

Unlocking The Role of Biofuel Energy Consumption and Democratic Accountability on Ecological Sustainability in The United States: A Quantile-based Analysis

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Abstract

Energy is vital for economic growth, but it concurrently generates CO₂, the primary driver of climate change and environmental degradation. This study investigates the impact of biofuel energy consumption on CO₂ in the United States. The study also considers the role of government stability, renewable energy, and democratic accountability. Utilizing data from 1990 to 2019, the empirical analysis employs advanced quantile-based methodologies, providing an all-inclusive insight into the interrelationships at various quantiles of the data distribution. The results from the analysis highlight that government stability, democratic accountability, economic growth, and biofuel energy consumption collectively contribute to environmental sustainability in the United States. Furthermore, government stability, economic growth, and biofuel energy use increase ecological quality while democratic accountability dampens ecological sustainability. Lastly, all the regressors can significantly predict CO₂ across all quantiles. Based on these results, policies were formulated.

Keywords: Biofuel Energy Consumption, Government Stability, Democratic Accountability, Ecological Sustainability, USA

1. INTRODUCTION

Biofuels are alternative fuels from biological materials, such as plant matter or agricultural waste, rather than fossil fuels like oil, coal, or natural gas. They are often touted as a more sustainable and environmentally friendly source of energy because they are renewable and have lower carbon emissions than fossil fuels (Chou & Zhang, 2020; Zhang et al., 2023). However, the extent to which biofuel energy consumption is linked to ecological sustainability is a complex and debated issue. One of the main arguments for the ecological sustainability of biofuels is that they can reduce greenhouse gas (GHG) emissions. When biofuels are burned, they release carbon dioxide (CO₂) just like fossil fuels do, leading to adverse consequences on the environment (Al-Mulali, 2015a; Vanegas Cantarero, 2020). However, the carbon in biofuels comes from the atmosphere rather than being trapped underground for millions of years like fossil fuels. This means that the carbon emissions from biofuels are considered to be "carbon neutral," as they do not add any additional carbon to the atmosphere (Bildirici, 2017; Dai et al., 2023). In contrast, burning fossil fuels releases carbon stored underground, contributing to the overall increase in atmospheric GHGs and global warming.

There are several types of biofuels, including ethanol, biodiesel, and biogas. Ethanol is a biofuel from plant matter, such as wheat, corn, or sugarcane, and is often used as a gasoline additive. Biodiesel is made from vegetable oils, animal fats, or recycled cooking grease and can be used as a substitute for diesel fuel (Bhat et al., 2022). Biogas is produced from the decomposition of organic matter, such as food waste, and can be used to generate electricity or heat. One of the main criticisms of biofuels is that they can negatively impact the environment and local communities (Assadourian 2017). For example, the production of biofuels often requires large amounts of land, water, and other resources, which can lead to land degradation, deforestation, and water shortages. In addition, using certain biofuels, such as corn ethanol, can increase food prices due to the competition for land and resources between biofuel production and food production. This can have negative impacts on food security and access to affordable nutrition for communities around the world.

Biofuels may not always be more environmentally friendly than fossil fuels, depending on how they are produced. For example, the production of biofuels from feedstocks like palm oil, soy, and canola has been linked to deforestation, habitat destruction, and other environmental impacts (Zaman, 2017). However, biofuels produced from waste materials or non-food crops like switchgrass or algae may have a lower environmental impact. Despite these concerns, evidence suggests that biofuels can be a more sustainable and environmentally friendly energy source, especially when compared to fossil fuels (Caspeta et al., 2013). For example, corn ethanol has a lower GHG footprint than gasoline when the entire life cycle of both fuels is considered (Bildirici, 2017). This includes the GHG emissions from the production, transportation, and use of the fuels. Other studies have found that biodiesel from waste materials can have even lower GHG emissions than fossil fuels (Bhat et al., 2022).

It is worth noting that the environmental benefits of biofuels depend on various factors, including the feedstocks used, the production methods, and the end-use of the fuels. To maximize the ecological sustainability of biofuels, it is important to consider these factors

carefully and to adopt best practices in biofuel production and use. Thus, the empirical linkage between biofuel energy consumption and ecological sustainability is complex and depends on various factors.

