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An investigation into the anthropogenic effect of biomass energy utilization and economic sustainability on environmental degradation in E7 economies

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Abstract: Inspired by the Sustainable Development Goals (SDGs), this study focuses on the need for responsible and clean energy consumption, climate change mitigation, and sustainable economic growth. To this end, the study investigates the connection between biomass energy consumption, real GDP, investment in the energy sector, and CO_2 emissions in the emerging (E7) countries – China, India, Brazil, Mexico, the Russian Federation, Indonesia and Turkey – for the period 2000–2018. The study uses a battery of techniques, namely Pooled Mean Group-autoregressive distributed lag, ordinary least square, dynamic ordinary least square, Fully Modified Ordinary Least Squares (PMG-ARDL, OLS, DOLS FMOLS) and causality estimators, to measure the robustness of the conceptualized relationship among the variables of interest. Empirical results show that conventional energy from fossil fuel sources is a driver of CO_2 emissions within the E7 economies. On the other hand, biomass energy consumption and investments in the energy sector decrease CO_2 emissions. Furthermore, a feedback causality relationship between biomass energy consumption and CO_2 emissions is observed. Similarly, a feedback causality relationship is seen between economic growth and biomass energy consumption. Our study's empirical findings reveal that biomass energy consumption mitigated CO_2 emissions in the E7 economies

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that were examined, suggesting the pivotal role for biomass energy consumption in creating an eco-friendly environment and environmental sustainability. This requires investment from the private sector, stakeholders, and government administrators in cleaner energy technologies initiatives like biomass.

Key words: biomass energy consumption; Investment in Energy sector; real GDP, CO_2 emission, E7 states

Introduction

Rapid economic development across the world has intensified energy demands. This has environmental implications.[1] Tiba and Omri[2] noted that the interaction between energy, the ecosystem, and economic growth has led energy experts and economists to investigate the causal relationship between sustainable economic development, ecological factors, and energy usage. Increasing energy consumption has contributed to the widespread consumption of non-renewable energy supplies such as coal, oil, and gas, and has caused huge pollution challenges. Conversely, green energy supplies – bioenergy, hydropower, geothermal, solar, and wind energy – are the ideal solution to climate problems.[3–7] Increased energy consumption, which has accompanied attempts to boost global development and improve quality of life, has resulted in rising greenhouse gas pollution and growing ecological threats associated with global warming. The large increase in CO_2 emissions is attributed to increased energy use.[8] Carbon dioxide emissions are among the main drivers of air degradation and anthropogenic climate change, and are of significant importance to the atmosphere and to the sustainability of the earth.[9]

The Fourth Assessment Document of the United Nations on Global warming estimates that temperatures will increase by an estimate of 2 to 4.2 °C by 2100. Effluents that result from a rise in world economic activity are believed to be a major contributor to global warming, and the greenhouse influence is linked to six different gases that influence the environment. The Kyoto Protocol of 1997 called for a reduction in CO_2 pollution by 5.2%, relative to 1990 levels, during 2008–2012. The Protocol was put into practice in 2005. Carbon dioxide emissions are caused by the combustion of non-renewable energy sources. Carbon dioxide contributes 58.8% of all emissions. After the 1970s, rapid global development has had an impact on the sustainability of technological change. Projections of CO_2 emissions indicate that energy demand and economic development will be the most significant influences on the future of renewable energy.[10,11]

Energy from biomass is an intrinsic component of sustainability and has a significant role in the discourse on climate policies and stable growth initiatives across the planet.[12] Most emerging nations aim to utilize biomass products to meet approximately 35% of their energy requirements, increasing world usage to 13%.[13] Biomass production is classified into five categories: (i) wooded or compact biomass (agro-manufacturing crops in addition to woods, suburban plants, forest trees and agricultural forests); (ii) non-wooded biomass (derived from grass, leaves and crops and processed in anaerobic digesters); (iii) manufactured remainders (in the form of sawdust, bagasse, nuts in addition to shells); (iv) agricultural waste (such as feed and wastewater); (v) livestock manure (waste from livestock). Different types of biomass can be used for cooling, for the distribution of energy, and for additives. Mankind has been using biomass products for centuries, like wood fires for heat. Bildirici and Ozaksoy[14,15] (Bildirici and Ozaksoy 2017; Bildirici and Özaksoy 2018) clarified that biomass production is classified under three types: woody or compact biomass is developed in agriculture-manufacturing crops in addition to wetlands, built-up trees, scrubland trees, and farm trees; non-woody biomass is created in yield wastes such as grass, leaves and plant stems, and manufactured wastes such as wood chips, bagasse, seeds, and husks; and agricultural garbage such as food rough. Different varieties of biomass can be used explicitly or implicitly for the generation of heat and energy by way of distribution fuel and additives.[16] The earth needs an enormous volume of renewable resources for sustainable growth,[17] so that it can tackle sustainability challenges such as the use of fossil fuels, environmental degradation, air quality, and acidic rainfall by decreasing CO_2 emissions as well as other polluting greenhouse gases.[18]

This study examines the influence of biomass energy, investment in the energy sector, energy usage, and real GDP on CO_2 emissions from the emerging seven (E7) countries – China, India, Brazil, Mexico, the Russian Federation, Indonesia, and Turkey. All these countries were among the top 25 countries producing CO_2 emissions worldwide as of 2017. China was first with 9898.3 million metric tons. India was third with 2466.8 million metric tons, while Russia created 1692.8 million metric tons, ranking fourth. Mexico was 11th with an output of 490.3 million metric tons and Indonesia was 12th with 486.8 million metric tons. Brazil was the 13th largest producer, creating 476.1 million metric tons. Turkey was the last E7 nation to appear on the list and was the 15th largest producer of CO_2, producing 447.9 million metric tons (see www.usato.com). From these statistics on the mass production of CO_2 emissions by E7 countries, one can conclude that they produce large CO_2 emissions due to the economic activities they undertake. The E7 economies are mainly characterized by activities like mining, agriculture, and extraction. The E7 is the group of developing countries with the fastest growing population. It is integrated with the international economy, and has the goal of becoming one of the strongest economies in the world, like the G7 countries. The E7 economies are at the pre-industrial stage. The pre-industrial stage is a phase where the emphasis is on economic growth – that is, on increasing the real income level relative to environmental stability.[19] The choice of E7 is pertinent given that approximately 70% of its energy mix is generated from non-renewable energy sources, mainly dominated by coal.

