears to consistently reduce emissions. In other words, Model 2 indicates that the main findings are consistent and robust, given that the effect of energy use and income on the environment remained unchanged across different specifications.

Table 3: The results of group-mean FMOLS and DOLS.

	Model 1		Model 2	
Regressors	FMOLS	DOLS	FMOLS	DOLS
Fossil Fuels	0.834*** (3.913)	0.768***(2.65)	1.109** (2.01)	0.881*** (2.98)
Biomass	-0.082* (1.70)	-0.068** (1.93)	-0.116** (1.88)	-0.104*** (2.56)
Income	2.632** (1.79)	0.692** (1.92)	0.985* (1.66)	0.735** (1.81)
Urbanization	-	-	0.041* (1.65)	0.01 (1.34)
Trade Openness			0.120**(1.79)	0.303*** (6.02)

Note: ***, **, * denote the statistical significance at 1%, 5% and 10% levels, respectively.

In this study, both DOLS AND FMOLS were applied, since both methods are efficient given the nature of our data. In addition, the FMOLS can serve as a robustness check to the DOLS. The coefficients derived from FMOLS have the same indications as those obtained from DOLS. This demonstrates that DOLS results are resilient and thus suitable for inference. Generally, we can conclude that the estimates of panel DOLS are robust.

4 Conclusion and policy recommendations

Without a doubt, energy is a crucial factor in modern production, but its production and consumption have detrimental effects on the environment and contribute to climate change. In light of the environmental commitments countries have made, it is more important than ever to investigate environmentally friendlier alternatives to the conventional energy sources.

This paper estimates the effect of biomass energy use on emission levels in ASEAN countries over the 1990 – 2020 period. To date, majority of the studies have examined the significance of renewable energies. Here is a panel of countries that have recently pledged to reduce environmental pollution through energy source diversification. The theoretical framework is based on the EKC hypothesis; however, the study employed a linearized form of EKC due to the regression issues associated with the quadratic form. In addition, the dataset was examined for the possibility of cross-sectional dependence in an effort to avoid producing erroneous results.

Internationally, energy and environmental policymakers try to implement interventions that will reverse the trend of rising CO2 emissions. Considering the global pressures on economic growth, however, various stakeholders seek the most efficient solutions, such as minimising costs while maximising social benefits. This study's findings support the widely held belief that investing in biomass is a viable strategy for energy policymakers seeking to reduce emissions over the long term.

The expansion and development of agricultural production systems is intrinsically linked to biomass production, which is associated with an increase in rural communities' living standards. Policymakers should also focus their R&D efforts on developing more efficient agricultural production systems to help realise the immense potential of energy crops.

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