Over several decades, there has been a growing interest in the relationship between government stability and democratic accountability, biofuel energy consumption, and ecological sustainability. This interest stems from recognizing that these three factors are interconnected and significantly impact society's overall health and well-being. Government stability refers to the ability of a government to maintain power and effectively govern a country (Korkut et al. 2022). Democratic accountability, on the other hand, refers to the extent to which a government is held accountable to its citizens through regular elections, transparent decision-making processes, and the rule of law.

There is a strong empirical linkage between government stability and democratic accountability. Held (2002) stated that when a stable government effectively governs and implement policies that benefit its citizens and their livelihoods, it leads to a greater democratic accountability, as the government is held accountable for its actions through regular elections and other democratic processes. Conversely, when a government is unstable, it may be more prone to corruption and abuse of power, leading to a lack of democratic accountability. One example of this relationship can be seen in the case of biofuel energy consumption. Biofuels, such as ethanol and biodiesel, are derived from renewable plant materials and have been promoted as a way to reduce reliance on fossil fuels and decrease greenhouse gas emissions. However, the production and use of biofuels can also have negative ecological impacts, such as deforestation and land conversion for biofuel crops.

In a government with democratic accountability, there is a greater likelihood that these negative ecological impacts will be considered when deciding on biofuel policies (Li et al., 2023; Purcel Alexandra-Anca, 2019). For example, a government may implement regulations or incentives to encourage biofuel production with a lower environmental impact. On the other hand, in a government without democratic accountability, there may be less pressure to consider these impacts, leading to the adoption of policies prioritizing economic interests over ecological sustainability. This is where the relationship between government stability and ecological sustainability comes into play. When a government is stable and accountable, it is more likely to adopt policies promoting economic development and ecological sustainability. The government is held accountable to its citizens, who may prioritize environmental concerns. In contrast, when a government is unstable or lacks democratic accountability, it may prioritize short-term economic gains over long-term ecological sustainability, leading to negative environmental impacts.

The empirical linkage between government stability, democratic accountability, biofuel energy consumption, and ecological sustainability is multifaceted and complex. Government stability and democratic accountability are crucial for implementing policies that promote economic development and ecological sustainability, such as the use of biofuels. On the other hand, a lack of government stability and democratic accountability may lead to policies prioritizing short-term economic interests over long-term ecological sustainability, resulting in negative

environmental impacts. Therefore, governments need to prioritize both stability and democratic accountability to promote both economic development and ecological sustainability. Given the preceding, this study utilizes novel empirical techniques to examine the drivers of CO₂ emissions, including DA, GS, REC, GDP BF and CO₂ in the case of the United States.

The next section reviews related literature and then presents the data, methods, and models used to achieve the study's objectives. Section four discusses the study's empirical results and findings, while section five concludes with the study's core implications, recommendations, and limitations.

2. LITERATURE REVIEW

There is a link between democratic accountability (DA), government stability (GS), economic growth (GDP), biofuel energy consumption (BF), and carbon dioxide emissions (CO₂). It is important to state that democratic accountability and government stability are elements of good governance. In addition, democratic accountability is linked to democracy, while government stability is linked to political stability.

Held (2002) stated that DA could be theorized as a proposed structure in which governance actions significantly impact people's lives. According to Bernauer & Koubi (2009), democracy improves air quality. Xu et al. (2019) expressed that democracy deepening improves the legal system, supports pollution control, promotes energy consumption, and fosters renewable energy adoption. Uzar (2020a) established that DA is one of the institutional categories linking institutions and the environment. Uzar (2020b) viewed DA as one of the important factors in determining environmental policies. In addition, global problems associated with human rights, justice, inequalities, and the environment are freely discussed due to the institutionalization of democracy. Ahmed et al. (2022a) also stated that environmental policies and sustainability are greatly determined by democracy. According to Güngör et al. (2021a), DA reduces CO₂ in the long-run in 9 selected economies. Wang et al. (2022) found that the quality of democracy greatly impacts the environment.