Due to increasing CO_2 emissions, there is a need for sustainable energy supplies.[20] Biomass production could make a significant contribution to any kind of energy and ecological conservation.[21] However, empirical studies on the connection between economic development and CO_2 emissions remain inconclusive in the literature.[8] For instance, Bilgili *et al.*[9] observed that, biomass energy decreases CO_2 emissions in the US economy whiles Salarin *et al*[22] also identify that both biomass energy and nonrenewable energy increases the realize of CO_2. Shahbaz *et al.*[23] concluded that biomass energy speeds up the amount of CO_2 emissions, whereas a study by Shahbaz *et al.* [24] proposed that biomass energy consumption decreases levels of toxicity. Dogan and Inglesi-Lotz[21] emphasized that renewable technology helps mitigate CO_2 emissions. Overall, these studies are inconclusive with regard to how biomass energy use decreases CO_2 emissions. This study therefore explores the effects of biomass energy use on CO_2 emissions in the E7 countries in an attempt to offer policies relevant to green development and ecological conservation. To obtain robust outcome, the authors included investment in energy and energy use as additional variables into the carbon-income literature. The unique contribution of the current study is in considering the effects of biomass energy usage on CO_2 emissions in the E7 countries, given the strong dependence on biomass energy within the ecosystems of E7 economies.

The E7 economies are under domestic and foreign pressure to achieve a rapid rate of economic development while decreasing emission levels. Studies such as Shahbaz *et al.*[25] and Danish and Wang[12] have concentrated on the correlation between biomass usage and economic development in the 'Brazil, Russia, India, China, and South Africa' (BRICS) economies. However, no studies have taken CO_2 emissions into consideration in their analysis of the connection between biomass energy and economic development for all E7 members. This current research explores the function of biomass energy consumption in CO_2 emission in offering policy direction for decision makers about their environmental sustainability actions.

A literature review is presented in the following section. The study then focuses on the data and methods. Empirical results are presented and interpreted, and then the final section discusses conclusions and policy implications.

Literature review

The causal connection between energy consumption and economic sustainability has been explored in several experiments over the past 20 years. A detailed analysis of these studies can be found in Ozturk.[26] The methodological findings from these studies are often incompatible with each other. For Ozturk,[26] the use of different statistics, varied econometric approaches, and the features of various nations are the key explanations for this contradictory result. The articles have provided contradictory findings on the causal relationship between energy consumption and sustainable development.

Four hypotheses can be found in this literature:

(i) Development theory. Energy demand plays a critical role, either in itself or as a counterpart to resources and employment in the cycle of economic development. The development theory is supported by the discovery of uni-directional causality from energy consumption to sustainable development.

(ii) The recycling principle. This suggests that environmental development is a phenomenon that induces energy intake. There is unidirectional causality from economic development to energy intake.

(iii) The feedback theory. There is a feedback causality between energy consumption and sustainable development.

(iv) The equilibrium principle suggests that the production of energy does not impact sustainable development.

The causal link between green energy use and economic development has been examined in several areas in recent years. Apergis and Payne[27] evaluated the correlation between sustainable energy use and sustainable development for a group of 20 OECD states for the period 1985–2005. The Granger findings show a bi-directional causality between green energy use and sustainable development both in the short and long term. Apergis and Payne[27] analyzed the association between green energy uses and GDP for a group of six Central American nations throughout 1980–2006. They observed bi-directional causality between clean energy use and GDP, both in the short and long term, in the nations surveyed.

However, by including biomass in the research, Bildirici[28] looked at the connection between biomass energy use and sustainable development in seven unindustrialized and growing Latin American states using autoregressive distributed lag (ARDL) estimation. This showed unidirectional causality among GDP and biomass energy usage in Colombia, Bolivia, Brazil, and Chile. However, bidirectional causality among the variables was found in Guatemala. From 1980–2009, Bildirici[29] analyzed short-term and long-term causal research involving biomass energy use and economic development in ten unindustrialized and rising economies utilizing the ARDL boundary-test method of co-integration plus vector error-correction methods. The findings of the co-integration studies indicate that there was co-integration among biomass energy use and sustainable development in nine out of the ten Latin America nations, although no co-integration was seen in Paraguay.

Payne[30] investigated the connection between biomass energy usage and actual gross domestic product (GDP) in a multivariate US framework using data over the 1949–2007 period. The findings demonstrate the unidirectional causality of the actual GDP intake of biomass energy and support the development theory. Apergis and Danuletiu[31] examined the link between green energy and socio-economic development for 80 nations under the Canning and Pedroni long-term causality check, which showed that there was long-term positive causality from clean energy to real GDP for the overall survey and across areas. Empirical studies prove that renewable energy use is crucial for overall economic growth which recent research supports this theory Apergis and Danuletiu[31]. The existence of causality offers an outlet for the continued need for policy measures that encourage the growth of the sustainable energy market. Sebri and Ben-Salha[32] studied the causal association between economic development and sustainable energy use in the BRICS nations throughout 1971–2010 under a multivariate system. The ARDL research methodology for co-integration and the vector error correction mechanism (VECM) were employed to investigate the long-term and causal association among sustainable development, green energy consumption, trade transparency, and greenhouse gas pollution. Empirical data suggest that there is a stronger causality regarding economic development and sustainable energy use, indicating a feedback mechanism, which can justify the function of sustainable energy in promoting economic development in the BRICS states. Ozturk and Bilgili[33] analyzed the long-term patterns of economic development and biomass consumption by implementing complex panel analyses for 51 sub-Saharan African nations for the 1980–2009 period. The findings indicate that the consumption, transparency, and development of biomass have an important positive effect on economic development in African nations. The report also indicated that biomass use has an effective impact on GDP in the 51 African nations.

