Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

Asymmetric linkage between biomass energy consumption and ecological footprints in top ten biomass-consuming nations

Yongrong Xin, Huaizheng Li, Tomiwa Sunday Adebayo & Abraham Ayobamiji Awosusi

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 3, 2147567
https://doi.org/10.1080/1331677X.2022.2147567

Asymmetric linkage between biomass energy consumption and ecological footprints in top ten biomass-consuming nations

Yongrong Xin[a], Huaizheng Li[b], Tomiwa Sunday Adebayo[c] and Abraham Ayobamiji Awosusi[d]

[a]Business School, Jiangsu Open University, Nanjing, China; [b]School of Marxism, University of International Business and Economics, Beijing, China; [c]Department of Economics, Faculty of Economics and Administrative Science, Cyprus International University, Nicosia, Turkey; [d]Department of Economics, Faculty of Economic and Administrative Science, Near East University, Nicosia, Cyprus

ABSTRACT

In the current sustainable growth framework, the role of renewable energy cannot be overemphasized. Furthermore, several sustainable development targets necessitate the optimal utilization of biomass energy. Their benefits, trade-off dynamics, and implementation vary according to geography, necessitating an in-depth examination to manage their influence. Therefore, we investigated the impact of biomass energy utilization on the ecosystem in the top ten biomass-consuming nations: India, Austria, Brazil, China, Germany, Sweden, Finland, Italy, the United Kingdom, and the United States. To compare the impact of biomass energy utilization on ecological footprint, this study employed a quarterly dataset covering the period between 1970 and 2018. To achieve this objective, we used the Quantile-on-Quantile approach, which suggests that biomass improves environmental quality in six nations (i.e. Austria, Brazil, China, Germany, Sweden, and United Kingdom) but it degrades the environment in the other countries (i.e. Finland, Italy, India, and the USA). Furthermore, the study employed the Granger causality test in quantile, and the results indicate that biomass energy utilization and ecological footprint can predict each other in nine nations (i.e. Austria, Brazil, China, Germany, Sweden, Finland, Italy, UK, and the USA). However, for India, we detected the absence of causality between biomass energy and ecological footprint. Based on this outcome, this study suggests policies such as intensifying and coordinating the transition from traditional to contemporary biomass, which might increase the green impacts of biomass use, hence lowering environmental degradation. This transition will strengthen the energy efficiency of biomass energy generation, providing additional opportunities to revitalize the forest areas.

Abbreviations: BIO: Biomass energy usage; CO_2e: Carbon emissions; ECF: Ecological footprint; IEA: International Energy Agency;

ARTICLE HISTORY
Received 18 August 2022
Accepted 10 November 2022

KEYWORDS
Biomass energy; ecological footprint; quantiles on quantiles; Granger causality-test in quantile

JEL CODES
Q54; Q56; Q13; Q18

CONTACT Huaizheng Li bipai18987@163.com

QQ: quantile-on-quantile; QQR: Quantile-on-Quantile Regression; SDGs: Sustainable Developmental Goals

1. Introduction

Since a rise in a country's energy demand has characteristics that are comparable to economic development and expansion, the degree of energy utilization is used as a measure of development (Adekoya et al., 2022; Raza et al., 2017; Sharif et al., 2022). One can observe that the body of research on the influence of energy on economic expansion is continuously expanding. Several studies in the energy literature support the positive interaction between growth and energy usage (Fareed et al., 2021; Ozturk & Acaravci, 2016). Expansion in energy consumption is caused by population growth, transportation, industry, urbanization, and economic expansion. According to the International Energy Agency (IEA), global primary energy usage increased by 12.68% between 2010 and 2018, with fossil fuels[1] meeting a significant portion of this demand.

In other words, fossil fuels are essential to the world's survival. On a global basis, this reliance causes two significant issues, the first of which is energy security (Kirikkaleli & Adebayo, 2021). There are numerous consequences to the energy security concern, including failures in energy supply and price shocks in energy. Such a trade imbalance in economies causes inflationary pressures and a detrimental impact on country output and competitiveness, significantly enhancing the reliance on energy-importing nations (Miao et al., 2022; Xuefeng et al., 2022). The second issue is the environmental degradation caused by fossil fuels. Fossil energy sources contribute to several environmental issues, including climate change, global warming, local air pollution, and acid rain (Abbasi et al., 2022; Adedoyin et al., 2021; Bilgili et al., 2022). Moreover, at the United Nations, Climate Change Conference (COP26) in Glasgow, a variety of significant concerns about global warming were highlighted, which require unprecedented efforts to promote a sustainable environment. These efforts entail the development of appropriate energy policies which could reduce the reliance on fossil fuels while minimizing environmental degradation, which will help achieve sustainable growth. However, such regulations would incur substantial risks and costs, although the benefits outweigh the substantial risks and costs (He et al., 2021; Irfan et al., 2022).

Biofuels, biomass, hydropower, hydrogen, ocean wave, wind, solar, and geothermal energy are all examples of renewable energy sources. They are regarded as being environmentally friendly. Especially when properly utilized; their environmental impact will be minimized and generate minimal secondary waste (Ibrahim et al., 2022; Yuping et al., 2021). As a result, the general public and policymakers are enthusiastic about renewable energy sources (Le & Ozturk, 2020; Xu et al., 2021). Biomass is one of the most widely regarded renewable energy sources (Bilgili, 2012). It is considered to be more desirable than other renewable energy sources for a variety of reasons. The first explanation is related to the percentage of primary energy demand met by biomass sources, about 10% of the primary energy demand globally (IEA, 2020). Additionally, biomass accounts for about 77% of global renewable energy consumption (IEA 2020). The second reason is that even though the globe has vast amounts of renewable biomass sources, only 7% of biomass energy potential is being used (Bilgili et al., 2016).

Biomass energy offers significant political, economic, and environmental benefits and is an alternative to fossil fuels. Biomass can potentially safeguard energy-importing economies from the politically unstable experience in energy-exporting countries (Bilgili et al., 2017). As a result, biomass can reduce energy reliance while contributing to national energy security. Energy-importing nations can reduce trade imbalances by substituting biomass for fossil fuels (Omer, 2005). Furthermore, biomass energy has the potential to regenerate unsuitable soils, increase biological variety, retention of water and soil fertility (Sarkodie et al., 2019). Consequently, biomass energy could help developing economies reduce poverty by increasing employment in rural regions and strengthening the agricultural economy (Solarin et al., 2018). Moreover, biomass has the potential to boost economic growth. As a result, policymakers may want to encourage biomass energy utilization in rural and urban areas (Bilgili et al., 2017). Additionally, biomass enables central banks to maintain price stability, increase global competitiveness, and boost economic output (Bilgili et al., 2016). However, furthering the exploitation of biomass energy increases the risks in terms of conversion of natural areas into controlled monocultures, contamination of coastal waters with agricultural toxins, exposure of food supply or farm livelihoods to risk due to land competition, and an increase in the level of pollution to the environment resulting from greater energy-intensive production technology or deforestation. These phenomena are evident, thereby justifying our concerns. As investments in biomass energy increase, there has been an intensive and continuing discussion concerning maintaining the balance between the positive and negative aspects of biomass energy utilization. Therefore, the environmental effect of biomass energy needs to be investigated.

However, prior studies offer contrasting outcomes regarding the environmental effect of biomass energy. For instance, Wang et al. (2020) established that biomass energy utilization positively interacts with ecological footprint, resulting in environmental deterioration. However, in the study conducted in Australia by Sarkodie et al. (2019), it was concluded that there is no significant effect on ecological footprint. Still, Sulaiman et al. (2020) confirmed a negative connection between biomass energy utilization and environmental degradation. Furthermore, the connection between biomass energy usage and ecological footprint has been addressed in prior studies for many economies, but as discussed in the second section of the current research, no investigation for the top ten biomass energy usage consumers is currently available. Lastly, Several studies have investigated the connection between different forms of renewable energy, such as nuclear energy (Bandyopadhyay et al., 2022; Mishra et al., 2020; Sharif et al., 2022), hydro energy (Chang et al., 2022a), wind energy (Chang et al., 2022b), natural resources (Razzaq et al., 2022a) and solar energy (Sharif et al., 2021) using the novel '*quantile-on-quantile (QQ)*' approach. This motivates us to conduct a thorough examination of the dynamic relationship between biomass energy consumption and ecological footprint

The present work adds to the existing literature in the following ways: (i) Most existing research has utilized the panel data technique, which offers uniform outcomes on the biomass energy usage-ecological footprint association, even though certain nations exhibit no independent proof that such a relationship is established. However, the current research employs the novel *'quantile-on-quantile (QQ)'* approach, which can analyze the time-series dependency for each nation specifically to provide country-specific findings for the connection between parameters. This approach captures the regressor's effect on the intended policy indicator across the dataset obtained via quantile decomposition. (ii) The connection between biomass energy usage and ecological footprint has several complexities, which conventional econometric approaches cannot capture. For instance, the pattern of environmental degradation (ecological footprint) will react differently to biomass energy consumption when the economy is in a boom period compared to a period of economic downturn. Also, a high level of biomass energy utilization may have a distinct impact on ecological footprint compared to a low-level consumption of biomass energy. (iii) The effect of biomass energy utilization on ecological footprint would be heterogeneous and varying when the capability for generation varies. In the framework, the QQ approach proved to be a highly useful methodology, allowing for a detailed assessment of the essential interaction between biomass energy utilization and ecological footprint that would generally be impossible to achieve using standard techniques. (iv) This research investigates the nonlinear or asymmetric impacts of the quantiles of biomass energy usage on the quantiles of ecological footprint, with the findings describing the connection between these parameters used at both the bottom, middle, and top-tailed quantiles of the data distribution. We anticipate an asymmetric connection between biomass energy usage and ecological footprint due to underlying dispersion properties whereby economic parameters usually follow a nonlinear or asymmetric trend. (v) This research would be useful for governments and other stakeholders to consider their options in terms of biomass energy utilization and environmental regulations at distinct levels of biomass energy utilization and ecological footprint. It also makes crucial suggestions that will facilitate the pathway for subsequent studies on the connection between biomass energy utilization and ecological footprint and its ramifications for different world economies, specifically the top ten biomass-consuming economies. Therefore, concentrating on these nations could be valuable for supporting strong policy initiatives to achieve sustainable development.

The current work is as follows: Section 2 reviewed earlier studies and theoretical frameworks relevant to the topic issue. Section 3 contains the data and methods. Section 4 contains the findings and discussion of the results, while Section 5 will concentrate on the conclusion and policy recommendations.