Studies have also shown that DA can fail to protect the environment. Satrovic et al. (2021) established that DA promotes CO₂ in the GCC region. In 46 SSA countries, Acheampong et al. (2022) observed that democracy indicators have the capacity to drive the degradation of the environment. However, different results were derived when SSA countries were subdivided into regions. In West Africa, the indicators of democracy increase CO₂, while it reduces CO₂ in Southern and Central Eastern Africa. In Pakistan, Shehzad et al. (2022) stated that governance can support environmental sustainability. However, when there are negative societal shocks, governance can increase CO₂. Eren (2022) explained that a higher level of democracy improves the environment in low and medium-emission economies, while it increases CO₂ in high-emission economies. In India, Usman et al. (2019) discovered that democratic accountability and environmental degradation have a weak relationship in the long-run, but strong in the short-run. In a panel of 127 countries, Selseng et al. (2022) established that democratic qualities have no impact on CO₂ emissions over-time.

According to the USIP (2022), unwavering governance prevents political spoilers (profiteers) from filling the governance vacuum and mismanaging the states resources. It entails the provision of essential services by the state and the effective management of state resources. In addition, stable governance captures other variables, such as accountable government representatives through political and legal processes and the participation of the general public on governance matters through civil and social organizations. Purcel Alexandra-Anca (2019) stated that when political conditions are unstable, it weakens the government's position in adopting pollution-mitigating policies. In countries with high CO₂ emissions, Liu et al. (2020) found a negative link between political stability and CO₂. Su et al. (2021) opined that a more suitable political atmosphere helps lower CO₂ emissions in Brazil. Muhammad & Long (2021) explained that government stability is sometimes measured by political stability because the government representatives are meant to perform their declared tasks and days in office. The study further showed that a strong and stable government makes formulating and implementing fair environmental policies possible. Also, political stability lowers CO₂ emissions in 65 BRI countries.

In BRICS, Zhao et al. (2021) noted that GS reduces CO₂ emissions in China, while insignificant results were found in other countries. Also, in BRICS, Zhang et al. (2022) found that positive shocks in GS impact CO₂ negatively in the long-run, while negative shocks in GS impact CO₂ negatively in the long-run. In Malaysia, Abd Razak et al. (2021) argued that GS and CO₂ have an inverse relationship in the short and long-run. Wang & Yang (2022) argued that a stable government allows green complexity to reduce CO₂ in 78 countries. Green complexity measures the productive capability of green products.

Grossman & Krueger (1991) established that a country's initial economic development would lead to environmental degradation. However, after a certain growth threshold, GDP contributes to the quality of the environment. Ritchie (2021) stated that historically, there has been a strong correlation between CO₂ and GDP. Also, high-income countries are believed to emit more CO₂ emissions than lower-middle-income countries. However, in recent times, this assertion no longer holds true for some higher-income countries such as the UK, Germany, Denmark, and France, amongst others. This is due to GDP and CO₂ decoupling, as well as renewables. Wu et al. (2018) used a decoupling analysis to examine the link between global GDP and CO₂ and found that in developed economies, a strong decoupling is found. On the other hand, a weak decoupling is observed in developing economies.

Puppan (2002) stated that biodiesel and ethanol are the two most common biofuel sources. The research further demonstrated that biofuels are environmentally friendly, but their production might cause pollution. Demirbas (2009) explained that adopting biofuels can create new economic opportunities for those living in rural areas, especially for oil-importing and developing countries. Acaroğlu & Aydoğan (2012) found that biofuels can reduce environmental pollution in Turkey. Caspeta et al. (2013) revealed that biofuels can contribute significantly to future energy supply and lessen CO₂ emissions. Fulton et al. (2015) mentioned that biofuels are essential for achieving a low-carbon transport sector.