Bilgili and Ozturk[34] also examined the long run dynamics of biomass energy consumption and GDP growth through homogeneous and heterogeneous variance structures for G7 countries. This includes cumulative statistics for the period 1980 to 2009. The results indicated that there is a long run relationship between real GDP, capital formation and biomass energy consumption. The findings supported the development theory: the use of biomass energy has had beneficial impacts on the economic development of the G7 nations. However, Gyamfi *et al.*[35] analyzed the effects of biomass energy usage on carbon dioxide emissions in the G7 countries from 1995–2016. Their findings showed that the consumption of biomass energy negatively correlated with pollutants. On the other hand, the association regarding energy usage and pollutants was strong and positive, indicating that primary energy use is not advantageous for environmental protection. The findings showed that GDP raised long-term pollution in the context of the G7, reinforcing the G7 block growth-induced emission hypothesis. They identify a unidirectional causal association among these variables: biomass and pollutants, pollutants and production, biomass and output, biomass and energy use, output and energy use. These findings imply a policy consequence for G7 countries that suggests that policymakers must give careful attention to technical expertise and energy mixes, especially biomass, which is eco-sustainable, as well as further paradigm changes towards renewables. Kim *et al.*[36] investigated the causal relationship between overall biomass energy consumption, CO_2 production, and GDP for 1973–2016 in the USA. This study also discusses Kuznets' environmental hypothesis (EKC). The results revealed a unidirectional, traditional causal relation among biomass intakes and GDP and total carbon emission. This response implies that biomass consumption is one way in which US carbon pollution is reduced and monitored. In contrast, the inverted U-shaped EKC hypothesis is acceptable in the case of the USA. The results of this study indicate that energy policies should encourage improved biomass to mitigate increased CO_2 emissions. Using a groundbreaking computational approach, Sarkodie *et al.*[13] examined the impact of energy generation on food emission reduction and nation growth in a multivariate sense and reported that biomass energy reduces gas emissions. Dogan *et al.*[21] investigated the association of biomass energy and carbon dioxide emissions in biomass-overwhelming states and reported that biomass reduces emissions. Baležentis *et al.*[37] stated that, unlike many sustainable energy sources, biomass power decreases carbon pollution.

Nevertheless, Hakimi & Hamdi[38] find the liberalization of trade harmful to the sustainability of the environment. If restrictions to trade are lowered, low ecological requirements will lead to expanded trading practices involving the transition of unclean technology.[12] Ulucak[39] discussed the connection between biomass power and actual income and CO_2 emission for China.

There is a gap in the literature; there is a need to explore the connection between biomass energy and CO_2 in a comprehensive manner. The variables covered in this current study are timely and worthwhile given the inconclusive outcomes in the literature in the energy-environment debate. To our best of knowledge, none of the studies mentioned above used a battery of techniques such as PMG-ARDL, OLS, FMOLS, and DOLS to estimate the long-term and short-term relationships between biomass energy consumption and pollutants. This study is intended to fill this gap. Furthermore, studies such as Shahbaz *et al.*[25] and Danish and Wang[12] concentrated on the correlation between biomass consumption and economic development in the BRICS nations, which include only four of the E7 members. However, no studies took into consideration CO_2 emissions and biomass in the E7 context.

Materials and methods

This section presents the methodology and data related to the hypothesized connection between biomass energy consumption, investment in energy consumption, and CO_2 emissions in E7 economies. The data for this analysis were collected from the World Bank Indices (www.databank.worldbank.org) to analyze long-term and short-term relations regarding economic growth (GDP), energy usage (EC), investment in the energy sector (INVE), and CO_2 emissions in E7 states. In line Danish and Wang[12] and Mahmood *et al.*,[40] data on biomass energy (consumption) are measured in tonnes per capita and retrieved from the Global Material Flow Database. The collection of variables for this investigation is focus on the Sustainable Development Goals (SDGs) 7 and 13.[41] Energy supply and associated infrastructure play a crucial role in economic growth and thus environmental growth (SDG 7), and climate change mitigation relies on prudent energy use and output choices and associated infrastructure (SDG 13). Yearly frequency data from 2000 to 2018 are used to analyze the correlations between the variables in question. The variables studied were used in their logarithmic form to mitigate heteroscedasticity issues. Gross domestic product and pollutants are utilized as proxies for economic sustainability and ecological degradation. Economic sustainability (GDP) is measured in constant USD 2010; pollutants (CO_2) are measured in metric tons per capita, energy use (EC) is measured in kg oil equivalent per capita, and investment in energy with private participation (INVE) is measured in current US$.

This study followed a series of stages. First, there was a preliminary analysis of basic summary statistics and correlations among the variables. Second, stationarity test by Fisher Augmented Dickey-Fuller (Fisher ADF) and Phillips Perron unit root test. Third, investigation into cointegration analysis and long-run regression advanced by Pesaran's PMG-ARDL methodology. However, the FMOLS and DOLS techniques was utilized for robustness purposes. Fourth, the Dumitrescu and Hurlin technique was used to investigate the causal relationship among the variables which will help in recommending policy direction for the E7 economics.

The method was influenced by various studies.[12,40,42] It analyzes the connection between real income and biomass energy and CO_2 pollutants, taking into consideration expenditure in the energy industry. It can be expressed as in the equations below:

$$\mathrm{CO_2} = \mathrm{f}\left(\mathrm{GDP,BEME,EC,INVE}\right) \tag{1}$$

$$\begin{aligned}\mathrm{LnCO}_{2\mathrm{t}} = {}& \alpha_0 + \beta_1 \,\mathrm{LnGDP_t} + \beta_2 \,\mathrm{LnBEMC_t}) + \beta_3 \,\mathrm{LnEC_t}) \\ & + \beta_4 \,\mathrm{LnINVE_t}) + \mu_\mathrm{t}\end{aligned} \tag{2}$$

where CO_2 represent CO_2 emissions, BEMC represent biomass energy consumption, EU represent Energy use and INVE represent investment in energy, α is the constant term, and the βs are slope perimeters, which need to be examined. All the variables are transformed to their natural logarithm form to ensure homoscedasticity of the coefficients.

Consequently, four estimation techniques are used in this study: OLS, FMOLS, DOLS, and the pooled mean group-ARDL by Pedroni,[43] Pedroni,[44] Kao and Chiang,[45] and Pesaran *et al.* (1999), respectively. Interestingly, the DOLS can correct for correlation between the dependent variable and the stochastic term and it adds lags for the independent variables.

