



# Does wood biomass energy use reduce CO<sub>2</sub> emissions in European Union member countries? Evidence from 27 members

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## ABSTRACT

This study investigates the effect of wood biomass energy consumption on CO<sub>2</sub> emissions in 27 European Union (EU) member countries for the 1990–2017 period. Applying panel dynamic ordinary least squares (DOLS), the results revealed that CO<sub>2</sub> emissions decline with an increase in wood biomass energy consumption. While fossil fuel, GDP per capita and trade openness are found to be increasing CO<sub>2</sub> emissions. The finding implies that CO<sub>2</sub> emissions in EU member countries can be effectively reduced by increasing the amount wood biomass energy consumption in production processes. This will eventually contribute to tackling global warming. The estimated results are considered robust as they were validated by panel FMOLS and pooled OLS. The study recommends for EU member countries to increase the share of wood biomass energy in their energy mix to reduce CO<sub>2</sub> emissions. Policy makers in these countries should also invest more in wood biomass energy production to increase its supply and accessibility. The authorities of these countries can equally emphasize on efficiency and sustainability of wood biomass energy to achieve energy security and reduce dependency on fossil fuel.

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## 1. Introduction

As the world strives to ensure energy security and at the same time curb CO<sub>2</sub> emissions, the use of wood for energy production grows in importance. IEA (2008) reported that under the current policies, the supply of energy from renewable sources remains stable at 11% and projected that it will increase to 14% based on certain policies under deliberations. The global wood energy production raised by 41% during the 1961–2006 period, while industrial round wood production raised by 63% (FAO, 2008). Currently, wood serves as the major source of renewable energy in Europe by contributing more than 50% to the total renewable energy consumed (Nilsson, 2005). The global increase in price of fossil fuels, commitment to decrease CO<sub>2</sub> emissions and determination to achieve energy security have made the demand for wood to increase in the energy sector (Brack, 2017).

The major reason for increased wood energy demand is the need to reduce the high dependence on fossil fuels and to control greenhouse gas emissions with the aim of mitigating climate

change. For instance, the European Union policy for renewable energy sources demands that 20% of the energy consumption in European Union by 2020 should come from renewable energy sources (Lauri et al., 2012). Driven by the desire to achieve this target, the European Union (EU) members have begun to diversify their sources of energy and one feasible and important renewable source is wood, as wood based fuels are renewable and considered carbon neutral (Lauri et al., 2012). In other words, woody biomass stores carbon as it grows and releases it when it is burnt; as such the net change in carbon gases in the atmosphere is unchanged (Forestry commission of UK, 2015). Therefore, it only recycles carbon in the atmosphere but does not add new. Equally, the annex 1 party of Kyoto protocol, which all the EU member countries belong to, has a target to achieve in terms of curbing CO<sub>2</sub> emissions. The EU annex 1 party members target to curb CO<sub>2</sub> emissions using different alternative energy sources and strategies. One of these sources of renewable energy recognized by EU is wood biomass energy. Woods et al. (2015) maintains that biomass is one of the renewable energy options that can displace and equally mitigate greenhouse gas emissions on a large scale. Faaij (2018) added that biomass is so important due to its versatility in many mitigation scenarios and represents 60% of the Europe's renewable energy mix. The increase in the demand for wood biomass energy which is

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brought about by political will and market forces would definitely change the wood flow pattern due to the price changes among the various applications (Brack, 2017). Technically, a rise in the demand for wood energy shifts its demand curve to the right.

The EU's renewable resources strategy aims at reducing CO<sub>2</sub> emissions and achieving energy self-sufficiency through decreasing fossil fuel consumption (Cioca et al., 2015). To achieve this, wood based energy plays a very important role by serving as reliable alternative source of energy that is easily renewable (Owusu and Asumadu-Sarkodie, 2016).