2. Literature review

The interconnection between renewable energy usage and the environment in the long term has been scrutinized strongly in several works of literature. However, the influence regarding its positive or negative effect is continuously contentious. This can be accredited to the form of renewable energy used in the country. Thus, the interaction between renewable energy and environmental degradation is interwoven with the degree of innovation, financial development, and a country's natural resource capacity. On the flip side, the contentious issue over whether the expansion of energy utilization in the form of renewable energy is linked to enhanced environmental quality or if a high degree of renewable energy has resulted in environmental degradation merits more examination.

We emphasize that the interconnection between biomass and the environment has been addressed in two-strand of literature. The first is the time series assessment of this interaction. Kim et al. (2020) analyzed the monthly dataset from 1973 to 2013 to inspect the interaction between carbon emissions and biomass energy utilization in the USA. The authors concluded that reduction in carbon emissions could be achieved through biomass energy in the USA. Furthermore, they conclude that energy policy should encourage an upsurge in biomass output towards mitigating the level of emissions. Katircioglu (2015) probed into a similar investigation in Turkey using the annual dataset ranging between 1980 and 2010 using the ARDL approach. The author detected an adverse interconnection between biomass energy utilization and carbon emissions. Bilgili et al. (2016) employed the wavelets coherence technique to assess the interaction between biomass energy and carbon emission in the USA using the monthly dataset ranging from 1984 to 2015. They suggested that in the short term (1–4 years period), the influence of biomass energy utilization on carbon emission was positive between 1984 and 2005; however, in the long term (4–8 years period), biomass utilization minimizes the level of emissions in the USA, indicating a negative connection for the period between 2006 and 2015.

Also, the study of Bilgili, (2012) in the USA suggested a negative association between biomass energy utilization and carbon emission between January 1990 and September 2011. Ulucak (2020) deployed the dynamic ARDL procedure to inspect the interrelation between biomass energy and carbon emissions in China using the dataset covered between 1982 and 2017 and confirmed a negative connection between biomass energy utilization and carbon emissions. Furthermore, the author suggests that the Chinese's objectives concerning sustainable energy could be met by reducing carbon emissions and substituting biomass energy for fossil fuels (Razzaq et al., 2022). Hadj (2021) employed a more comprehensive metric for environmental degradation (ecological footprint) to inspect the interconnection between biomass energy utilization and the environment in Saudi Arabia. The author employed the annual dataset between 1984 and 2017 and established that a positive variation in biomass energy utilization in Saudi Arabia will mitigate the country's environmental degradation level. In contrast, the negative variation of biomass energy utilization on ecological footprint is insignificant. A similar outcome regarding insignificant was established by the study done for the case of Australia by Sarkodie et al. (2019) using the DARDL approach for the period between 1970 and 2017. The literature review regarding the use of time series analysis has been summarized in Table 1. It discloses the researchers' names, study period, investigated nation, and outcome.

For the panel dataset, Shahbaz et al. (2019) discovered a negative interconnection between biomass energy usage and carbon emissions in MENA (Middle East and North African) economies for the timeline between 1990 and 2015. Sulaiman et al. (2020) utilized the POLS, DOLS, and FMOLS approach to detect the interconnection

Table 1. Summary of literature reviewed for time series analysis.

Researchers	Period of investigation	Country	Outcome
Kim et al. (2020)	1973M1-2013M12	USA	BME→CO_2e (-)
Katircioglu (2015)	1980–2010	Turkey	BME→CO_2e (-)
Bilgili et al. (2016)	1984M1-2015M12	USA	Outcome differs
Bilgili (2012)	1990M1-2011M9	USA	BME→CO_2e (-)
Ulucak (2020)	1982–2017	China	BME→CO_2e (-)
Hadj (2021)	1984–2017	Saudi Arabia	BME^{+}→ EF (-) $BME^{-} \neq$ EF
Sarkodie et al. (2019)	1970–2017	Australia	BME $\neq$ EF (+)

BME: Biomass energy usage, CO_2e: Carbon emissions, EF: Ecological footprint.
Source: Authors compilation.

between CO_2 emissions and biomass energy in twenty-seven EU member economies employing the data which covered the timespan between 1990 and 2017 and confirmed a negative connection between biomass energy utilization and carbon emissions. The study by Dogan and Inglesi-Lotz (2017) scrutinized the interrelationship between biomass energy and carbon emission, which spanning between 1985 and 2012 in twenty-two nations. The authors' findings buttress the global consensus that investment in infrastructure and supply of biomass energy is a viable approach for energy policymakers to take in their attempts to minimize long-term environmental degradation. Gao and Zhang (2021) detected a negative connection between biomass energy utilization in thirteen Asian developing nations for the period spanning from 1980 to 2010.

The study by Aydin (2019) looked into the interaction between biomass energy utilization and carbon emission for BRICS economies and detected a negative connection between biomass energy utilization and carbon emission. Furthermore, they suggested that these nations increase their biomass energy usage to strengthen the economy and minimize energy reliance. The study by Sulaiman and Abdul-Rahim (2020) established an adverse interaction between biomass energy utilization and carbon emissions. Ahmed et al. (2016) used the PARDL approach to scrutinize the interaction between biomass energy utilization and carbon emissions and confirmed that utilizing biomass energy decreases carbon emissions but is insignificant. The authors concluded that the insignificant is due to the small percentage of biomass energy accounts in the overall energy of these nations. Danish and Wang (2019) looked into the connection between biomass energy utilization and carbon emissions in BRICS nations and confirmed a negative association between biomass energy utilization and carbon emissions. Solarin et al. (2018) suggested that an upsurge in the utilization of biomass energy increases carbon emissions in eighty selected nations.

Furthermore, some studies employed a more comprehensive metric of environmental degradation when compared to carbon emission. For instance, Wang et al. (2020) studied the interconnection between biomass energy utilization and the ecological footprint of G-7 economies. The authors established that biomass energy utilization positively interacts with the ecological footprint, resulting in environmental deterioration in these countries. Conversely, the work of Yasmeen et al. (2022) in Belt & Road economies probed into the relations between ecological footprint and biomass energy utilization for the timeline between 1992 and 2017. It confirmed a negative connection between ecological footprint and biomass energy utilization.

Table 2. Summary of literature reviewed for panel data analysis.

Researchers	Period of investigation	Country	Outcome
Shahbaz et al. (2019)	1990–2015	MENA	BME→CO_2e (-)
Sulaiman et al. (2020)	1990–2017	twenty-seven EU member economies	BME→CO_2e (-)
Dogan and Inglesi-Lotz (2017)	1985–2012	twenty-two economies	BME→CO_2e (-)
Gao and Zhang (2021)	1980–2010	thirteen Asian developing nations	BME→CO_2e (-)
Aydin (2019)	1992–2013	BRICS	BME→CO_2e (-)
Sulaiman and Abdul-Rahim (2020)	1980–2015	eight African nations	BME→CO_2e (-)
Solarin et al. (2018)	1980–2010	eighty selected nations	BME→CO_2e (+)
Ahmed et al. (2016)	1980–2010	twenty-four EU economies	BME ≠ CO_2e (-)
Danish and Wang (2019)	1992–2013	BRICS	BME→CO_2e (-)
Wang et al. (2020)	1980–2016	G7 economies	BME → EF(+)
Yasmeen et al. (2022)	1992–2017	Belt & Road economies	BME → EF(-)
Awosusi et al. (2022)	1992–2018	BRICS	BME →EF (-)

BME: Biomass energy usage, CO_2e: Carbon emissions, EF: Ecological footprint.
Source: Authors compilation.

Likewise, the research of Awosusi et al. (2022a) detected a negative relation between ecological footprint and biomass energy utilization for the period that spans from 1992 to 2018 (Jin et al., 2021). The literature on the interrelationship between biomass energy utilization and environmental deterioration is equivocal. The absence of definitive conclusions necessitates further academic investigation, potentially using a more precise scientific approach. Identifying the connection path could provide more perspective for policymakers in crafting appropriate environmental policies. Table 2 summarizes the literature concerning the application of panel data analysis by revealing the researchers' names, study time, country researched, and findings.

Reviewing the extant literature reveals that extensive research on the environmental impact of biomass energy has been conducted in the United States (e.g., Aydin, 2019; Bilgili, 2012; Bilgili et al., 2016; Danish & Wang, 2019; Kim et al., 2020), and European nations (e,g, Ahmed et al., 2016; Sulaiman et al., 2020). Also, Asian economies, either as a single nation just like the case of China (e.g., Ulucak, 2020), Australia (e,g., Sarkodie et al., 2019) or as a group (e.g., Gao & Zhang, 2021; Liu, Saydaliev, et al., 2022; Yasmeen et al., 2022) probed into the biomass energy and environment nexus. Furthermore, the use of several econometric approaches (MMQR, ARDL, GMM, NARDL and many more) are employed to probe the nexus.

However, extant studies have probed into the environmental effect of biomass energy in different countries. Therefore there is currently no research that examines such a nexus for the top biomass-consuming nation in a single study using ecological footprint to measure environmental degradation. Additionally, the quantile techniques like QQ have not been used in this research to conduct quantile-based analysis. We acknowledge the study of Liu, Razzaq, et al. (2022) probed into the connection between biomass energy and CO_2 emissions for top biomass-consuming nations. However, this study did not employ ecological footprint, which is a more comprehensive measure of environmental degradation than CO_2 emissions (Akadiri et al., 2022). Also, the study failed to conduct a causality-based quantiles assessment. Based on this, we concluded that there is a gap in the literature. As a result, we probed into the biomass energy and ecological footprint nexus for top biomass-consuming nations. We employed a comprehensive quantile-based analysis, which adds to the existing literature.