The DOLS is estimated using Eqn. (3), which is given as:

$$\begin{aligned}LNC02_{it} = {}& \mu_i + x_{i,t}\Psi_{i,t} + \sum_{j=-p}^{p} \beta_j LNC02_{i.t-j} \\ & + \sum_{j=-q0}^{q0} p_{1.j} LNBEMCGDP_{i.t-j} \\ & + p_{2.j} \sum_{j=-q1}^{q1} LNEC_{i.t-j} + p_{3.j} \sum_{j=-q2}^{q2} LNGDP_{i.t-j} \\ & + p_{4.j} \sum_{j=-q2}^{q3} LNINVE_{i.t-j} + \mu_{it}\end{aligned} \tag{3}$$

p and *q* are the number of leads/lags. The long-run relationship is estimated from the FMOLS equation, given as:

$$LNC02 = \mu_i + x_{i.t}\psi + v_{it} \tag{4}$$

$$x_{i.t} = x_{i.t} + \mathfrak{C}_{i.t}$$

where x 5*1 vector of explanatory variables is, μ_i is the intercept while $\mathfrak{C}_{i.t}$ and v_{it} are the error terms. However, the estimation of ψ is expressed as:

$$\widehat{\psi}_{FMOLS} = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \left(x_{i.t} - \bar{x}_{i.t} \right) * \left(x_{i.t} - \bar{x}_{i.t} \right)' \right)^{-1} * \left(\sum_{i=1}^{N} \left(\sum_{t=1}^{T} \left(x_{i.t} - \bar{x}_{i.t} \right) * \widehat{LNC0_2}_{it} - T\hat{\Delta}_{v\mathfrak{C}} \right) \right) \tag{5}$$

We also examined both short-and long-term forecasts utilizing the Pesaran *et al.* (1999) method. The analysis advanced with the evaluation of biomass energy utilization-GDP-energy-emissions nexus identified in Eqn. (1) in the autoregressive distributed lag (ARDL: p, q) system, which integrates all pollution lags including regressors, provided that:

$$LNC0_{2it} = \beta_i + \sum_{j=0}^{p} \delta_{ij} LNCO_2 \, Z_{it-j} + \sum_{j=1}^{q} \varphi \delta_{i,j} Z_{it-j} + \varepsilon_{it} \tag{6}$$

where, Z_{it} = ($LnBEMC_{it,}$ $LnEC_{it}$, $LnGDP_{it,}$ $LnINVE_{it}$) is a function for the explanatory variables used in this analysis. β_i indicates the country-level fixed results, δ_{ij} indicates the slope of the lagged pollution vector, and $\varphi_{i,\,j}$ indicates the slope of the lagged explanatory variables.

The PMG-ARDL co-integration methodology has important econometric strengths relative to conventional panel data models. It can fix endogeneity problems in econometric models and at the same time handle either short-or long-term parameters. The ARDL co-integration method is also capable of taking into account variables in a combined integration order, such as I(0) or / and I (1) but not I (2). Pesaran *et al.* (1999) also reported that the pool mean group (PMG) technique helps in situations where the variables have properties of mixed order of integration at I (0) or [I(1)].

Results and discussion

Pre-estimation diagnostics

The summary statistics proofs that investment in energy sector has the highest mean, median, maximum, minimum and standard deviation whiles real GDP has the lowest mean, median, minimum, maximum and standard deviation (Table 1). Evidence from the correlation matrix shows that the dependent variable, which is CO_2 emission, has a positive connection with real GDP and primary energy usage, which we denoted as energy usage, but CO_2 emission has a negative connection with investment in energy consumption (Table 2).

From Table 3 below, it can be seen that there is stationarity among the variables in both order zero [1(0)] and order one [1(1)] respectively. However, biomass energy consumption, energy usage and investment in the energy sector are stationary at level. On the other hand, the Pedroni cointegration test rejected the null hypothesis, which proves that none of the variables are statistically significant (Table 4).

Out of the seven outcomes from the Pedroni cointegration test, four of them – panel ADF-Stat, Group ADF-Stat, Group PP-Stat, and Panel PP-Stat – proved to be statistically

Table 1. Summary statistics.

	$LnCO_2$	LnBEMC	LnGDP	LnINVE	LnEC
Mean	1.221	17.182	8.618	21.224	7.231
Median	1.259	17.373	9.082	21.393	7.270
Maximum	2.548	19.003	9.620	24.263	8.550
Minimum	–0.036	15.372	6.717	14.914	6.031
Std. dev.	0.721	0.875	0.810	1.640	0.648
Skewness	0.251	–0.073	–0.823	–0.983	0.371
Kurtosis	2.110	2.294	2.345	4.601	2.765
Jarque-Bera	5.783	2.875	17.420	35.632	3.357
Probability	0.055	0.237	0.000	0.000	0.186
Sum	162.518	2285.325	1146.276	2822.832	961.756
Sum sq. dev.	68.660	101.204	86.625	355.181	55.462
Observations	133	133	133	133	133

Source: Authors' computations.
NOTE: CO_2= CO_2 emission, BEMC= biomass energy consumption, GDP= real GDP per capita, INVE= investment in energy and EC= Energy use.

Table 2. Correlation matrix analysis.

VARIABLES	$LnCO_2$	LnBEMC	LNGDP	LnINVE	LnEC
$LnCO_2$	1				
P-value	-				
LnBEMC	–0.069	1			
P-value	(0.4315)	-			
LnGDP	0.633***	0.001	1		
P-value	(0.0000)	(0.9948)	–		
LnINVE	–0.277***	0.270***	–0.002	1	
P-value	(0.0013)	(0.0017)	(0.9794)	–	
LnEC	0.956***	0.092	0.734***	–0.237***	1
P-value	(0.0000)	(0.2915)	(0.0000)	(0.0060)	–

Source: Authors' computations.
Note: * = 0.01, **= 0.05 and ***=0.10
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

Table 3. Unit root test results.