There is limited literature on the link between wood biomass and CO<sub>2</sub> emissions. As such related literature on renewable energy and CO<sub>2</sub> emissions or economic growth are reviewed here. On the link between renewable energy and CO<sub>2</sub> emissions, a few literature are available. Khanna et al. (2011) revealed that biofuels consumption can potentially lower CO<sub>2</sub> emissions in Illinois. Employing United States data, Bilgili (2012) indicated that while fossil fuel consumption has a positive effect on greenhouse gas (GHG) emissions, biomass energy consumption has been revealed to have a negative effect on GHG. Also, Acaroğlu and Aydoğan (2012), using data of Turkey, found that GHG can be significantly lessened by increase in biofuels consumption. Ahmed et al. (2016), after controlling for technological innovation in 24 European countries, established that aggregate biomass consumption is insignificant in reducing CO<sub>2</sub> emissions in the selected countries. The study further revealed the existence of environmental Kuznets curve only in the long-run. Destek and Okumus (2019) revealed that an increase in biomass energy in the total energy consumption in G-20 countries would lead to an increase in economic growth and decrease in CO<sub>2</sub> emissions. Whereas, Shahbaz et al. (2019) reported that biomass energy consumption has positive relationship with CO<sub>2</sub> emissions in G-7 countries.

On the other hand, literature on the nexus between renewable energy and economic growth were reviewed. Payne (2011) revealed a unidirectional causality running from biomass energy consumption to economic growth, after applying Toda-Yamamoto procedure. Hence, the finding supports growth hypothesis, which imply that biomass energy consumption promotes economic growth. Bildirici (2013), using autoregressive distributed lag (ARDL) model, indicated that biomass energy consumption facilitates economic growth in 10 developing and emerging economies. Other similar studies with findings of unidirectional causality between biomass and economic growth include Apergis and Payne (2011) for emerging countries and Menyah and Rufael (2010) for USA. After applying dynamic panel framework of dynamic ordinary least squares (DOLS) in a sample of 51 African countries, Ozturk and Bilgili (2015) discovered that biomass energy consumption can significantly increase economic growth. Bilgili and Ozturk (2015) also found that economic growth can be significantly facilitated by biomass energy consumption in G7 countries. Apergis and Payne (2010a) employed a sample of 20 OECD countries to investigate relationship between renewable energy consumption and economic growth and reported a bidirectional causality between the two. A similar bidirectional causality finding is reported in Apergis and Payne (2010b) for Eurasia, Apergis and Payne (2011) for central American countries, Apergis et al. (2010) for developed and developing countries, Tugcu et al. (2012) for G7 countries, and Sadorsky (2009) for emerging countries. The neutrality hypothesis has also been upheld by some studies on the link between renewable energy consumption and economic growth. These studies include Menegaki (2011) for Europe and Payne (2009) for USA.

Ntanos et al. (2018) investigated the relationship between renewable energy sources and economic growth in 25 European countries. The results indicated that there is higher correlation

between renewable energy and economic growth in EU countries with higher GDP than those with lower GDP. The promotion of economic growth by renewable energy is also reported in Europe and Greece (see, Ntanos et al., 2015a). The relationship between energy consumption and CO<sub>2</sub> emissions was also examined at the global level by Ntanos et al. (2015b). Using one-way ANOVA test, the study revealed that there is relationship between GDP and energy consumption, and between GDP and carbon emissions from electricity and transport sectors. Maji et al. (2019) found that renewable energy, especially biomass slows down economic growth in West African countries as most of the biomass energy used in the sub-region is traditional and polluting.

It can be seen from the foregoing review that there are few studies that specifically investigated the impact of biomass on CO<sub>2</sub> emissions and these few studies only concentrated on the aggregate biomass. This study contributes to the literature by specifically investigating the impact of wood biomass (a component of biomass) on CO<sub>2</sub> emissions in 27 selected EU member countries.