3. Theoretical framework, data and method

3.1. Theoretical framework

Energy is acknowledged as a fundamental factor for production, and increasing energy utilization is favorable for enhancing economic output (Liu, Zhang, et al., 2022; Wang et al., 2023). On the other hand, rising energy usage influences environmental deterioration due to energy combustion, particularly fossil fuels. Therefore, the rise in the usage of fossil fuels degrades the environment. Lowering dependence on non-renewable energy and optimizing their use will culminate in improved energy efficiency, contributing to the reduction in energy utilization, and emissions as well as the replacement of fossil fuel. Therefore, using biomass energy can benefit any nation by achieving environmental sustainability. Biomass energy consumption is a vital aspect of the attempts to achieve sustainability in discussions regarding policies of climate change and practices that are regarded as relevant for sustainable growth across the world (Umar et al., 2021). Biomass energy is important since it is one of the primary sources that may be utilized to reduce carbon emissions. Furthermore, it is projected that biomass energy utilization will have an adverse effect on carbon emissions because it enables modern and improved means of generating and utilizing energy. By changing the energy generation and utilization pattern with biomass energy, the world could efficiently strengthen and contribute to economic expansion while also reaffirming its environmental regulations. In this context, improvements in biomass resource availability would provide a solid structure for a sustainable energy infrastructure that promotes a sustainable lifestyle. Biomass energy is one of the most significant forms of green energy, providing a viable option to the usage of fossil fuels due to its clean and ubiquitous nature. In this relation to this theoretical viewpoint mentioned above, the functional form for this current study is as follows:

$$\mathrm{ECF}_t = f(BIO_t) \qquad [1]$$

Where: ECF and BIO indicate ecological footprints and biomass energy use, respectively.

3.2. Data

The dataset in this current study covers two variables: ecological footprint, the endogenous variable, and the exogenous variable, biomass energy consumption. The emphasis of this current study is centered on the top ten economies with the highest biomass energy usage in the world. The study employs the quarterly dataset, which covers the period between 1970 and 2017. However, the unavailability of data constraints the period of study. The ecological footprint data was sourced from Global Footprint Network, measured in Gha per capita. Biomass energy consumption is sourced from the Material Flows Database and measured in tons per capita. Figures 1 and 2 present the flow trend of the variables. Furthermore, these data are transformed into the form of their logarithm. The flow of analysis is depicted in Figure 3.

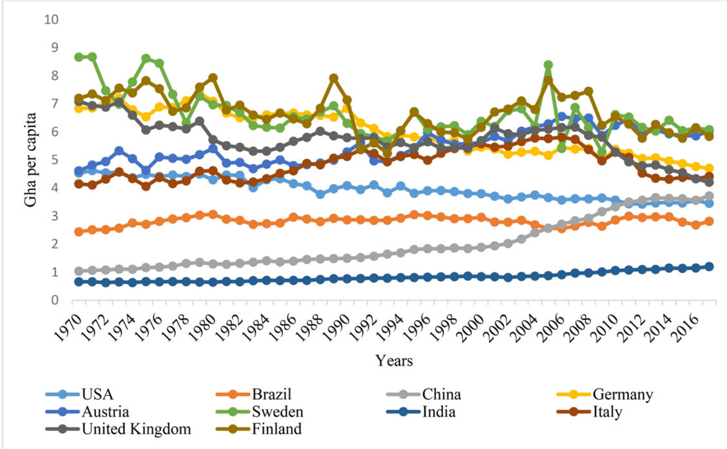

Figure 1. The trend of ecological footprint for the selected nations.
Sources: Global Footprint Network (GFN, 2022)

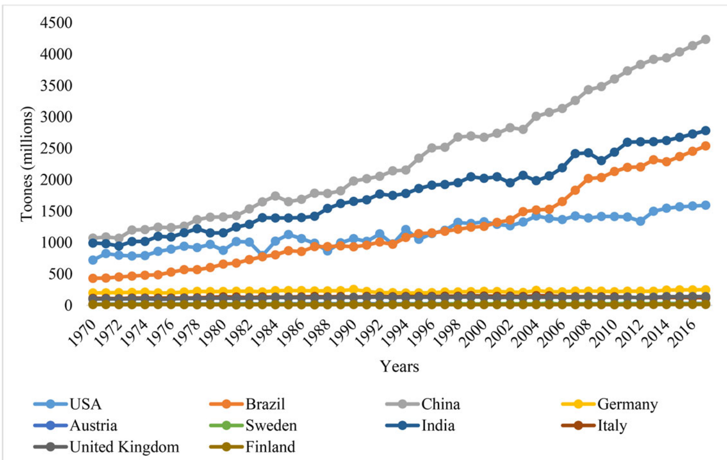

Figure 2. The trend of biomass energy for the selected nations.
Sources: Material Flows Database (MFD, 2022)

3.3. Methodology

This section presents the techniques employed in exploring the effect of biomass energy consumption on ecological footprint. The flow of analysis is presented in Figure 3.

3.3.1. Quantile cointegration

This investigation is unique in that it detects the effect of various frequencies of one parameter on another parameter's amplitude, location, and shape. We apply the Quantile cointegration test Xiao (2009) developed. The standard cointegrating approach includes endogeneity limits by deconstructing the cointegrating procedure defects into lead-lags, which is a unique novelty by adding the (Saikkonen, 1991)

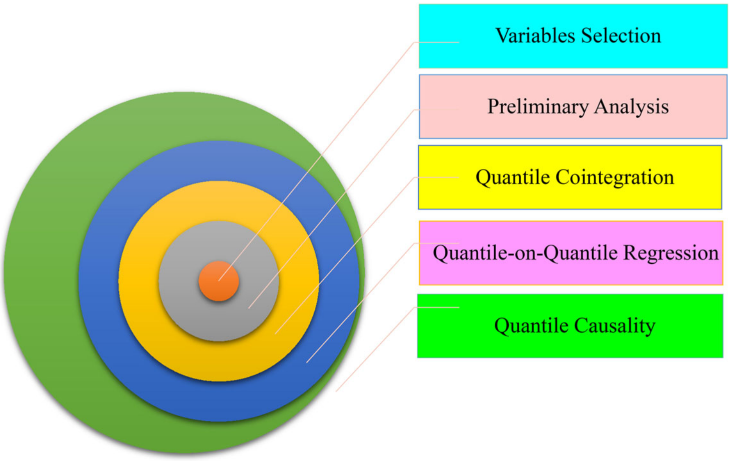

Figure 3. Flow of the study.
Source: Authors compilation.

principles. This model, which expands the (Engle & Granger, 1987) cointegration model, includes the constant vector. This is defined as

$$Y_t = \propto + \beta^{`} Z_t + \sum_{j=-k}^{k} \Delta Z^{`}_{t-j} \prod_j + \mu_t \quad [2]$$

$$Q_t^Y \left(Y_t | I_t^Y . I_t^z \right) = \propto (\tau) + \beta(\tau)' Z_t + \sum_{j=-k}^{k} \Delta Z^{`}_{t-j} \prod_j + F_u^{-1}(\tau) \quad [3]$$

The quadratic term incorporated to the regressor, showing Equation (4):

$$Q_t^Y \left([\![Y_t | I]\!]_t^Y . I_t^z \right) = \propto (\tau) + \beta(\tau)' Z_t + \gamma(\tau)' Z^2{}_t + \sum_{j=-k}^{k} \Delta Z'_{t-j} \prod + \sum_{j=-k}^{k} \Delta Z^{2'}{}_{t-j} \prod F_u^{-1}(\tau) \quad [4]$$

In equation (4), the null hypothesis for the model is H_0: $\beta(\tau) = \beta$ for all quantiles.

3.3.2. Quantile-on-quantile regression (QQR) approach

The work explores the interrelation between biomass energy usage and ecological footprint for a certain nation under investigation deploying the novel QQR approach suggested by Sim and Zhou (2015), which has been undertaken by other studies such (Mishra et al., 2019; Shahzad et al., 2017; Sharif et al., 2019; Xu et al., 2021). The QQR technique is included in the Quantile model, which examines the influence of the quantile of renewable energy on the quantile of ecological footprint. This unique method combines non-parametric assessment with quantile regression. The standard Quantile Regression model investigates the impact of biomass energy usage on various quantiles of ecological footprint. In addition, the usual Linear Regression model analyzes the influence of a certain quantile of the exogenous variable on the endogenous variable. The QQ technique merges these two conventional methods to frame biomass quantiles and ecological footprint interrelationships. Compared to other previously used evaluation approaches, like the Ordinary Least Squares model and Quantile Regression, this provides a detailed representation of the relationship between the parameters under consideration. The following is the framework for the QQ model, which is centered on the Non-Parametric Quantile Regression model.

$$Y_t = \beta^{\vartheta}(X_t) + \mu_t^{\theta} \quad [5]$$

Where: the endogenous parameter is depicted by Y_t, Xt represents the regressors; subscript t represents the period of concern, the θth quantile of Y conditional distribution is represented by θ, the error term of the Y conditional distribution is depicted by μ. The adopted QQ model shows the effect of biomass energy usage on the ecological footprint of the world's top 10 biomass energy-consuming countries.

The selection of appropriate bandwidth is critical in a non-parametric analysis due to its critical function in influencing the smoothness of the estimates. Increased bandwidth indicates more bias intensity, whereas decreased bandwidth indicates greater variation in estimates. The right bandwidth decision is critical in achieving an equilibrium between bias and variation in estimates. Depending on the research of Sim and Zhou (2015), we used the bandwidth limitation $h = 0.05$ in this study.

3.3.4. Granger causality in quantiles

The present study improves the environmental literature by employing the Granger causality in quantiles, a novel econometric approach developed by Troster (2018). Granger (1969) asserts that if X_i cannot anticipate Z_i, it implies that X_i does not cause Z_i. Consider the vector $\left(\mathcal{M}_i = \mathcal{M}_i^{\mathcal{Z}}, \mathcal{M}_i^{\mathcal{X}}\right) \in \Re^{e}$, $e = o + q$. where $\mathcal{M}_i^{\mathcal{X}}$ is the preceding evidence series of $\mathcal{X}_i$ $\mathcal{M}_i^{\mathcal{X}} = (\mathcal{X}_{i-1}, \ldots\ldots \mathcal{X}_{i-q})' \in \Re^{q}$ Furthermore, the null hypothesis (H_o) is illustrated as follows.

$$\mathcal{H}_{o}^{\mathcal{X} \nrightarrow \mathcal{Z}} : \mathcal{F}\mathcal{Z}\left(\mathcal{Z}\middle|\mathcal{M}_{i}^{\mathcal{Z}}, \mathcal{M}_{i}^{x}\right) = \mathcal{F}\mathcal{Z}\left(\mathcal{Z}\middle|\mathcal{M}_{i}^{\mathcal{Z}}\right) \text{for all } \mathcal{X} \epsilon \Re, \quad [7]$$

$\mathcal{F}\mathcal{Z}\left(.\middle|\mathcal{M}_i^{\mathcal{Z}}, \mathcal{M}_i^{x}\right)$ is viewed as $\mathcal{Z}i$'s conditional scattering function provided that $\mathcal{M}_i^{x}, \mathcal{M}_i^{z}$ are within the scope of the null hypothesis, as indicated by Equation 6. We used Troster (2018) study to evaluate the Dt test, which identifies the structure of QA $(\cdot)$ for all $\pi \in \Gamma \subset [0,1]$, based on the Granger causality null hypothesis. The same can be formulated as follow:

$$QAR(1) : m_1\left(\mathcal{M}_i^{\mathcal{Z}}\middle|\partial(\pi)\right) = \lambda 1(\pi) + \lambda 2(\pi)\mathcal{Z}_{i-1} + \mu t \psi_{\mathcal{X}}^{-1}(\pi) \quad [8]$$

Here $\partial(\pi) = \lambda 1(\pi), \lambda 2(\pi)$ and μt are re-assessed by the likelihood of supremacy in quantiles grid region that is equivalent, and $\psi_{\mathcal{X}}^{-1}(\cdot)$ is the inverse of a regular conventional dispersion function. We may subsequently alter the causality sign between parameters by assessing the QAF framework in Equation 7 with the lagged parameter to another parameter. The QAR (1) is shown in Equation 8:

Table 3. Descriptive statistics for biomass energy utilization and ecological footprints.