	UNIT ROOT TEST							
	ADF				PP			
	AT LEVEL		AT 1ST LEVEL		AT LEVEL		AT 1ST LEVEL	
VARIABLES	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$
$LnCO_2$	0.8441	0.7751	0.0031***	0.0143***	0.8480	0.6985	0.0030***	0.0143***
LnBEMC	0.7994**	0.0112	0.0012***	0.0069***	0.4243	0.2790	0.0035***	0.0339***
LnGDP	0.9982	0.2931	0.0217**	0.0676	0.9999	0.2696	0.0067**	0.0059
LnINVE	0.5346*	0.8532**	0.0014***	0.0018***	0.5262*	0.8499**	0.0017***	0.0009***
LnEC	0.8360	0.8798**	0.0063***	0.0241*	0.8346	0.8037*	0.0063***	0.0238***

Source: Authors' computations.
Note: *=0.01, **=0.05 and ***=0.100. again, $\pi\tau$ is represent constant whiles $\pi\vartheta$ represent constant and trend.
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

significant, indicating that the variables are cointegrated. Further analysis using the Kao cointegration test confirmed the variables cointegration with a significance level of 5% (Table 5).

Empirical results

The analysis reported in Table 6 shows a long-run estimation of the panel dynamic OLS, DOLS, and FMOLS results. As the OLS estimation shows, the coefficient of biomass energy intake is negatively significant at 1% which means that biomass energy consumption decreases pollutants by 0.27%. This result proves that, the higher the consumption of biomass energy source, the more the environmental degradation reduces. This outcome confirms the findings of Gyamfi *et al.*,[35] Sakodie *et al.*,[13] and Shahbaz *et al.*,[42] but is contrary to the findings of Mahmood *et al.*[40] and Solarin *et al.* (2019).

The OLS results also show a significant negative relationship between real GDP and pollution. Meanwhile the relationship between the two variables is strong and positive in both DOLS and FMOLS estimates. The implication from the OLS estimation is that a 1% increase in real GDP will decrease pollutants by 0.199%, while with the DOLS and FMOLS, a 1% increase in real GDP will increase pollutants by 0.81% respectively. The outcome from Table 6 reveals that GDP increases pollution, which is inconsistent with Ulucak (2020a, b). Again the OLS estimations prove that investment in the energy sector is strongly and negatively related to CO_2 emissions. This implies that a 1% increase in investment in the energy sector will reduce pollutants by 0.029%. Moreover,

Table 4. Pedroni cointegration test.

Deterministic intercept and trend					
	Weighted stat	*P*-value		Statistic	*P*-value
Panel v-Stat	−3.591	(0.9998)	Group rho-Stat	3.149	(0.9992)
Panel rho-Stat	2.424	(0.9923)	Group PP-Stat	−2.399***	(0.0082)
Panel PP-Stat	−1.033*	(0.0507)	Group ADF-Stat	−2.259**	(0.0119)
Panel ADF-Stat	−2.503***	(0.0062)			
			No deterministic trend		
	Weighted stat	p-value		Statistic	*P*-value
Panel v-Stat	−2.296	(0.9892)	Group rho-Stat	2.062	(0.9804)
Panel rho-Stat	1.297	(0.9027)	Group PP-Stat	−2.992***	(0.0014)
Panel PP-Stat	−1.923**	(0.0272)	Group ADF-Stat	−3.108***	(0.0009)
Panel ADF-Stat	−3.201***	(0.0007)			
			No deterministic intercept or trend		
	Weighted stat	*P*-value		Statistic	*P*-value
Panel v-Stat	−2.702	(0.9966)	Group rho-Stat	2.818	(0.9976)
Panel rho-Stat	1.632	(0.9487)	Group PP-Stat	−0.096*	(0.0617)
Panel PP-Stat	−0.088*	(0.0648)	Group ADF-Stat	−0.398**	(0.0451)
Panel ADF-Stat	−0.445**	(0.0281)			

Source: Authors' computations.
Note: *=0.01, **=0.05 and ***=0.10
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

Table 5. Kao[44] cointegration test.

	t-statistic	*P*-value
ADF	−2.038**	(0.0207)
Residual variance	0.002	
HAC variance	0.001	

Source: Authors' computations.
Note: *=0.01, **=0.05 and ***=0.10
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

Table 6. Long run results from panel dynamic OLS, DOLS and FMOLS.

VARIABLES	OLS	DOLS	FMOLS
LnBEMC	−0.274***	−0.165	0.013
P-value	(0.0000)	(0.1896)	(0.6549)
LnGDP	−0.198***	0.810**	0.184**
P-value	(0.0000)	(0.0295)	(0.0383)
LnINVE	−0.029**	0.034	0.0008
P-value	(0.0227)	(0.1054)	(0.8678)
LnEC	1.144***	0.231	0.885***
P-value	(0.0000)	(0.5998)	(0.0000)
R-SQUARE	0.899	0.998	0.994
ADJ R-SQUARE	0.897	0.992	0.993

Source: Authors' computations.
Note: *=0.01, **=0.05 and ***=0.10
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

the result from energy use proves that both OLS and FMOLS have a positive and significant relationship with pollutants. It indicates that a 1% increase in energy use will increase pollutants in the range of 0.89% to 1.14%. Our findings are confirmed by Kais and Sami[47], and Alam *et al.*[48] This means that an increase in energy consumption causes CO_2 emissions in the E7 states (Table 7).

The long-run estimation of the biomass energy consumption is negative and is significant at 1%. That is, a 1% rise in biomass energy consumption will lessen pollution by 0.053%, which again confirms the early findings from the OLS. Moreover, the real GDP revealed a positive significant relation with CO_2, implying that a 1% increase in GDP will increase CO_2 by 0.52%. However, investment in the energy sector also has a negative significance level of 1%, which implies that a change in investment in energy consumption will also decrease pollution by 0.039%. But, there is a positive significant relationship between energy utilization and pollution. Thus, a percentage increase in energy consumption

Table 7. PMG-ARDL test (1, 2, 2, 2, 2).