## 2. Methodology and data

The modelling framework for this study follows the existing literature, specifically the work of Bilgili (2012), in which CO<sub>2</sub> emissions are modelled as a function of fossil fuel and biomass energy consumption. In order to avoid omitted variable bias and model specification error, this study has added GDP per capita and trade openness as control variables. The addition of these two control variables can also be supported by the work of Kais and Sami (2016). Hence, the study estimates the following model:

$$\ln CO_{2it} = \omega_0 + \omega_1 \ln F_{it} + \omega_2 \ln WB_{it} + \omega_3 \ln Y_{it} + \omega_4 \ln T_{it} + \varepsilon_{it} \quad (1)$$

where  $CO_{2it}$  is the CO<sub>2</sub> emission for country  $i$  across time  $t$ .  $F_{it}$  is the fossil fuel energy consumption for country  $i$  across time  $t$ .  $WB_{it}$  is the wood biomass energy consumption for country  $i$  across time  $t$ .  $Y_{it}$  is the GDP per capita for country  $i$  across time  $t$ .  $T_{it}$  is trade openness for country  $i$  across time  $t$ .  $\varepsilon_{it}$  is the error term for country  $i$  across time  $t$ .  $\ln$  represents the natural logarithm.  $\omega_0 - \omega_4$  are the parameters in the model. The expected sign of the parameters are:  $\omega_1 > 0$ ,  $\omega_2 < 0$ ,  $\omega_3 > 0$ , and  $\omega_4 > 0$ .

CO<sub>2</sub> emission is measured by CO<sub>2</sub> emissions in metric tons per capita. Fossil fuel energy consumption is proxied by fossil fuel energy consumption (% of total). Wood biomass energy consumption is measured by extraction (used) of biomass from forestry. GDP per capita is measured by GDP per capita (constant 2010 US\$). Trade openness is measured by the total of import and export as a percentage of GDP. All the data on these variables were sourced from world development indicators (WDI) of World Bank, except for wood biomass data that were collected from materials flow database (<http://www.materialflows.net>). The data cover 1990 to 2017 period. The sample consist of 27 EU member countries- Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom. There are actually 28 EU member countries. But due to data unavailability on Malta, which is the suppose 28th member, the authors had to limit their sample to 27 members by excluding Malta.

### 2.1. Estimation procedure

The methodological framework for this study begins with the estimation of unit root test to identify the order of integration of the variables and then panel cointegration to test for long-run

relationship among them. Since heterogeneity (as a result of differences in economic conditions among countries) may arise in our sample, conducting these two tests is paramount.

There are numerous unit root tests suggested in the literature for identifying the order of integration of the variables. These include Maddala and Wu (1999), Breitung (2001), Hadri (2000), Levin et al. (2002), Im et al. (2003), and Pesaran (2007). This paper focuses on unit root tests proposed by Levin et al. (2002) and Im et al. (2003) to check the unit root properties of each variable in the series. These two unit root tests have been chosen due to their estimation power and also to be consistent with most existing literature. To carry out these tests, the following model is considered:

$$\Delta x_{it} = \phi_i + \alpha_i x_{i,t-1} + \delta_i t + \sum_{j=1}^k \gamma_{ij} \Delta x_{i,t-j} + \mu_{it} \quad (2)$$

$$H_0 : \alpha_1 = \alpha_2 = \dots = \alpha_N = 0 \quad (3)$$

Where  $x_{it}$  is the dependent variable;  $\phi_i$ ,  $\alpha_i$ ,  $\delta_i$  and  $\gamma_{ij}$  are parameters in the model;  $\Delta$  represents first difference operator;  $\mu_{it}$  is the error term with zero mean and constant variance (i.e., white noise);  $i$  and  $t$  represent country and time period, respectively. Under the null hypothesis in Equation (3), all  $x_{it}$  series have unit root. The rejection of this hypothesis confirms the stationarity of the series.

After identifying the order of integration of the variables, the next step is to examine the long-run relationship among the variables. A number of cointegration tests are common in the literature. These tests include: Kao (1999), Kao and Chiang (2001), Pedroni (1999), Pedroni (2004), Stock (1993), and Westerlund (2007) cointegration tests. This study chooses the most commonly used test for panel cointegration in the literature, i.e., Pedroni panel cointegration test proposed by Pedroni (2004). This test comprises seven test statistics, which are residual based. The following equation is specified:

$$y_{it} = \beta_i + \Omega_i t + \sum_{j=1}^k \pi_{ji} x_{ji,t} + \vartheta_{it} \quad (4)$$

Where  $t$  and  $i$  are time series and cross-sectional dimension, respectively.  $\beta_i$  and  $\Omega_i$  are individual intercept and trend, respectively, which vary across each cross-section.  $y_{it}$  and  $x_{ji,t}$  are required to be  $I(1)$ ,  $\vartheta_{it}$  denotes the residuals of the model.