	Mean	Maximum	Minimum	Std. Dev.	Jarque-Bera	ΔADF	ΔPP
Panel A: Biomass energy consumption							
Austria	0.7745	0.8925	0.6528	0.0592	7.2321**	−6.3077*	−4.9308*
Brazil	1.8425	3.0822	1.1160	0.5807	19.6946*	−5.5630*	−4.8258*
China	0.4944	0.7685	0.3079	0.1369	15.7343*	−5.7258*	−4.3053*
Germany	0.6884	0.8091	0.6025	0.0479	7.5713**	−5.5581*	−4.5573*
India	0.4662	0.5221	0.4052	0.0308	7.4648**	−5.5869*	−4.1751*
Sweden	0.5929	1.0923	0.4120	0.1080	296.8560*	−6.8638*	−6.3738*
Finland	0.6036	0.7746	0.4661	0.0696	2.7663	−5.7014*	−4.4152*
Italy	0.5822	0.6825	0.4913	0.0511	9.9893*	−6.0862*	−4.5493*
UK	0.5252	0.5829	0.4309	0.0357	19.9594*	−6.2034*	−4.6309*
USA	1.0825	1.2270	0.8003	0.1010	11.5432*	−4.8407*	−5.5360*
Panel B: Ecological footprint							
Austria	1.3670	1.6455	1.1281	0.1419	13.0650*	−4.4442*	−4.2487*
Brazil	0.7034	0.7696	0.5991	0.0385	12.2901*	−5.0413*	−4.3827*
China	0.4979	0.9542	0.2542	0.2166	27.7255*	−3.9491**	−4.0262*
Germany	1.5004	1.8497	1.1726	0.1947	15.9950*	−5.7637*	−4.2601*
India	0.2050	0.3050	0.1557	0.0409	21.6498*	−4.1911*	−4.3857*
Sweden	1.6588	2.2142	1.2935	0.2071	46.5299	−6.5573*	−6.8766*
Finland	1.6678	2.0081	1.2881	0.1753	5.0017	−5.4565*	−4.3817*
Italy	1.2117	1.4526	1.0088	0.1352	15.2241*	−5.0412*	−4.6939*
UK	1.4305	1.7892	1.0430	0.1610	0.8905	−3.5999*	−4.5317*
USA	0.9916	1.1556	0.8404	0.0938	15.2582*	−4.7559*	−6.9068*

Source: Authors compilation.

$$\mathcal{Q}_{\pi}^{\mathcal{Z}} = \left(\mathcal{Z}_i \middle| \mathcal{M}_i^{\mathcal{Z}}, \mathcal{M}_i^{x}\right) = \lambda 1(\pi) + \lambda 2(\pi)\mathcal{Z}_{i-1} + \eta(\pi)\mathcal{X}_{i-1} + \mu \ell \psi_{\mathcal{X}}^{-1} \quad [9]$$

4. Results and discussion

The preliminary and major outcomes of this research along with discussion, are disclosed in this part of the article

4.1. Preliminary findings

The outcomes of the descriptive statistics and the unit root test of biomass energy utilization and ecological footprints for the top 10 biomass energy usage nations are presented in Table 3. For biomass energy utilization. Brazil has the highest average value of 1.8425 tons per capita, ranging from 1.1160 to 3.0822. The USA has the second average value of 1.0825 tons per capita, with value range of 0.8003 and 1.2270. Also, Austria and Germany are ranked third and fourth with average values of 0.7745 and 0.6884 tons per capita, respectively. For ecological footprint, Finland has the highest mean value of 1.6678 Gha per capita, ranging between 1.2881 and 2.0081. Sweden has the second-highest average value of 1.6588 Gha per capita, ranging between 1.2935 and 2.2142. Germany and the United Kingdom are ranked third and fourth with average values of 0.7745 and 0.6884 Gha per capita, respectively. Furthermore, as indicated in Table 3, the Jarque-Bera results for biomass energy utilization are not normally distributed for all economies except for Finland, whose dataset is normally distributed. Also, the dataset for ecological footprint is not normally distributed for all selected nations except for Sweden and Finland. The outcomes from the Jarque-Bera statistics justify the use of the QQ approach. In addition, the

Table 4. Outcomes of the quantile cointegration test.

Model	Coefficient	$Sup_{\tau}\lvert V_{\pi}(\tau)\rvert$	CV1	CV5	CV10
Austria	β	8484	7035	5365	3254
ECF_t Vs BIO_t	α	785	624	476	283
Brazil	β	6015	4555	3370	1925
ECF_t Vs BIO_t	α	463	220	138	82
China	β	5866	4075	3283	2145
ECF_t Vs BIO_t	α	567	408	283	124
Germany	β	7868	5096	3836	1923
ECF_t Vs BIO_t	α	686	475	353	230
India	β	4513	3116	2233	1214
ECF_t Vs BIO_t	α	503	312	184	102
Sweden	β	9518	7141	5489	3509
ECF_t Vs BIO_t	α	785	541	385	212
Italy	β	8741	6167	4856	3529
ECF_t Vs BIO_t	α	678	483	368	233
UK	β	4880	3420	2857	1234
ECF_t Vs BIO_t	α	580	392	285	142
USA	β	6646	4799	3139	2021
ECF_t Vs BIO_t	α	586	430	312	221
UK	β	5682	4285	3082	1223
ECF_t Vs BIO_t	α	487	342	282	134

Source: Authors compilation.

stationary test was undertaken by using the ADF and PP unit roots tests, the results of which confirmed that both biomass energy and ecological footprint are stationary at first difference for all nations of concern.

4.2. Quantile cointegration results

The findings of the quantile cointegration test for each concerned nation are presented in Table 4. The τth quantile of biomass energy is denoted as τ. The value of the coefficient for the supremum norm (i.e. β and γ) are the parameters' stability. Having compared the coefficient value of the supremum norm with its critical values, we observe that the quantile cointegration test findings indicate a cointegrating interconnection between biomass energy utilization and ecological footprint across the quantile distribution for each nation. Thus, it is evident that there is an asymmetric or nonlinear connection between biomass energy utilization and ecological footprint in the long run for all nations' understudy.

4.3. Quantile-on-quantile regression results

This section presents the outcomes of the effect of biomass energy use on ecological footprint in the top 10 biomass energy-consuming economies. The slope of the estimated coefficient $\beta_1(\theta, \tau)$ is illustrated in Figure 4a–e, presenting the influence of the quantile of X (τth) on the quantile of Y (θth) at several values of τ and θ. The findings of the QQ approach are shown in Figure 4a–e. The outcome of the influence of biomass energy on EF in Austria is presented in Figure 4a. A weak and positive association is evident in the areas which merge the lower-tail quantiles of biomass energy (i.e. 0.2–0.3) with the middle and higher quantiles of EF (i.e. 0.6-0.90), indicating that biomass energy utilization increases the degradation of the environment by boosting

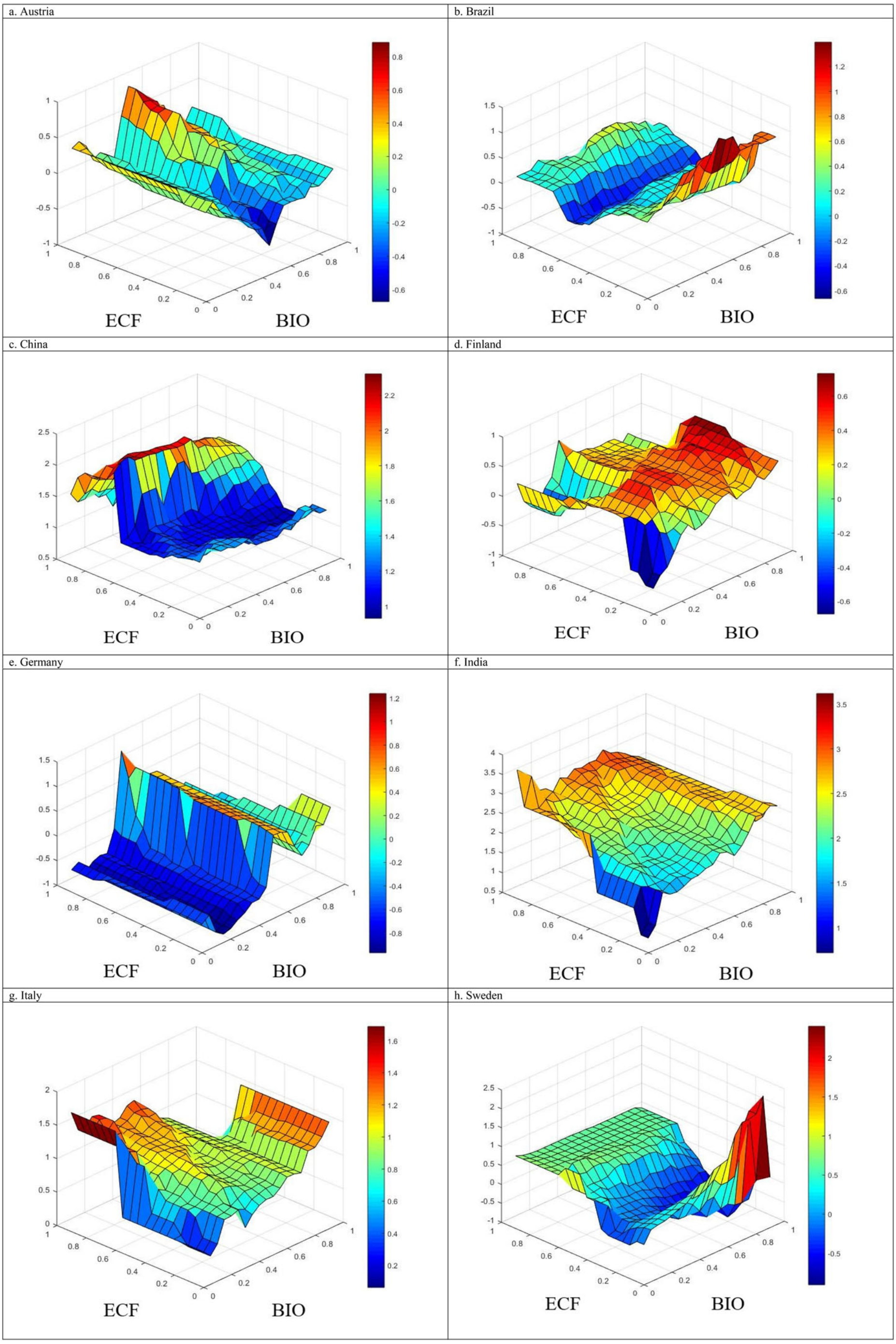

Figure 4. The effect of Biomass energy consumption on ecological footprint.
Source: Authors Compilation with MALAB Software.