Upon examination, the investigation outcomes reveal that the influence of democratic accountability on CO₂ can either rise or decline, government stability predominantly diminishes CO₂ levels, economic growth exhibits a variable impact on CO₂, and the utilization of biofuels leads to a reduction in CO₂. Notably, the existing literature highlights an absence of comprehensive studies delving into the roles of biofuels, government stability, and democratic accountability in shaping ecological sustainability within the United States. This research addresses this gap by employing an index as a proxy for democratic accountability and government stability. A thorough exploration of the intricate dynamics within these interrelationships is imperative to disclose trends, recognize effective policy initiatives, and substantially contribute to the United States' route toward a future that is sustainable. Integrating quantitative insights, coupled with attention to long-term impacts, fosters the robustness of research findings. This approach facilitates the derivation of actionable proposals to achieve ecological integrity in the United States. This study distinguishes itself by examining, for the first time, the impact of democratic accountability, government stability, and biofuels on CO₂. Additionally, the QKRLS method, introduced by Adebayo et al. (2024), quantile-on-quantile Granger causality (QQGC) suggested by Adebayo & Özkan (2024a), the quantile-based ADF and PP tests suggested by Adebayo & Özkan (2024a) are employed. Thus, this research contributes to the existing literature by offering novel insights into the effects of democratic accountability, government stability, and biofuels on CO₂ in the United States, utilizing QKRLS methodology from 1990 to 2019.

3. DATA AND METHODOLOGY

3.1 Data

In this analysis, we investigate the determinants of CO₂ in the United States, focusing on factors such as biofuel energy, renewable energy, and democratic accountability. The dependent variable is CO₂ emissions, while the independent variables include biofuel energy (BF), renewable energy (REC), democratic accountability (DA), government stability (GS), and gross domestic product (GDP). The study covers the period from 1990 to 2019 due to the unavailability of data on biofuel before 1990 and the absence of data on democratic accountability and government stability after 2019. Table 1 provides detailed information on the variables under examination. Additionally, in line with the methodologies employed by Shahbaz et al. (2020) and Pata et al. (2022), we converted yearly data into quarterly data to mitigate concerns related to small sample sizes.

Table 1: Unit

Variables	Representation	Definitions	Source
Carbon Emissions	CO ₂	Tonnes per capita	OWD (2023)
Biofuel Production	BF	TWh	OWD (2023)
Renewable Energy	REC	Per Capita (Kwh)	OWD (2023)
Democratic Accountability	DA	Index	PRS Group (2022)
Government Stability	GS	Index	PRS Group (2022)
Economic Growth	GDP	Per Capita Constant US\$ 2015	WDI (2023)

Note: OWD denotes Our World in Data, and WDI denotes World Bank Development Indicator

3.2 Empirical methodology

This study utilizes the Quantile-on-Quantile Kernel Regularized Least Squares (QQKRLS) approach proposed by Adebayo & Özkan (2024b). Li et al. (2015) developed the Quantile technique, while Sim & Zhou (2015) proposed the quantile-on-quantile method. Hainmueller & Hazlett (2014) created the KRLS as a machine learning technique. The advantage of this method is that regression analysis can be carried out without specifications and assumptions. The KRLS uses Gaussian kernels to locate and learn the optimum fitting function, eliminating incorrect specifications. This method examines the predictor variable's marginal influence on each of the predicted variable's data points. By investigating the distribution of these marginal effects, heterogeneous (nonlinear) impacts can be identified. Furthermore, KRLS shows the degree of effect and empirical significance of the predictor variable impact on the predicted variable by averaging the pointwise marginal effects. The KRLS is presented in Equation 1.

$$E_N \left[\frac{\widehat{\beta Y}}{\beta X_k} \right] = \frac{-2}{\sigma^2 N} \sum_k \sum_i j_i e^{\frac{\|X_i - X_k\|^2}{\sigma^2}} (X_i - X_k) \quad (1)$$