The seven test statistics of Pedroni cointegration can be grouped into two: within and between dimension. Under the within dimension, there are four statistics, namely: panel  $v$ -statistic, panel  $\rho$ -statistic, panel PP-statistic and panel ADF statistic. Whereas, under between dimension, there are three statistics, which include: group  $\rho$ -statistic, group PP-statistic and group ADF-statistic.

The null hypothesis of all the seven statistics,  $H_0 : \lambda_i = 1$ , suggests nonexistence of cointegration for all  $i$ . Whereas the alternative hypothesis,  $H_a : \lambda_i < 1$ , suggests existence of cointegration for all  $i$ . The rejection of the null hypothesis confirms the existence cointegration among the series. Where  $\lambda_i$  is the autoregressive term of the residuals in Equation (4), which is explicitly defined in Equation (5). Finally, it is worthy to note that Kao (1999)'s panel cointegration test result will be reported as robustness check.

$$\vartheta_{it} = \lambda_i \vartheta_{it-1} + \sigma_{it} \quad (5)$$

After confirming long-run relationship among series, the next step is to estimate the long-run model using dynamic ordinary least squares (DOLS) method. There are a number of long-run estimation methods such as ordinary least squares (OLS), dynamic ordinary

least squares (DOLS) and fully modified ordinary least squares (FMOLS) estimators. Pedroni (2001) suggested that OLS is associated with second order asymptotic bias and serial correlation problem. To overcome these problems, DOLS was developed by Stock and Watson (1993) and FMOLS was advanced by Phillips and Moon (1999). Both panel DOLS and FMOLS have the power to address the problem of small sample bias attributed to OLS estimator. In this paper, we apply panel DOLS owing to its estimation power in correcting simultaneity bias and serial correlation challenges. Nevertheless, FMOLS and pooled OLS results will be reported as robustness check.

Panel DOLS as advanced by Stock and Watson (1993), has the power to correct potential simultaneity bias among the regressors. The approach is similar to the one in preceding methodology by Phillips and Hansen (1990). The method regresses  $I(1)$  variable on other  $I(1)$  and  $I(0)$  variables through taking leads and lags. The reason for including leads and lags in the estimation of the method is to remove small sample bias and simultaneity bias among the regressors. The representation of a DOLS in system is as:

$$\Delta Z_t^1 = \chi_t^1 \quad (6)$$

$$Z_t^2 = \psi_0 + \psi Z_t^1 + \theta_t^i \quad (7)$$

Where  $Z_t' = [Z_t^1' / Z_t^2']$  with  $(p-r)$  and  $(r \times 1)$  as the respective dimensions for  $Z_t^1$  and  $Z_t^2$ . To obtain the equivalent of the maximum likelihood estimator (MLE), the normalised cointegrating vector ( $\psi$ ) is estimated using OLS by including leads and lags of  $\Delta Z_t^1$ . To represents our model in panel DOLS form, we specify the following:

$$\ln CO_{2it} = \eta_i + X_{it}' \rho + \sum_{j=-k}^k \varphi_{im} \Delta X_{it+k} + v_{it} \quad (8)$$

If both  $\ln CO_{2it}$  and  $X_{it}$  are  $I(1)$  and cointegrated, the methodologies by Kao and Chiang (2001) and Pedroni (2001b) are good estimators of the long-run parameters of DOLS.

### 3. Results and discussion

The estimation process begins with preliminary tests. Table A1 (in appendix) presents the summary statistics, which show that the variables have normal distribution. The correlation test results are presented in Table A2 (in appendix). The results indicate no high correlation among the explanatory variables, which show absence of multicollinearity problem. As such the variables can be estimated within the same model without encountering multicollinearity.

Unit root tests were conducted and reported in Table A3 (in appendix). The results from Levin, Lin and Chu (LLC) and Im, Pesaran and Shin (IPS) tests reveal that all the variables can be regarded as  $I(1)$ , as all of them became stationary after taking first difference. Therefore, dynamic panel method such as DOLS is suitable.