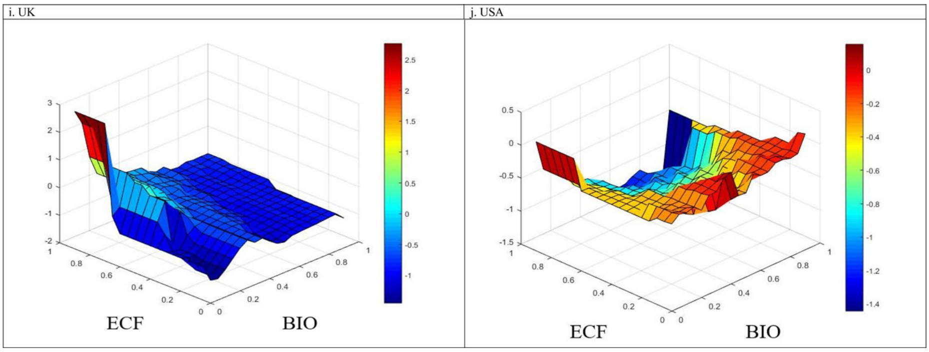

Figure 4. Continued

pollution during the period of low biomass energy utilization in Austria. Moreover, in the areas that combine the middle-tailed quantile of biomass energy with all quantiles of EF (i.e. 0.1-0.9), the influence of biomass on ecological footprint is strong and negative, suggesting that moderate utilization of biomass energy increases the environmental quality during the upward and downward trend in EF for Austria. Also, in the regions in which the upper-tailed quantiles of biomass (i.e. 0.7-0.8) are combined with the middle and higher quantiles of EF, the influence of biomass energy on ecological footprint is weak and positive. This clear positive relationship with moderate biomass energy utilization shows that biomass energy utilization contributes to ecological footprint reduction in Austria. Moreover, a strong and positive connection is detected in the area that merges the upper quantile of biomass energy utilization (i.e. 0.85-0.95) with all quantile of EF (i.e. 0.1-0.95). This notable positive relationship during periods of increased biomass energy utilization shows that it induces a substantial increase in ecological footprint in Austria during higher biomass energy utilization periods, enhancing environmental degradation. Thus, in the majority of the quantiles, the influence of biomass energy utilization on ecological footprints is negative in Austria

The QQ approach findings for the impact of biomass energy on ecological are shown in Figure 4b for Brazil. A strong and positive association is detected in the regions where all quantiles of biomass energy utilization combine with the lower tailed quantile of ecological footprint (i.e. 0.1–0.25), showing that biomass energy utilization deteriorates the environment. Furthermore, in the regions that combine the middle and upper tailed quantiles of biomass energy usage (i.e. 0.3–0.9) with all quantiles of EF (i.e. 0.1–0.9), the impact of biomass energy utilization on ecological footprint is adversely related. This indicates that biomass energy utilization increases the quality of the environment by reducing ecological footprint during the period in which Brazil has a moderated and upward trend of biomass energy utilization. However, the negative association is strong in all quantiles of biomass energy utilization (i.e. 0.1–0.9) at the mid-tail quantiles of EF (i.e. 0.5–0.75). Therefore, the influence of biomass energy utilization on EF is adversely related since the majority of the quantiles indicate a negative interconnection for the case of Brazil.

For China, Figure 4c depicts the estimates of the influence of biomass energy utilization on ecological footprint. In the regions that merge all quantiles of biomass energy utilization (i.e. 0.1–0.9) with all quantiles of EF (i.e. 0.1–0.85), the influence of biomass energy on ecological footprint is strong and negative. However, a relatively strong and positive connection is evident in the regions where all quantiles of biomass energy utilization (i.e. 0.1–0.95) combine with the upper quantiles of EF (i.e. 0.90–0.95). Thus, because most of the quantiles revealed a negative association, we conclude that there is a negative connection between biomass energy utilization and ecological footprint in China.

Furthermore, Figure 4d presents information about the estimates of the influence of biomass energy utilization on ecological footprint in Finland. A strong and negative association is identified in the region where the lower quantiles of biomass energy utilization (i.e. 0.2–0.3) merge with the lower quantiles of EF (i.e. 0.2–0.4), indicating that biomass energy utilization reduces environment deterioration by reducing ecological footprint during the period of low biomass usage in Finland. In the region where the middle and higher quantiles of biomass energy utilization (i.e. 0.45–0.9) are combined with the middle and higher quantiles of EF (i.e. 0.45–0.90), the impact of biomass energy utilization on ecological footprint is positive, suggesting that biomass energy utilization deteriorates the environment, increasing ecological footprint during the period of the moderate and upward trend in the usage of biomass in Finland. However, there is a strong and positive interconnection between biomass energy utilization and EF in areas where the upper quantiles of biomass energy utilization (i.e. 0.7–0.9) merge with the lower and middle quantiles of EF (i.e. 0.1–0.65). Therefore, for Finland, in many of the quantiles, the influence of biomass energy utilization on ecological footprint is positively related.

For Germany, the estimate of the impact of biomass energy utilization on ecological footprint is depicted in Figure 4e. In this figure, the region where the low and mid quantiles of biomass energy utilization (i.e. 0.1–0.75) merge with all quantile of EF (i.e. 0.1–0.9) confirm that the impact of biomass energy utilization on ecological footprint is negative. This suggests that biomass energy improves the quality of the environment by reducing the level of ecological footprint during the period of downward and moderate usage of biomass energy. However, the influence of biomass energy utilization becomes positive when the region in which the mid-tail quantile of biomass energy utilization (0.75–0.80) combines with all quantiles of ecological footprint, suggesting that environmental degradation increases as a result of biomass energy utilization in the period of moderate ecological footprint in Germany. Also, a weak and negative connection exists in the area where the upper tail quantiles of biomass energy usage (0.85–0.95) combine with all quantiles of EF (i.e. 0.1–0.95), indicating that the upward trend in the utilization of biomass energy causes an adverse impact on ecological footprint. Since most of the quantiles indicate a negative connection, we conclude that biomass energy utilization improves the environmental quality, thereby reducing the ecological footprint in Germany.

Figure 4f reveals the influence of biomass energy utilization on ecological footprint in India. A strong and negative connection is confirmed in the zone where the lower quantiles of biomass energy utilization (i.e. 0.1–0.25) combine with the lower and middle tail quantiles of ecological footprint (i.e. 0.1–0.55), indicating that a lower trend in biomass energy utilization improves the quality of the environment in India.

Furthermore, a weak and positive connection is observed in the region where the middle and upper quantiles of biomass energy utilization merge with all quantiles of ecological footprint, suggesting that a moderate upsurge in the utilization of biomass energy degrades the environment. Thus, with several quantiles showing a positive influence of biomass energy utilization on ecological footprint, it is evident that biomass energy utilization degrades the environment in India.

Next is Figure 4g, which presents the influence of biomass energy utilization on ecological footprint in Italy. In the region where the lower quantiles of biomass energy utilization (i.e. 0.1–0.25) combine with the lower and middle tail quantile of ecological footprint (i.e. 0.1–0.55), a weak and negative connection is confirmed, indicating that a lower trend in consumption of biomass energy decreases the degradation of the environment in Italy. However, a strong and positive connection is discovered in the sections where the lower quantiles of biomass energy utilization (i.e. 0.1–0.25) merge with the upper quantiles of EF (i.e. 0.8–0.95), suggesting that a downward trend in the utilization of biomass energy degrades the environment. Furthermore, in the areas where the middle and upper quantiles of biomass energy usage (i.e. 0.3–0.95) combine with all quantiles of ecological footprints, a relatively weak and positive association is detected, suggesting that a moderate surge in biomass energy utilization serves as an important driver of environmental degradation in Italy during the period of downward and upward trend in ecological footprint. Many of the quantiles indicate a positive interaction between biomass energy utilization and ecological footprint; therefore, one can conclude that biomass energy utilization degrades the environment in Italy.

The estimate of the influence of biomass energy utilization on ecological footprint for Sweden is depicted in Figure 4h. A relatively weak and negative connection is detected in the region where all quantiles of biomass energy utilization (i.e. 0.1–0.95) combine with all quantiles of ecological footprint (i.e. 0.1–0.95), This reveals a negative relationship in circumstances of lower and higher levels of ecological footprint, which suggests that biomass energy utilization acts as a crucial driver enhancing environmental quality by lowering the ecological footprint for Sweden throughout periods of both decline and increase in the level of ecological footprint. However, in the upper quantile of biomass energy utilization (i.e. 0.8–0.95) in conjunction with the lower quantiles of ecological footprint (i.e. 0.1–0.25), the impact of biomass energy utilization on ecological footprint is strong and positive in Sweden, suggesting that an upsurge in the consumption of biomass energy contributes to the level of environmental degradation in Sweden during periods in which the ecological footprint is low. Thus, considering that several quantiles confirm that biomass energy utilization has a negative relationship with ecological footprint, biomass energy utilization contributes to the wellbeing of the environment in Sweden.