LONG RUN EQUATIONS			
VARIABLES	COEFFICIENT	STD. ERROR	*t*-STATISTIC
LnBEMC	–0.053***	0.009	–5.567
LnGDP	0.521***	0.032	0.034
LnINVE	–0.003***	0.001	–2.755
LnEC	1.140***	0.043	25.929
	SHORT RUN EQUATION		
VARIABLES	COEFFICIENT	STD. ERROR	*t*-STATISTIC
COINTEQ01	–0.574***	0.188	–3.041
D(LnBEMC)	–0.053	0.079	–0.665
D(LnBEMC(–1))	–0.087	0.108	–0.803
D(LnGDP)	–0.399	0.351	–1.134
D(LnGDP(–1))	1.439	1.175	1.224
D(LnINVT)	–0.003	0.005	–0.621
D(LnINVE(–1))	–0.001	0.003	–0.304
D(LnEC)	0.333	0.415	0.803
D(LnEC(–1))	0.022	0.157	0.140
Constant	–3.487***	1.118	–3.119

Source: Authors' computations.
Note: *=0.01, **=0.05 and ***=0.10.
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

Table 8. Dumitrescu and Hurlin causality result.

Null hypothesis:	Zbar stat	*P*-value
LnBEMC ≠ LnCO$_2$	3.303***	(0.0010)
LnCO$_2$ ≠ LnBEMC	1.970**	(0.0488)
LnGDP ≠ LnCO$_2$	2.049**	(0.0404)
LnCO$_2$ ≠ LnGDP	–0.385	(0.7000)
LnINVE ≠ LnCO$_2$	–0.133	(0.8939)
LnCO$_2$ ≠ LnINVE	–0.168	(0.8663)
LnEC ≠ LnCO$_2$	0.927	(0.3539)
LnCO$_2$ ≠ LnEC	–0.070	(0.9437)
LnGDP ≠ LnBEMC	4.834***	(1.E-06)
LnBEMC ≠ LnGDP	2.879***	(0.0040)
LnINVE ≠ LnBEMC	–0.395	(0.6927)
LnBEMC ≠ LnINVE	1.347	(0.1778)
LnEC ≠ LnBEMC	2.412**	(0.0158)
LnBEMC ≠ LnEC	1.696*	(0.0899)
LnINVE ≠ LnGDP	1.518	(0.1289)
LnGDP ≠ LnINVE	0.789	(0.4298)
LnEC ≠ LnGDP	–0.803	(0.4217)
LnEC ≠ LnGDP	1.893	(0.0582)
LnEC ≠ LnINVE	–0.246	(0.8050)
LnINVE ≠ LnEC	–0.492	(0.6222)

Note: *=0.01, **=0.05 and ***=0.10
*0.01% significance level.
**0.05% significance level.
***0.10% significance level.

will increase pollution by 1.14%. however, none of the variables have a significant relationship with CO2emission in the short run which implies that, Biomass energy consumption, real GDP, Investment in Energy sector and Energy consumption does not cause pollutants in the short period within the E7 nations.

Heterogeneous causality test

Correlation is not necessary causality therefore the authors sought to identify the causal association among the variables. The Dumitrescu and Hurlin causality test analysis is reported in Table 8. The estimation proofs a feedback causality regarding these variables: biomass energy consumption and CO$_2$ emission, economic sustainability and biomass energy as well as energy consumption and biomass energy. However, there is a one-way causal association regarding real GDP which is economic sustainability and carbon emission. Nevertheless, the result indicated that there is no causality between investment in energy section and pollutants, energy consumption and pollutants, investment in energy utilization and biomass energy utilization, investment in the energy sector and energy utilization, energy utilization and economic sustainability, and energy utilization and investment in energy sector. From the analysis it is clear that biomass utilization causes CO$_2$ emissions directly.

Based on the results of this paper, it is prudent for the E7 countries to invest actively in research and development and identify a more refined technical means to increase the consumption of clean energy like biomass energy sources. This will help play a key role in combating CO$_2$ emissions for a healthy atmosphere for its population.

Conclusion and policy implications

Several analyses have been conducted on the consumption of biomass in energy, energy generation, economic development, and pollution. However, the current analysis differs by introducing a new element: investment in energy consumption in a carbon-income environment. As far as the authors are aware, no studies have been found in case of the E7 states (China, India, Brazil, Mexico, Russia, Indonesia, and Turkey). The E7 has the second highest GDP in the world after the G7. This study analyzed the effect of biomass energy consumption, energy usage, investment in energy sector, and economic development, on CO_2 emission in the developing seven states (E7) for the period from 2000 to 2018. The study used the PMG-ARDL, OLS, DOLS and FMOLS regression coefficients and the Dumitrescu and Hurlin causality test.

The current study revealed that biomass energy consumption is negatively and significantly related to CO_2 emission, which is consistent with the findings of several studies.[13,35,42] These findings mean that biomass energy is a sustainable source that can help minimize carbon dioxide emissions in the environment. Biomass energy is a preferred energy supply to help mitigate emissions in the E7 nations. The findings indicate that green energy options such as biomass suit these ecosystems well in mitigating CO_2 emissions. On the other hand, investments in energy also decrease pollutants. This outcome implies that investment in the energy sector in the form of identifying new technology through research and development helps bring new ideas, which in the long run could decrease pollution. Moreover, economic development in the nations under analysis is not a catalyst for combating emission levels, as it leads to increased emissions. Furthermore, Ulucak (2020a, b) does not affirm that GDP has a favorable connection with emissions and does not actually indicate that if a nation increases its economic fortunes it assumes a clean atmosphere or is free from CO_2 emissions. Nevertheless, this analysis identified energy use as having a positive and statistically meaningful association with emissions. This result means that energy consumption in E7 countries does not support emission control, neither is it healthy for humans. Energy consumption in these economies should be reconsidered as the countries need to combat air emissions related to energy use. Further attention should be paid to the economies' technological and energy balance as it does not contribute to mitigating environmental pollution.

The causality test also showed a feedback effect between biomass energy consumption and CO_2 emissions, economic sustainability, and biomass energy consumption, and energy consumption and biomass energy consumption. Furthermore, there is a one-way causal relationship between real GDP, which is economic sustainability, and pollution, which implies there is a proof of EKC within the E7 states. Moreover, biomass energy consumption has negatively significant relationship with CO_2 emission. Biomass energy is considered to be a renewable source of energy that will continue to replace fossil fuels in the E7 environment. Investment in the energy sector also leads to the elimination of CO_2 emissions but the consumption of energy and real GDP do not appear to do so.