Having identified the order of integration of the variables, the study then tested the existence of long-run relationship among the variables. The long-run test was carried out using Pedroni residual cointegration test and validated using Kao residual cointegration test. Table 1 presents the results of the two tests. Pedroni (1999) suggested two types of residual tests, namely: within dimension and between dimension. The within dimension type includes four sub-tests- panel- $v$ , panel- $\rho$ , panel PP and panel ADF statistics. Whereas the between dimension consists of three sub-tests- group  $\rho$ , group PP and group ADF statistics. The null hypotheses of all the seven statistics from both within and between dimensions

**Table 1**  
Results for cointegration test.

Pedroni Residual Cointegration Test	Dependent variable: GDP per capita	
	Without Trend	With Trend
<i>Within Dimension</i>		
Panel v-Statistic	0.808	−0.437
Panel rho-Statistic	−0.536	0.525
Panel PP-Statistic	−6.174***	−6.956***
Panel ADF-Statistic	−6.814***	−7.550***
<i>Between Dimension</i>		
Group rho-Statistic	1.393	2.133
Group PP-Statistic	−7.001***	−8.972***
Group ADF-Statistic	−6.953***	−9.477***
KAO Residual Cointegration Test		
ADF	−3.944***	

Notes: \*\*\* indicates significant at 1% level.

suggest no cointegration. Rejection of the null hypothesis indicates existence of long-run relationship. It can be seen that from Table 1, four out of the seven Pedroni test statistics are significant, thus, the null hypothesis is rejected. It implies existence of long-run relationship among the variables. This decision is based on the suggestion by Pedroni (1999), who upheld that for one to conclude about the existence of cointegration in Pedroni test, panel ADF and group ADF statistics have to be significant. Consistently, panel ADF and group ADF statistics are significant. This finding is further validated by the result obtained from Kao residual cointegration test (see, lower part of Table 1). The result also suggests the existence of long-run relationship among the variables.

Panel DOLS model was then estimated and Table 2 shows its result alongside the results of panel FMOLS and pooled OLS. This study focuses on the result of panel DOLS. Whereas the results of panel FMOLS and pooled OLS serve as robustness checks. The panel DOLS result suggests that wood biomass energy is negatively and significantly related to CO<sub>2</sub> emissions at 1% level. This implies that an increase in wood biomass energy consumption reduces CO<sub>2</sub> emissions in the selected EU countries. Precisely, 1% increase in wood biomass energy consumption will lead to 0.088% decline in CO<sub>2</sub> emissions. This finding is consistent with Bilgili (2012) and contradicts Ahmed et al. (2016). The finding suggests that EU member countries have prospect of achieving their renewable energy target by increasing the amount of wood biomass energy consumed. The reduction in CO<sub>2</sub> emissions craved for by these countries, can be somewhat achieved by increasing the quantity of wood biomass energy use in production processes.

Fossil fuel yields positive and significant effect on CO<sub>2</sub> emissions. This suggests that an increase in fossil fuel consumption by 1% facilitates CO<sub>2</sub> emissions by 0.785%. This finding is consistent with energy studies by Apergis and Payne (2009), Apergis and James (2010a,b), Hossain (2011), Bhattacharyya and Ghoshal (2010), and Ang (2008). This finding implies that more consumption of fossil

fuel accelerates CO<sub>2</sub> emission in these countries. GDP per capita enters with positive and significant coefficient, implying that an increase in income by 1% results in rise in CO<sub>2</sub> emissions by 0.497%. This finding substantiates Perman and Stern (2003), Halicioglu (2009) and Hossain (2011). It suggests that CO<sub>2</sub> emissions in these countries rise with an increase in economic growth. Trade openness also enters with positive and significant coefficient. Specifically, a 1% increase in trade openness will lead to 0.205% increase in CO<sub>2</sub> emissions. This suggests that more trade openness will lead to more CO<sub>2</sub> emissions. This finding is in conformity with Jalil and Mahmud (2009) and contradicts Sulaiman et al. (2013). By implication, CO<sub>2</sub> emissions in these countries increase as they open up more for trading activities.