$E_N \left[\frac{\widehat{\beta Y}}{\beta X_k} \right]$ represents the predictor variable X 's average pointwise marginal impact on the predicted variable Y . In addition, a single observation is symbolized as k , while the sample size is denoted as N . Thus far, it is apparent that the KRLS is not focused on the predictor variable; instead, it simply considers the whole distribution of the predicted variable. Furthermore, even though each predicted variable's data point demonstrates nonlinear impact, empirical significance is conveyed using a single value: the average pointwise marginal effect. The QQKRLS was proposed to cover this shortfall, which incorporates all predictor variable distributions and empirical significance for all predictor and predicted variables distributions. The QQKRLS reveals the degree of impact and numerical significance of the influence of the quantiles of the predictor variable on the predicted variable's quantiles by computing the average pointwise marginal effect for each quantile pairwise. Likewise, heterogeneous or nonlinear associations can be ascertained between variables by utilizing the QQKRLS approach. Thus, the QQKRLS is presented in Equation 2.

$$E_N \left[\frac{\widehat{\beta QY_\tau}}{\beta QX_{\theta k}} \right] = \frac{-2}{\sigma^2 N} \sum_k \sum_i j_i e^{\frac{\|X_{\theta i} - X_{\theta k}\|^2}{\sigma^2}} (X_{\theta i} - X_{\theta k}) \quad (2)$$

The average pointwise marginal effect of the predictor series X 's θ -th conditional quantile on the predicted series Y 's τ -th conditional quantile is represented by $E_N \left[\frac{\widehat{\beta QY_\tau}}{\beta QX_{\theta k}} \right]$. Moreover, τ -th and θ -th conditional quantile variables of Y and X are represented by QY_τ and QX_θ , respectively. Figure 2 provides a summary of the study's analysis.

4. RESULTS AND DISCUSSIONS

4.1. Statistical Information of Variables

Table 2 presents the statistical characteristics of the variables under consideration. The mean values for BF, CO₂, DA, GDP, GS, and REC are 5.0142, 2.9560, 1.7777, 10.810, 2.1089, and 8.4476, respectively. Examining the skewness values reveals a negative skew for all variables except REC, demonstrating a positive skew. This suggests that the dataset predominantly tends towards higher values for REC, while the distribution of the other variables is skewed towards lower values. Furthermore, considering the kurtosis statistics, all variables, except DA, exhibit kurtosis values less than three. This suggests that the distributions are relatively less peaked or more dispersed than a normal distribution. The JB Test indicates that, excluding GS, the assumption of normal distribution across all variables is not met. Specifically, the JB Test does not provide sufficient proof to support the Ho for most variables, signaling deviations from normality in the dataset. These statistical observations serve as the foundation for comprehending the distributional attributes of the variables, a critical aspect for the subsequent analyses in the study.

Table 2: Descriptive Statistics

	BF	CO ₂	DA	GDP	GS	REC
Mean	5.0142	2.9560	1.7777	10.810	2.1089	8.4476
Median	4.9250	3.0092	1.7917	10.856	2.0991	8.3739
Maximum	6.4611	3.0602	1.8046	11.0191	2.3969	8.9207
Minimum	3.2325	2.7507	1.5947	10.563	1.6646	8.0259
Std. Dev.	1.1605	0.0948	0.0402	0.1332	0.1906	0.2237
Skewness	-0.0061	-0.7016	-3.1107	-0.4822	-0.2047	0.5865
Kurtosis	1.3196	1.8748	12.272	2.0143	2.1449	2.4476
Jarque-Bera	14.118	16.175	623.42	9.5085	4.4945	8.4066
Probability	0.0008	0.0003	0.0000	0.0086	0.1056	0.0149

4.2. Nonlinearity Test Results

The BDS examination, which assesses the linearity of variables, produces outcomes showcased in Table 3. In the BDS test, the alternative hypothesis posits that "the variable follows a linear distribution," whereas the null hypothesis contends that "the series lacks a normal distribution." Table 3 provides statistically significant evidence endorsing the null hypothesis, indicating that all variables do not conform to a normal distribution at a 1% significance level.