For the United Kingdom, the findings on the impact of biomass energy utilization on EF are presented in Figure 4i. A strong and negative interrelation is detected at all quantiles of both ecological footprint (i.e. 0.1–0.95) and biomass energy utilization (i.e. 0.1–0.95). This result implies that the use of biomass energy improves the quality of the environment by lowering ecological footprint levels in the UK in periods of both downswings and upsurge in ecological footprint. However, between the lower quantiles of biomass energy utilization (i.e. 0.5–0.15) and upper quantiles of ecological footprint (i.e. 0.8–0.95), the influence of biomass energy utilization on ecological footprint is negative, suggesting that low usage in biomass energy contributes to the degradation of the environment during the periods in which the ecological footprint is high in the United Kingdom. In many of the quantiles, a negative association exists between biomass energy utilization and ecological footprint in the United Kingdom.

Finally, Figure 4j presents the results of the impact of biomass energy utilization on ecological footprint of the USA. A strong and positive connection is detected in the zones where the lower quantiles of biomass energy utilization (i.e. 0.05–0.3) conjoin with all quantiles of EF (i.e. 0.1–0.95), indicating that low-level consumption of biomass energy degrades the environment in the period of downturn and rise in ecological footprints in the USA. Also, in the area where the mid and upper-tail quantiles of biomass energy (i.e. 0.4–0.9) join with the lower and mid-tail quantiles of EF (i.e. 0.1–0.65), a strong and positive connection is detected, suggesting that usage of biomass energy degrades the environment in the period of the moderate and upward trend in biomass energy in the USA. A strong and negative connection is discovered in the area where the middle and upper quantiles of biomass energy utilization (i.e. 0.70–0.95) merge with the medium and upper quantiles of EF (i.e. 0.55–0.95) in the USA. This reveals that biomass energy usage improves the quality of the environment in periods of moderate and higher trends in ecological footprint. Thus, with several quantiles showing a positive influence of biomass energy utilization on EF, this reveals that biomass energy utilization degrades the environment in the USA.

4.4. Troster (2018) causality outcomes

The next phase of the current study involves the causal interaction between biomass energy utilization and ecological footprint using the Granger causality-test in quantile proposed by (Troster, 2018), the outcomes of which are presented in Table 5. For Austria, there is evidence of a causal interaction from biomass energy to ecological footprint in all quantiles except for the 0.5 and 0.95 quantiles. Likewise, a causal association from ecological footprint to biomass is confirmed in all quantiles excluding the 0.5 and 0.95 quantiles. Generally, there is a causal feedback interconnection between biomass energy utilization and ecological footprint in Austria. Additionally, there is evidence of a causal interaction from biomass energy utilization to ecological footprint in these quantiles (i.e. 0.2, 0.3, 0.4, 0.7, 0.8 and 0.9) for Brazil. Furthermore, a causality association from ecological footprint to biomass energy utilization was detected in all quantiles excluding the 0.1 and 0.5 quantiles. Hence, we conclude that biomass energy utilization can predict ecological footprint, whereas ecological footprint can also predict biomass energy utilization in Brazil.

In China, we detected a causal interaction from biomass energy utilization to ecological footprint in all quantiles. Also, we discovered a causal interaction from ecological footprint to biomass energy utilization in all quantiles. Thus, a feedback causality is detected between China's energy utilization and ecological footprint. A causal interaction is identified from biomass energy utilization to ecological footprint in all quantiles except Finland's 0.5 and 0.95 quantiles. A causal interaction is detected from ecological footprint to biomass energy in all quantiles except in the 0.5,

Table 5. Troster (2018) causality outcomes.

Countries	Causality	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
Austria	ECO→ECF	0.55	**0.00**	**0.00**	**0.00**	**0.00**	0.51	**0.00**	**0.00**	**0.00**	**0.00**	0.57
	ECF→ECO	0.22	**0.00**	**0.00**	**0.00**	**0.00**	0.26	**0.01**	**0.00**	**0.00**	**0.00**	0.33
Brazil	ECO→ECF	0.81	0.08	**0.00**	**0.00**	**0.06**	0.04	0.06	**0.00**	**0.00**	**0.02**	0.45
	ECF→ECO	0.47	**0.00**	**0.00**	**0.00**	**0.00**	1.00	**0.00**	**0.04**	**0.00**	**0.00**	**0.00**
China	ECO→ECF	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	ECF→ECO	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Finland	ECO→ECF	0.37	**0.00**	**0.00**	**0.00**	**0.00**	0.14	**0.00**	**0.00**	**0.00**	**0.01**	0.37
	ECF→ECO	0.27	**0.00**	**0.00**	**0.00**	**0.00**	0.17	**0.02**	**0.00**	**0.00**	0.08	0.58
Germany	ECO→ECF	0.61	**0.00**	**0.00**	**0.00**	**0.00**	1.00	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	ECF→ECO	0.06	**0.00**	**0.00**	**0.00**	**0.00**	0.77	**0.00**	**0.00**	**0.00**	0.10	**0.00**
India	ECO→ECF	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.28	0.22	0.22	0.22
	ECF→ECO	0.00	0.13	0.22	0.22	0.22	0.22	0.28	0.22	0.22	0.22	0.22
Italy	ECO→ECF	0.30	**0.00**	**0.00**	**0.00**	**0.00**	0.71	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	ECF→ECO	0.33	**0.00**	**0.00**	**0.00**	**0.00**	0.06	**0.00**	**0.00**	**0.00**	**0.00**	0.62
Sweden	ECO→ECF	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	0.37	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	ECF→ECO	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.36	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
UK	ECO→ECF	0.49	**0.00**	**0.00**	**0.00**	**0.00**	0.40	**0.00**	**0.00**	**0.00**	**0.00**	0.48
	ECF→ECO	0.55	**0.00**	**0.00**	**0.00**	**0.00**	0.26	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**
USA	ECO→ECF	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.14	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	ECF→ECO	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.25	**0.00**	**0.00**	**0.00**	**0.00**	0.55

Note: The bold number represents a 5% level of significance.
Source: Authors compilation.

0.90, and 0.95 quantiles. We conclude that biomass energy utilization and ecological footprint can predict each other in Finland.

For Germany, a causal interaction from biomass energy utilization to ecological footprint is uncovered in all quantiles (except the 0.5 quantile). Moreover, there is a causal association between ecological footprint to biomass energy utilization in all quantiles apart from the 0.5 and 0.9 quantiles. Therefore, we can conclude that Germany has a two-way causal interaction between ecological footprint and biomass energy utilization. However, we discovered no causal interaction between ecological footprint and biomass energy utilization in all quantiles in India. Furthermore, there is a causal interaction from biomass energy utilization to ecological footprint in all quantiles (except in the 0.5 quantile) in Italy and the USA. Likewise, a causality association from ecological footprint to biomass energy utilization is evident in all quantiles (except in the 0.5 and 0.95 quantiles) for Italy and the USA. Therefore, we conclude that ecological footprint and biomass energy utilization can predict each other in Italy and the USA.

We discovered a causal interaction from ecological footprint to biomass energy utilization for Sweden in all quantiles (except in the 0.5 quantile). Similarly, a causal interaction from biomass energy utilization to ecological footprint was uncovered in all quantiles (except in the 0.5 quantile) for Sweden. We therefore conclude that there is a causal feedback interaction between ecological footprint and biomass energy utilization in Sweden. Moreover, in all quantiles (except in the 0.5 and 0.9 quantiles), we discovered a causal interconnection from biomass energy utilization to ecological footprint in the United Kingdom. Also, a causal association was found from ecological footprint to biomass energy utilization in all quantiles (except in the 0.5 quantile). Hence, we conclude that biomass energy utilization and ecological footprint Granger cause each other in the United Kingdom.

In summary, a causal feedback interaction between biomass energy utilization and ecological footprint is prominent in the ten selected economies (i.e. Austria, Brazil, China, Germany, Sweden, Finland, Italy, UK, and the USA). However, no causal interconnection was detected between biomass energy utilization and ecological footprint in India.

4.4. Discussion

The current research compared biomass energy utilization's influence on environmental deterioration. The results show a negative connection between biomass energy consumption and ecological footprint in many of the nations under investigation. The adverse impact of biomass energy usage on ecological footprint is prominent in six (i.e. Austria, Brazil, China, Germany, Sweden, and United Kingdom) of the ten selected economies, implying that biomass improves environmental quality in these economies, thereby reducing ecological footprint. The result that biomass energy usage decreases ecological footprint in these economies points to the relevance of biomass as a viable tool for combating environmental degradation and, as a result, the climate action objective of sustainable development goal thirteen (SDG 13) is achieved. Our empirical outcomes support our prediction as well as several prior studies, such as (Danish & Wang, 2019; Hadj, 2021; Katircioglu, 2015; Kim et al., 2020; Sulaiman & Abdul-Rahim, 2020; Wang et al., 2020), which demonstrates the effect of biomass-based renewable energy in the reduction of environmental deterioration. Also, this outcome corroborates with the research of (Yasmeen et al., 2022) in the Belt & Road economies, who discovered that biomass energy usage reduces ecological footprints. Also, this study gives credibility to the recent argument proposed at COP26. Highlighting the need to remove the impediments to renewable energy expansion. Concerns have been raised that biomass energy development has been connected to significant reductions in environmental degradation in recent years as a byproduct of technical improvements.

Furthermore, the positive effect of biomass energy utilization on ecological footprint is evident in Finland, Italy, India, and the USA, suggesting that biomass energy utilization is not ecological-friendly in these nations. Intensifying biomass energy usage could decrease carbon emissions directly, as suggested by (Bilgili, 2012; Bilgili et al., 2016; Sarkodie et al., 2019; Solarin et al., 2018), but contributes to the degradation of the other categories of ecological footprint such as fishing grounds, grazing land, cropland, and, notably, forest land. Hence, the adverse impacts of biomass energy on other crucial metrics of ecological footprint outweighs its favorable impacts on reducing carbon emissions. Moreover, the source-sink hypothesis for the production and usage of biomass energy offers an elaborate reason for the increase in ecological footprint and a possible reduction in carbon emissions. Considering that the rate at which plants regenerate as a source of biomass energy may be faster than the rate of usage, biomass energy consumption could minimize carbon emissions. It has been stated that biomass obtained from biological sources like residues from woods, timber, and animal husbandry can significantly mitigate anthropogenic emissions while also reducing land-use competition (Antar et al., 2021). These insights shows that the difficulties in meeting the sustainable development goals (SDGs) such as Life below Water (SDG 14), sustainable consumption and production (SDG 12) and Life on Land (SDG 15) are possibly caused by the usage of biomass.