The estimates of panel DOLS have been validated by panel FMOLS and pooled OLS. It can be observed that the coefficients obtained from panel FMOLS have the same sign and significant level with those from panel DOLS. This shows that results from panel DOLS are robust and thus, can be acceptable for inference. The coefficients from pooled OLS equally show the same sign with those from panel DOLS, but with a slight difference in significant level. However, on the general note, the estimates of panel DOLS can be adjudged to be robust and free from endogeneity and serial correlation problems.

To assess the impact of wood biomass energy consumption on CO<sub>2</sub> emissions in EU 27 countries based on their emission levels, the countries were divided into two groups- Six top emitter countries and 21 low emitter countries. The six top emitters in Europe are France, Germany, Italy, Poland, Spain, and United Kingdom. Table 3 reports the estimated result for the impact of wood biomass energy on CO<sub>2</sub> emissions in the six top emitters. While Table 4 displays the result of the estimated impact of wood biomass energy on CO<sub>2</sub> emissions in the low emitters. The results from Tables 3 and 4 both reveal that wood biomass energy has significant negative effect on CO<sub>2</sub> emissions. The results further indicate that the significant negative effect of wood biomass energy on CO<sub>2</sub> emissions is higher in top emitter countries than in the low emitter countries. Precisely, the magnitudes of the effect are −0.389 and −0.055 for top and low emitter countries, respectively. This suggests that a significant reduction in CO<sub>2</sub> emissions can be achieved in top emitter countries using wood biomass energy than in low emitter countries.

#### 4. Conclusion and policy recommendations

The current study investigated the effect of wood biomass energy consumption on CO<sub>2</sub> emissions in 27 EU member countries for the 1990–2017 period. Panel DOLS estimator was used to achieve the objective, with panel FMOLS and pooled OLS estimators serving as robustness checks. The estimated results reveal that CO<sub>2</sub> emissions can be significantly reduced by increasing wood biomass energy consumption in EU member countries, especially in six top emitter countries. GDP per capita, fossil fuel and trade openness are

**Table 2**  
The estimated results for the effect of wood biomass energy consumption on CO<sub>2</sub> emissions.

Dep. Var. = CO <sub>2</sub> emission; Regressors	Panel Dynamic OLS		Panel Fully Modified OLS		Pooled OLS	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
<i>Long-run coefficients</i>						
GDP per capita	0.497***	0.079	0.220***	0.043	0.246***	0.016
Wood biomass energy	−0.088***	0.017	−0.082***	0.014	−0.018	0.013
Fossil fuel	0.785***	0.120	0.860***	0.114	0.041	0.061
Trade openness	0.205***	0.063	0.258***	0.049	0.259***	0.016
Constant					−1.744***	0.333

Notes: \*\*\* indicates significant at 1% level.



**Table 3**The estimated results for the effect of biomass energy consumption on CO<sub>2</sub> emissions in EU 27's six top CO<sub>2</sub> emitter countries.

Dep. Var. = CO <sub>2</sub> emission; Regressors	Panel Dynamic OLS		Panel Fully Modified OLS		Pooled OLS	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
<i>Long-run coefficients</i>						
GDP per capita	−0.120	0.103	−0.030	0.084	0.173***	0.032
Wood biomass energy	−0.389***	0.062	−0.274***	0.054	0.132***	0.026
Fossil fuel	2.729***	0.424	2.622***	0.255	1.178***	0.107
Trade openness	0.369***	0.102	0.248***	0.077	−0.062	0.064
Constant					−4.449***	0.649

Notes: \*\*\* indicates significant at 1% level.

**Table 4**The estimated results for the effect of biomass energy consumption on CO<sub>2</sub> emissions in EU 27 (excluding six top CO<sub>2</sub> emitter countries).

Dep. Var. = CO <sub>2</sub> emission; Regressors	Panel Dynamic OLS		Panel Fully Modified OLS		Pooled OLS	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
<i>Long-run coefficients</i>						
GDP per capita	0.157***	0.046	0.179***	0.015	0.266***	0.014
Wood biomass energy	−0.055***	0.019	−0.093***	0.025	−0.037***	0.009
Fossil fuel	1.258***	0.156	0.870***	0.014	0.120	0.073
Trade openness	−0.057	0.061	−0.124***	0.028	0.193***	0.028
Constant					−1.562***	0.374

Notes: \*\*\* indicates significant at 1% level.

found to be increasing CO<sub>2</sub> emissions. The results from panel FMOLS and pooled OLS validated the results of panel DOLS.