The strategic implications of these results include the need for policymakers in E7 countries to invest more in biomass energy initiatives, especially research and development, to help tackle significant environmental problems for the E7 nations. This project would draw more investment funds to increase the development of biomass energy and by extension sustainable development. The goals of the E7 will be met by reducing greenhouse emissions and replacing fossil fuels with biomass energy. Biotechnology use may increase the development of biomass and tackle the its various by-products. Governments of the E7 and the private sector should engage and invest in the expansion of biomass energy via creativity to decrease the consumption of fossil fuels. The E7 states' governments should attract and encourage international investors through FDI for the creation of biomass energy to improve the growth of biomass energy and reduce emissions from this renewable energy source. Furthermore, multilateral arrangements should be concluded among governments to ensure the development of green energy and the effective use of energy in the E7 communities. This will be easily achieve by an effort of collaboration at the regional level by the E7 countries. Knowledge sharing in terms of technical advances and other relevant vital ventures conducted by national bodies should be crucial for nations to benefit from ingenuity and innovation. However, tax holidays are strong funding tools that will enable private sector companies to participate in clean energy growth, which would eventually have a ripple effect on final consumption. There should be an intergovernmental agreement among countries to encourage clean energy and energy conservation in the E7 countries. Governments must also build the potential for quick access to renewable energy investment funding, as illustrated in the Paris 21st Conference of the Parties (COP21) Agreement to enable partners to participate in renewable energy development (Gyamfi et al., 2021). Finally, policy makers should ensure the creation of a market where renewable energy may be exchanged and certificates issued, and implement a consolidated portfolio of sustainable energy capable of providing more space within the category of renewable energy.

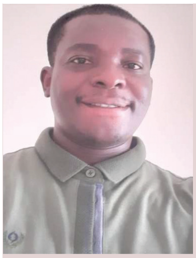
This will go a long way to achieving a high level of economic sustainability and good environmental quality, consistent with the United Nations' Sustainable Development Goals (UN-SDGs) targets 7 and 13 of clean energy access and mitigation of climate issues.

In conclusion, for future studies, quantile-on-quantile panel analysis can be conducted as seen in Atsalakis *et al.*[49]
It could be used as a different approach to analyze the impact of biomass energy consumption on the E7 economy and other emerging economies, such as that of sub-Saharan Africa.

References

1. Dumitrescu EI and Hurlin C, Testing for granger non-causality in heterogeneous panels. *Econ model* **29**(4):1450–1460 (2012).
2. Tiba S and Omri A, Literature survey on the relationships between energy, environment and economic growth. *Renew Sustain Energy Rev* **69**:1129–1146 (2017). https://doi.org/10.1016/j.rser.2016.09.113.
3. Bekun FV, Alola AA and Sarkodie SA, Toward a sustainable environment: nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. *Sci Total Environ* **657**:1023–1029 (2019a).
4. Bekun FV, Emir F and Sarkodie SA, Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Sci Total Environ* **655**:759–765 (2019b).
5. Gyamfi BA, Sarpong SY and Bein MA, The contribution of the anthropogenic impact of biomass utilization on ecological degradation: revisiting the G7 economies. *Environ Sci Pollut Res* **28**:11016–11029 (2021).
6. Gyamfi BA, Bein MA, Ozturk I and Bekun FV, The moderating role of employment in an environmental Kuznets curve framework revisited in G7 countries. *Ind J Sustain Account Manag* **4**(2) (2020c).
7. Owusu PA and Asumadu-Sarkodie S, A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Eng* **3**:1–14 (2016). https://doi.org/10.1080/23311916.2016.1167990.
8. Adewuyi AO and Awodumi OB, Biomass energy consumption, economic growth and carbon emissions: fresh evidence from West Africa using a simultaneous equation model. *Energy* **119**:453–471 (2017). https://doi.org/10.1016/j.energy.2016.12.059.
9. Bilgili F, Ozturk İ, Kocak E, Bulut Ü, Pamuk Y, Muğaloğlu E *et al.*, The influence of bio-mass energy consumption on CO2 emissions: a wavelet coherence approach. *Environmental Science and Pollution Research* **23**:19043–19061 (2016).
10. Pao HT, Fu HC and Tseng CL, Forecasting of CO2 emissions, energy consumption and economic growth in China using an improved grey model. *Energy* **40**(1):400–409 (2012).
11. Halicioglu F, An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy* **37**(3):1156–1164 (2009).
12. Danish D, and Wang Z, Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *Sci Total Environ* **670**:1075–1083 (2019). https://doi.org/10.1016/j.scitotenv.2019.03.268.
13. Sarkodie SA, Strezov V, Weldekidan H, Asamoah EF, Owusu PA and Doyi INY, Environmental sustainability assessment using dynamic autoregressive-distributed lag simulations - nexus between greenhouses gas emissions, biomass energy, food and economic growth. *Sci Total Environ* **668**:318–332 (2019). https://doi.org/10.1016/j.scitotenv.2019.02.432.
14. Bildirici ME, Ozaksoy F. The relationship between woody biomass consumption and economic growth: nonlinear ARDL and causality. *J For Econ* **27**:60–69 (2017). https://doi.org/10.1016/j.jfe.2017.01.002.
15. Bildirici ME, Özaksoy F. An analysis of biomass consumption and economic growth in transition countries. *Econ Res Istraživanja* **31**:386–405 (2018). https://doi.org/10.1080/1331677X.2018.1427610.
16. Bildirici ME, Relationship between biomass energy and economic growth in transition countries: panel ARDL approach. *GCB Bioenergy* **6**:717–726 (2014). https://doi.org/10.1111/gcbb.12092.
17. Herbert GJ and Krishnan AU, Quantifying environmental performance of biomass energy. *Renew Sustain Energy Rev* **59**:292–308 (2016).
18. Bilgili F, Koçak E, Bulut Ü and Kuşkaya S, Can biomass energy be an efficient policy tool for sustainable development? *Renew Sustain Energy Rev* **71**:830–845 (2017). https://doi.org/10.1016/j.rser.2016.12.109.
19. Sinha A and Shahbaz M, Estimation of environmental Kuznets curve for CO2 emission: role of renewable energy generation in India. *Renew Energy* **119**:703–711 (2018).
20. Dong K, Sun R and Dong X, CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China. *Sci Total Environ* **640–641**:293–302 (2018). https://doi.org/10.1016/j.scitotenv.2018.05.322.
21. Dogan E and Inglesi-Lotz R, Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: empirical evidence from the panel of biomass-consuming countries. *Energy* **138**:721–727 (2017).
22. Solarin SA, Al-Mulali U, Gan GGG and Shahbaz M, The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. *Environ Sci Pollut Res* **25**(23):22641–22657 (2018).
23. Shahbaz M, Balsalobre D and Shahzad SJH, The influencing factors of CO2 emissions and the role of biomass energy consumption: statistical experience from G-7 countries. *Environ Model Assess* **24**(2):143–161 (2018). https://doi.org/10.1007/s10666-018-9620-8.
24. Shahbaz M, Solarin SA, Hammoudeh S and Shahzad SJH, Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the United States. *Energy Econ* **68**:548–565 (2017a). https://doi.org/10.1016/j.eneco.2017.10.004.
25. Shahbaz M, Rasool G, Ahmed K and Mahalik MK, Considering the effect of biomass energy consumption on economic growth: fresh evidence from BRICS region. *Renew Sustain Energy Rev* **60**:1442–1450 (2016). https://doi.org/10.1016/j.rser.2016.03.037.
26. Ozturk I, A literature survey on energy–growth nexus. *Energy Policy* **38**(1):340–349 (2010).
27. Apergis N and Payne JE, The renewable energy consumption-growth nexus in Central America. *Appl Energy* **88**(1):343–347 (2011).
28. Bildirici M, The relationship between economic growth and energy consumption. *J Renew Sustain Energy* **4**(2):5 (2012).
29. Bildirici M, Economic growth and biomass energy. *Biomass Bioenergy* **50**:19–24 (2013).
30. Payne JE, On biomass energy consumption and real output in the US. *Energy Sources Pt B Econ Plan Policy* **6**(1):47–52 (2011).
31. Apergis N and Danuletiu DC, Renewable energy and economic growth: evidence from the sign of panel long-run causality. *Int J Energy Econ Policy* **4**(4):578–587 (2014).
32. Sebri M and Ben-Salha O, On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: fresh evidence from BRICS countries. *Renew Sustain Energy Rev* **39**:14–23 (2014).
33. Ozturk I and Bilgili F, Economic growth and biomass consumption nexus: dynamic panel analysis for sub-Sahara African countries. *Appl Energy* **137**:110–116 (2015).
34. Bilgili F and Ozturk I, Biomass energy and economic growth nexus in G7 countries: evidence from dynamic panel data. *Renew Sustain Energy Rev* **49**:132–138 (2015).