The significant percentage of biomass energy usage from conventional sources (animal waste, wood, and traditional charcoal) could be related to the positive influence of biomass energy usage on ecological footprint. Increased usage of contemporary biomass energy (biogas, biofuel, and bio-refineries) could underlie the dropping percentage of solid biomass in recent years, resulting in decreasing carbon emissions (Destek et al., 2021). The rate at which conventional biomass energy resources are converted is slow compared to modern resources, which is one of the key justifications for its positive influence on ecological footprint; however, if this transition is not accelerated and promoted, it will increase the adverse effects of biomass energy on the environment. Likewise, if deforestation proceeds at this current rate, the beneficial impact could be reversed. To mitigate the negative consequences of biomass energy utilization, more people must be aware of responsible land use.

5. Conclusion and policy ramifications

5.1. Conclusion

The current study examined the asymmetric interaction between biomass energy utilization and ecological footprint in the top ten biomass energy usage countries (Austria, Brazil, China, Germany, Sweden, Finland, Italy, UK, India, and the USA). The study employed a quarterly dataset covering the period between 1970 and 2017. The study employed the advanced econometric Quantile-on-Quantile approach developed by (Sim & Zhou, 2015) to detect the role of biomass energy utilization on ecological footprint. The findings of the Quantile-on-Quantile approach showed that the influence of biomass energy usage on ecological footprint is negative in six (i.e. Austria, Brazil, China, Germany, Sweden, and United Kingdom) of the ten selected economies, implying that biomass improves environmental quality in these economies. However, the influence of biomass energy utilization on ecological footprint is positive in Finland, Italy, India, and the USA, indicating that biomass energy utilization is not ecologically-friendly in these nations. A causal interaction was detected using the Granger causality-test in quantile, which was developed by Troster (2018). This outcome of the Granger causality test disclosed that biomass energy utilization and ecological footprint could predict each other in nine nations (i.e. Austria, Brazil, China, Germany, Sweden, Finland, Italy, UK, and the USA). However, no causal interconnection was found between biomass energy utilization and ecological footprint in India.

5.2. Policy ramifications

Regarding policy ramifications, our findings suggest that focusing exclusively on one objective in implementing regulations toward sustainable development goals might impede the achievement of other goals. As previously stated, the top nations in terms of biomass energy utilization have enacted biomass regulations emphasizing lowering air pollution, but environmental harm caused by biomass use has been overlooked. As a result, intensifying and coordinating the transition from traditional to contemporary biomass might increase the green impacts of biomass use, hence lowering environmental degradation. This transition could strengthen the energy efficiency of biomass energy generation, providing additional opportunities to revitalize the forest areas. Furthermore, implementing regulations and guidelines that permit facilities to operate in contemporary biomass industries might help minimize the exploitation of endangered biomass resources. Similarly, awareness-raising initiatives on the proper utilization of agricultural lands could be implemented to minimize the degradation of agricultural areas. Due to the small number of nations included in the sample, future studies could investigate the issue from a global perspective by increasing the sample size.

Note

1. coal, natural gas, and oil

Disclosure statement

No potential conflict of interest was reported by the authors.

Author's contribution

All the authors contributed equally to the final manuscript.

Funding

This work was supported by the Humanities and Social Sciences Research Fund Project of the Ministry of Education (17YJC880145), Jiangsu Province "333 High-level Talents Training Project" Young and Middle-aged Academic Leader Project (2018SZJS-005). This study was supported by "the Fundamental Research Funds for the Central Universities" in UIBE 20QD17.

Ethical approval

This study follows all ethical practices during writing.

Availability of data

Data is readily available at request from the corresponding author.

References

Abbasi, K. R., Hussain, K., Haddad, A. M., Salman, A., & Ozturk, I. (2022). The role of Financial Development and Technological Innovation towards Sustainable Development in Pakistan: Fresh insights from consumption and territory-based emissions. *Technological Forecasting and Social Change*, *176*, 121444. https://doi.org/10.1016/j.techfore.2021.121444

Adedoyin, F. F., Ozturk, I., Agboola, M. O., Agboola, P. O., & Bekun, F. V. (2021). The implications of renewable and non-renewable energy generating in Sub-Saharan Africa: The role of economic policy uncertainties. *Energy Policy*, *150*, 112115. https://doi.org/10.1016/j.enpol.2020.112115

Adekoya, O. B., Oliyide, J. A., & Fasanya, I. O. (2022). Renewable and non-renewable energy consumption – Ecological footprint nexus in net-oil exporting and net-oil importing countries: Policy implications for a sustainable environment. *Renewable Energy*, *189*, 524–534. https://doi.org/10.1016/j.renene.2022.03.036

Ahmed, A., Uddin, G. S., & Sohag, K. (2016). Biomass energy, technological progress and the environmental Kuznets curve: Evidence from selected European countries. *Biomass and Bioenergy*, *90*, 202–208. https://doi.org/10.1016/j.biombioe.2016.04.004

Akadiri, S. S., Adebayo, T. S., Altuntaş, M., & Awosusi, A. A. (2022). Environmental effects of structural change, hydro and coal energy consumption on ecological footprint in India: Insights from the novel dynamic ARDL simulation. *Environment, Development and Sustainability*, *9*(4), 201–222. https://doi.org/10.1007/s10668-022-02665-0

Antar, M., Lyu, D., Nazari, M., Shah, A., Zhou, X., & Smith, D. L. (2021). Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. *Renewable and Sustainable Energy Reviews*, *139*, 110691. https://doi.org/10.1016/j.rser.2020.110691

Awosusi, A. A., Adebayo, T. S., Altuntaş, M., Agyekum, E. B., Zawbaa, H. M., & Kamel, S. (2022). The dynamic impact of biomass and natural resources on ecological footprint in BRICS economies: A quantile regression evidence. *Energy Reports*, *8*, 1979–1994. https://doi.org/10.1016/j.egyr.2022.01.022

Aydin, M. (2019). The effect of biomass energy consumption on economic growth in BRICS countries: A country-specific panel data analysis. *Renewable Energy*. *138*, 620–627. https://doi.org/10.1016/j.renene.2019.02.001

Bandyopadhyay, A., Rej, S., Villanthenkodath, M. A., & Mahalik, M. K. (2022). The role of nuclear energy consumption in abatement of ecological footprint: Novel insights from quantile-on-quantile regression. *Journal of Cleaner Production*, *358*, 132052. https://doi.org/10.1016/j.jclepro.2022.132052

Bilgili, F. (2012). The impact of biomass consumption on CO2 emissions: Cointegration analyses with regime shifts. *Renewable and Sustainable Energy Reviews*, *16*(7), 5349–5354. https://doi.org/10.1016/j.rser.2012.04.021

Bilgili, F., Koçak, E., Bulut, Ü., & Kuşkaya, S. (2017). Can biomass energy be an efficient policy tool for sustainable development? *Renewable and Sustainable Energy Reviews*, *71*, 830–845. https://doi.org/10.1016/j.rser.2016.12.109

Bilgili, F., Öztürk, İ., Koçak, E., Bulut, Ü., Pamuk, Y., Muğaloğlu, E., & Bağlıtaş, H. H. (2016). The influence of biomass energy consumption on CO2 emissions: A wavelet coherence approach. *Environmental Science and Pollution Research International*, *23*(19), 19043–19061. https://doi.org/10.1007/s11356-016-7094-2

Bilgili, F., Ozturk, I., Kocak, E., Kuskaya, S., & Cingoz, A. (2022). The nexus between access to electricity and CO2 damage in Asian Countries: The evidence from quantile regression models. *Energy and Buildings*, *256*, 111761. https://doi.org/10.1016/j.enbuild.2021.111761

Chang, L., Lu, Q., Ali, S., & Mohsin, M. (2022). How does hydropower energy asymmetrically affect environmental quality? Evidence from quantile-based econometric estimation. *Sustainable Energy Technologies and Assessments*, *53*, 102564. https://doi.org/10.1016/j.seta.2022.102564

Chang, L., Saydaliev, H. B., Meo, M. S., & Mohsin, M. (2022). How renewable energy matter for environmental sustainability: Evidence from top-10 wind energy consumer countries of European Union. *Sustainable Energy, Grids and Networks*, *31*, 100716. https://doi.org/10.1016/j.segan.2022.100716

Destek, M. A., Sarkodie, S. A., & Asamoah, E. F. (2021). Does biomass energy drive environmental sustainability? An SDG perspective for top five biomass consuming countries. *Biomass and Bioenergy*, *149*, 106076. https://doi.org/10.1016/j.biombioe.2021.106076

Dogan, E., & Inglesi-Lotz, R. (2017). 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. https://doi.org/10.1016/j.energy.2017.07.136
Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251–276. https://doi.org/10.2307/1913236
Fareed, Z., Salem, S., Adebayo, T. S., Pata, U. K., & Shahzad, F. (2021). Role of export diversification and renewable energy on the load capacity factor in Indonesia: A Fourier quantile causality approach. *Frontiers in Environmental Science*, *9*, 434. https://doi.org/10.3389/fenvs.2021.770152
Gao, J., & Zhang, L. (2021). Does biomass energy consumption mitigate CO2 emissions? The role of economic growth and urbanization: Evidence from developing Asia. *Journal of the Asia Pacific Economy*, *26*(1), 96–115. https://doi.org/10.1080/13547860.2020.1717902
Granger, C. W. J. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica*, *37*(3), 424–438. https://doi.org/10.2307/1912791
Hadj, T. B. (2021). Nonlinear impact of biomass energy consumption on ecological footprint in a fossil fuel–dependent economy. *Environmental Science and Pollution Research International*, *28*(48), 69329–69342. https://doi.org/10.1007/s11356-021-15521-x
He, K., Ramzan, M., Awosusi, A. A., Ahmed, Z., Ahmad, M., & Altuntaş, M. (2021). Does Globalization moderate the effect of economic complexity on CO2 emissions? Evidence from the top 10 energy transition economies. *Frontiers in Environmental Science*, *9*, 555. https://doi.org/10.3389/fenvs.2021.778088
Ibrahim, R. L., Adebayo, T. S., Awosusi, A. A., Ajide, K. B., Adewuyi, A. O., & Bolarinwa, F. O. (2022). Investigating the asymmetric effects of renewable energy-carbon neutrality nexus: Can technological innovation, trade openness, and transport services deliver the target for Germany? *Energy & Environment*, *12*(6), 0958305X2211270. https://doi.org/10.1177/0958305X221127020
Irfan, M., Razzaq, A., Sharif, A., & Yang, X. (2022). Influence mechanism between green finance and green innovation: Exploring regional policy intervention effects in China. *Technological Forecasting and Social Change*, *182*, 121882. https://doi.org/10.1016/j.techfore.2022.121882
Jin, C., Razzaq, A., Saleem, F., & Sinha, A. (2021). Asymmetric effects of eco-innovation and human capital development in realizing environmental sustainability in China: Evidence from quantile ARDL framework. *Economic Research-Ekonomska Istraživanja*, *9*(7), 1–24.
Katircioglu, S. T. (2015). The impact of biomass consumption on CO2 emissions: An empirical investigation from Turkey. *International Journal of Climate Change Strategies and Management*, *7*(3), 348–358. https://doi.org/10.1108/IJCCSM-06-2014-0077
Kim, G., Choi, S.-K., & Seok, J. H. (2020). Does biomass energy consumption reduce total energy CO2 emissions in the US? *Journal of Policy Modeling*, *42*(5), 953–967. https://doi.org/10.1016/j.jpolmod.2020.02.009
Kirikkaleli, D., & Adebayo, T. S. (2021). Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. *Sustainable Development*, *29*(4), 583–594. https://doi.org/10.1002/sd.2159
Le, H. P., & Ozturk, I. (2020). The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. *Environmental Science and Pollution Research International*, *27*(18), 22680–22697. https://doi.org/10.1007/s11356-020-08812-2
Liu, F., Zhang, X., Adebayo, T. S., & Awosusi, A. A. (2022). Asymmetric and moderating role of industrialisation and technological innovation on energy intensity: Evidence from BRICS economies. *Renewable Energy*, *198*, 1364–1372. https://doi.org/10.1016/j.renene.2022.08.099
Liu, X., Razzaq, A., Shahzad, M., & Irfan, M. (2022). Technological changes, financial development and ecological consequences: A comparative study of developed and developing economies. *Technological Forecasting and Social Change*, *184*, 122004. https://doi.org/10.1016/j.techfore.2022.122004