The reduction in CO<sub>2</sub> emissions as revealed by our results can be greatly achieved in six top emitter countries- France, Germany, Italy, Poland, Spain, and United Kingdom, than in other EU member countries. This is attributed to the higher fossil fuel consumption in these countries, which can be substituted with wood biomass energy. In line with EU's ambition to reduce CO<sub>2</sub> emissions, wood biomass energy can play a vital role. The authorities of EU can emphasize on improving the sources, efficiency, and sustainability of wood biomass energy to reduce emissions.

This study recommends more investment in wood biomass energy production to minimize emissions. It will assist in achieving energy security and reduce over dependence on other polluting energy sources. Since fossil fuel energy consumption is proven to be a significant factor facilitating CO<sub>2</sub> emissions, more wood biomass energy can substitute fossil fuel energy in large scale production of goods and services to reduce emissions. The authorities of these countries can equally emphasize on efficiency and sustainability of wood biomass energy to achieve energy security and reduce dependency on fossil fuel. This will help to diversify EU's renewable

and sustainable energy strategy. It is important to note that, while striving to reduce emissions by increasing biomass energy, the environmental quality should not be compromised. This is because the source of wood biomass is trees, which if unsustainably harvested can cause forest degradation.

#### Authors contribution section

All the three authors contributed to writing, estimation, analysis, and revision of the paper.

#### Declaration of competing interest

I wish to declare that there is no conflict of interest.

#### Appendix A

**Table A1**

Summary Statistics

Variable	Observation	Mean	Std. Deviation	Min	Max
CO <sub>2</sub> emission per capita	729	8.278	3.763	2.682	27.431
GDP per capita	729	28150	19269	3134.6	11000.1
Wood biomass energy	729	0.946	1.396	0.000	6.436
Fossil fuel	729	76.535	17.595	17.198	99.675
Trade openness	729	95.688	49.928	33.982	357.475

**Table A2**

Correlation matrix

	GDP per capita	Biomass energy	Fossil fuel	Trade openness
GDP per capita	1.000			
Wood biomass energy	0.038	1.000		
Fossil fuel	0.061	−0.732	1.000	
Trade openness	0.439	−0.030	−0.032	1.000

**Table A3**  
Results for the unit root tests

Series	Levin Lin & Chu		IPS	
	No Trend	Trend	No Trend	Trend
Level				
CO <sub>2</sub> emission per capita	1.793 (0.963)	3.597 (0.999)	2.473 (0.993)	5.185 (0.999)
GDP per capita	−5.851*** (0.000)	−2.293** (0.010)	−0.436 (0.331)	1.706 (0.956)
Wood biomass energy	−5.977*** (0.000)	−7.050*** (0.000)	−4.071*** (0.000)	−6.032*** (0.000)
Fossil fuel	5.141 (0.999)	2.312 (0.989)	7.456 (0.999)	3.966 (0.989)
Trade openness	−2.228** (0.012)	−4.040*** (0.000)	1.215 (0.888)	−4.143*** (0.000)
First Difference				
CO <sub>2</sub> emission per capita	−5.404*** (0.000)	−5.330*** (0.000)	−8.597*** (0.000)	−8.400*** (0.000)
GDP per capita	−10.760*** (0.000)	−8.100*** (0.000)	−9.076*** (0.000)	−7.733*** (0.000)
Wood biomass energy	−15.001*** (0.000)	−12.170*** (0.000)	−15.662*** (0.000)	−13.149*** (0.000)
Fossil fuel	−9.207*** (0.000)	−9.975*** (0.000)	−9.458*** (0.000)	−9.535*** (0.000)
Trade openness	−15.752*** (0.000)	−13.445*** (0.000)	−13.872*** (0.000)	−11.086*** (0.000)

Notes: \*\*, \*\*\* indicate significant at 5% and 1%, respectively. Parentheses are the *p*-values.

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