35. Gyamfi BA, Bein AM and Bekun VF, Investigating the nexus between hydroelectricity energy, renewable energy, non-renewable energy consumption on output: evidence from E7 countries. *Environ Sci Pollut Res* **27**:25327–25339 (2020b). https://doi.org/10.1007/s11356-020-08909-8.
36. Kim G, Choi SK and Seok JH, Does biomass energy consumption reduce Total energy CO2 emissions in the US? *J Policy Model* **42**:953–967 (2020).
37. Baležentis T, Streimikiene D, Zhang T and Liobikiene G, The role of bioenergy in greenhouse gas emission reduction in EU countries: an environmental Kuznets curve modelling. *Resour Conserv Recycl* **142**:225–231 (2019).
38. Hakimi A and Hamdi H, Trade liberalization, FDI inflows, environmental quality and economic growth: a comparative analysis between Tunisia and Morocco. *Renew Sustain Energy Rev* **58**:1445–1456 (2016).
39. Ulucak R, Linking biomass energy and CO2 emissions in China using dynamic autoregressive-distributed lag simulations. *J Clean Prod* **250**:119533 (2020).
40. Mahmood N, Wang Z, Yasmin N, Manzoor W and Rahman A, How to bend down the environmental Kuznets curve: the significance of biomass energy. *Environ Sci Pollut Res* **26**:21598–21608 (2019).
41. United Nations, 2015. Sustainable development goals. Available: sustainabledevelopment.un.org/?menu=1300.
42. Shahbaz M, Balsalobre-Lorente D and Sinha A, Foreign direct investment– CO2 emissions nexus in Middle East and north African countries: importance of biomass energy consumption. *J Clean Prod* **217**:603–614 (2019). https://doi.org/10.1016/j.jclepro.2019.01.282.
43. Pedroni P, Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econ Theor* **20**:597–625 (2004).
44. Pedroni P, Purchasing power parity tests in cointegrated panels. *Rev Econ Stat* **83**:727–731 (2001).
45. Kao C and Chiang MH, On the estimation and inference of a Cointegrated regression in panel data, in *Nonstationarity Panels, Panel Cointegration and Dynamic Panels. Advances in Econometrics, Vol. 15*, ed. by Baltagi BH. Amsterdam, JAI Press (Elsevier Science), pp. 179–222 (2000).
46. Kao C, Spurious regression and residual-based tests for cointegration in panel data. *J Econ* **90**:1–44 (1999).
47. Kais S and Sami H, An econometric study of the impact of economic growth and energy use on carbon emissions: panel data evidence from fifty eight countries. *Renew Sustain Energy Rev* **59**:1101–1110 (2016). https://doi.org/10.1016/j.rser.2016.01.054.
48. Alam MM, Murad MW, Noman AHM and Ozturk I, Relationships among carbon emissions, economic growth, energy consumption and population growth: testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. *Ecol Indic* **70**:466–479 (2016). https://doi.org/10.1016/j.ecolind.2016.06.043.
49. Atsalakis GS, Bouri E and Pasiouras F, Natural disasters and economic growth: a quantile on quantile approach. *Ann Operat Res*:1–27 (2020). https://doi.org/10.1007/s10479-020-03535-6.



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