Liu, Z., Saydaliev, H. B., Lan, J., Ali, S., & Anser, M. K. (2022). Assessing the effectiveness of biomass energy in mitigating CO2 emissions: Evidence from Top-10 biomass energy consumer countries. *Renewable Energy*, *191*, 842–851. https://doi.org/10.1016/j.renene.2022.03.053

Miao, Y., Razzaq, A., Adebayo, T. S., & Awosusi, A. A. (2022). Do renewable energy consumption and financial globalisation contribute to ecological sustainability in newly industrialized countries? *Renewable Energy*, *187*, 688–697. https://doi.org/10.1016/j.renene.2022.01.073

Mishra, S., Sharif, A., Khuntia, S., Meo, M. S., & Rehman Khan, S. A. (2019). Does oil prices impede Islamic stock indices? Fresh insights from wavelet-based quantile-on-quantile approach. *Resources Policy*, *62*, 292–304. https://doi.org/10.1016/j.resourpol.2019.04.005

Mishra, S., Sinha, A., Sharif, A., & Suki, N. M. (2020). Dynamic linkages between tourism, transportation, growth and carbon emission in the USA: Evidence from partial and multiple wavelet coherence. *Current Issues in Tourism*, *23*(21), 2733–2755. https://doi.org/10.1080/13683500.2019.1667965

Omer, A. M. (2005). Biomass energy potential and future prospect in Sudan. *Renewable and Sustainable Energy Reviews*, *9*(1), 1–27. https://doi.org/10.1016/j.rser.2003.12.011

Ozturk, I., & Acaravci, A. (2016). Energy consumption, CO2 emissions, economic growth, and foreign trade relationship in Cyprus and Malta. *Energy Sources, Part B: Economics, Planning, and Policy*, *11*(4), 321–327. https://doi.org/10.1080/15567249.2011.617353

Raza, S. A., Sharif, A., Wong, W. K., & Karim, M. Z. A. (2017). Tourism development and environmental degradation in the United States: Evidence from wavelet-based analysis. *Current Issues in Tourism*, *20*(16), 1768–1790. https://doi.org/10.1080/13683500.2016.1192587

Razzaq, A., Sharif, A., An, H., & Aloui, C. (2022). Testing the directional predictability between carbon trading and sectoral stocks in China: New insights using cross-quantilogram and rolling window causality approaches. *Technological Forecasting and Social Change*, *182*, 121846. https://doi.org/10.1016/j.techfore.2022.121846

Razzaq, A., Wang, S., Adebayo, T. S., & Al-Faryan, M. A. S. (2022a). The potency of natural resources on ecological sustainability in PIIGS economies. *Resources Policy*, *79*, 102941. https://doi.org/10.1016/j.resourpol.2022.102941

Saikkonen, P. (1991). Asymptotically efficient estimation of cointegration regressions. *Econometric Theory*, *7*(1), 1–21. https://doi.org/10.1017/S0266466600004217

Sarkodie, S. A., Strezov, V., Weldekidan, H., Asamoah, E. F., Owusu, P. A., & Doyi, I. N. Y. (2019). Environmental sustainability assessment using dynamic Autoregressive-Distributed Lag simulations—Nexus between greenhouse gas emissions, biomass energy, food and economic growth. *The Science of the Total Environment*, *668*, 318–332. https://doi.org/10.1016/j.scitotenv.2019.02.432

Shahbaz, M., Balsalobre-Lorente, D., & Sinha, A. (2019). Foreign direct Investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *Journal of Cleaner Production*, *217*, 603–614. https://doi.org/10.1016/j.jclepro.2019.01.282

Shahzad, S. J. H., Shahbaz, M., Ferrer, R., & Kumar, R. R. (2017). Tourism-led growth hypothesis in the top ten tourist destinations: New evidence using the quantile-on-quantile approach. *Tourism Management*, *60*, 223–232. https://doi.org/10.1016/j.tourman.2016.12.006

Sharif, A., Afshan, S., & Qureshi, M. A. (2019). Idolization and ramification between globalization and ecological footprints: Evidence from quantile-on-quantile approach. *Environmental Science and Pollution Research International*, *26*(11), 11191–11211. https://doi.org/10.1007/s11356-019-04351-7

Sharif, A., Meo, M. S., Chowdhury, M. A. F., & Sohag, K. (2021). Role of solar energy in reducing ecological footprints: An empirical analysis. *Journal of Cleaner Production*, *292*, 126028. https://doi.org/10.1016/j.jclepro.2021.126028

Sharif, A., Saqib, N., Dong, K., & Khan, S. A. R. (2022). Nexus between green technology innovation, green financing, and CO2 emissions in the G7 countries: The moderating role of social globalisation. *Sustainable Development*, *4*(2), 12–24. https://doi.org/10.1002/sd.2360

Sim, N., & Zhou, H. (2015). Oil prices, US stock return, and the dependence between their quantiles. *Journal of Banking & Finance*, *55*, 1–8. https://doi.org/10.1016/j.jbankfin.2015.01.013

Solarin, S. A., Al-Mulali, U., Gan, G. G. G., & Shahbaz, M. (2018). The impact of biomass energy consumption on pollution: Evidence from 80 developed and developing countries. *Environmental Science and Pollution Research International*, *25*(23), 22641–22657. https://doi.org/10.1007/s11356-018-2392-5

Sulaiman, C., & Abdul-Rahim, A. S. (2020). Can clean biomass energy use lower CO2 emissions in African economies? Empirical evidence from dynamic long-run panel framework. *Environmental Science and Pollution Research International*, *27*(30), 37699–37708. https://doi.org/10.1007/s11356-020-09866-y

Sulaiman, C., Abdul-Rahim, A. S., & Ofozor, C. A. (2020). Does wood biomass energy use reduce CO2 emissions in European Union member countries? Evidence from 27 members. *Journal of Cleaner Production*, *253*, 119996. https://doi.org/10.1016/j.jclepro.2020.119996

Troster, V. (2018). Testing for Granger-causality in quantiles. *Econometric Reviews*, *37*(8), 850–866. https://doi.org/10.1080/07474938.2016.1172400

Ulucak, R. (2020). Linking biomass energy and CO2 emissions in China using dynamic Autoregressive-Distributed Lag simulations. *Journal of Cleaner Production*, *250*, 119533. https://doi.org/10.1016/j.jclepro.2019.119533

Umar, M., Ji, X., Kirikkaleli, D., & Alola, A. A. (2021). The imperativeness of environmental quality in the United States transportation sector amidst biomass-fossil energy consumption and growth. *Journal of Cleaner Production*, *285*, 124863. https://doi.org/10.1016/j.jclepro.2020.124863

Wang, C., Raza, S. A., Adebayo, T. S., Yi, S., & Shah, M. I. (2023). The roles of hydro, nuclear and biomass energy towards carbon neutrality target in China: A policy-based analysis. *Energy*, *262*, 125303. https://doi.org/10.1016/j.energy.2022.125303

Wang, Z. (2019). Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *The Science of the Total Environment*, *670*, 1075–1083. https://doi.org/10.1016/j.scitotenv.2019.03.268

Wang, Z., Bui, Q., Zhang, B., & Pham, T. L. H. (2020). Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. *The Science of the Total Environment*, *743*, 140741. https://doi.org/10.1016/j.scitotenv.2020.140741

Xiao, Z. (2009). Quantile cointegrating regression. *Journal of Econometrics*, *150*(2), 248–260. https://doi.org/10.1016/j.jeconom.2008.12.005

Xu, B., Sharif, A., Shahbaz, M., & Dong, K. (2021). Have electric vehicles effectively addressed CO2 emissions? Analysis of eight leading countries using quantile-on-quantile regression approach. *Sustainable Production and Consumption*, *27*, 1205–1214. https://doi.org/10.1016/j.spc.2021.03.002

Xuefeng, Z., Razzaq, A., Gokmenoglu, K. K., & Rehman, F. U. (2022). Time varying interdependency between COVID-19, tourism market, oil prices, and sustainable climate in United States: Evidence from advance wavelet coherence approach. *Economic Research-Ekonomska Istraživanja*, *35*(1), 3337–3359. https://doi.org/10.1080/1331677X.2021.1992642

Yasmeen, R., Zhaohui, C., Hassan Shah, W. U., Kamal, M. A., & Khan, A. (2022). Exploring the role of biomass energy consumption, ecological footprint through FDI and technological innovation in B&R economies: A simultaneous equation approach. *Energy*, *244*, 122703. https://doi.org/10.1016/j.energy.2021.122703

Yuping, L., Ramzan, M., Xincheng, L., Murshed, M., Awosusi, A. A., Bah, S. I., & Adebayo, T. S. (2021). Determinants of carbon emissions in Argentina: The roles of renewable energy consumption and globalization. *Energy Reports*, *7*, 4747–4760. https://doi.org/10.1016/j.egyr.2021.07.065