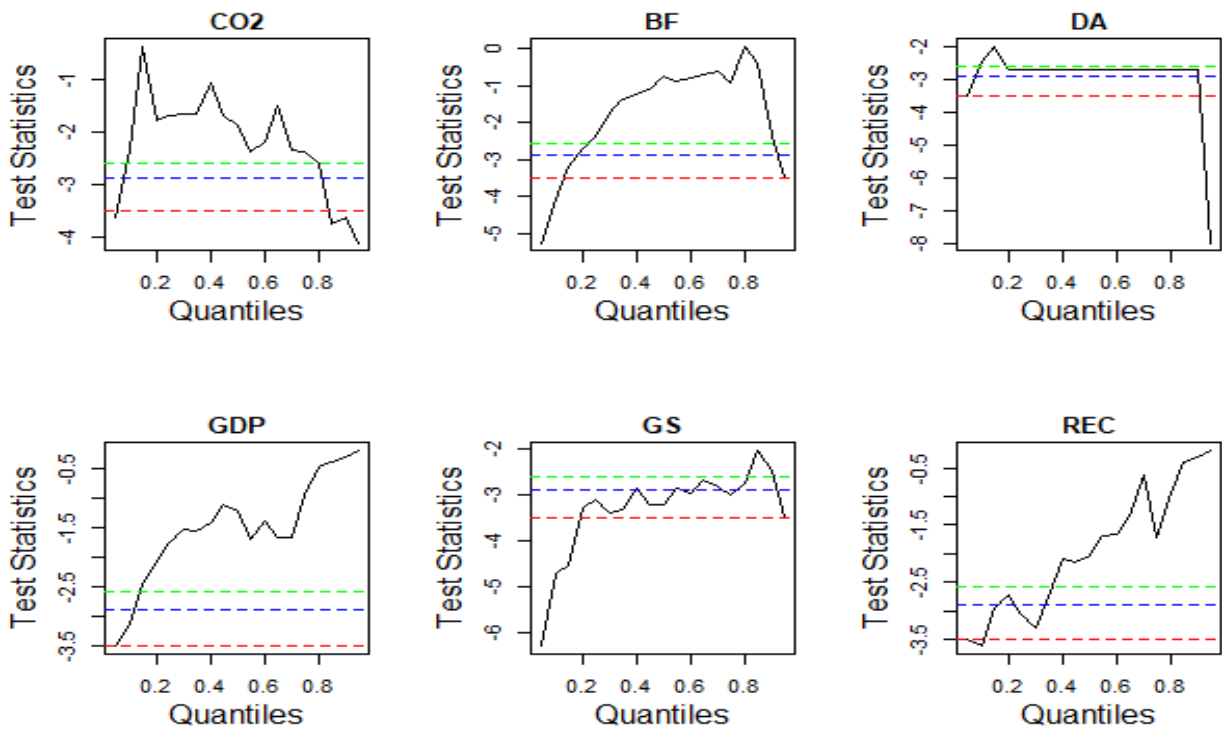
Table 3: BDS Test Results

	CO ₂	GDP	BF	GS	DA	REC
M2	33.829***	39.750***	50.072***	37.718***	10.866***	33.539***
Pvalue	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
M3	35.550***	42.397***	53.562***	38.530***	11.764***	34.751***
Pvalue	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
M4	37.871***	45.892***	58.026***	39.404***	12.550***	36.551***
Pvalue	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
M5	41.421***	51.055***	64.569***	41.013***	13.604***	39.565***
Pvalue	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
M6	46.467***	58.128***	73.588***	43.776***	15.007***	43.986***
Pvalue	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: ***< P 1%.

4.3. Stationarity Test Results

The outcomes derived from the BDS test indicate an absence of linearity in the study variables. Therefore, we must adopt nonlinear methodologies when appraising CO₂, GDP, BF, GS, DA, and REC stationarity characteristics. In line with this, we turn our attention to quantile-based unit root tests, specifically the quantile-based ADF and PP tests recommended by Adebayo & Oktay (2022), to delve into the stationarity features of the examined variables. The Quantile ADF (QADF) test outcomes, as depicted in Figure 1, and the Quantile PP (QPP) test, illustrated in Figure 2, elucidate that the variables exhibit stationarity at their first difference.

**Figure 1: Quantile ADF Result**

Note: Green, blue, and red lines represent the critical values of -2.58 , -2.89 , and -3.49 , corresponding to the 10 %, 5 %, and 1 % significance levels, respectively

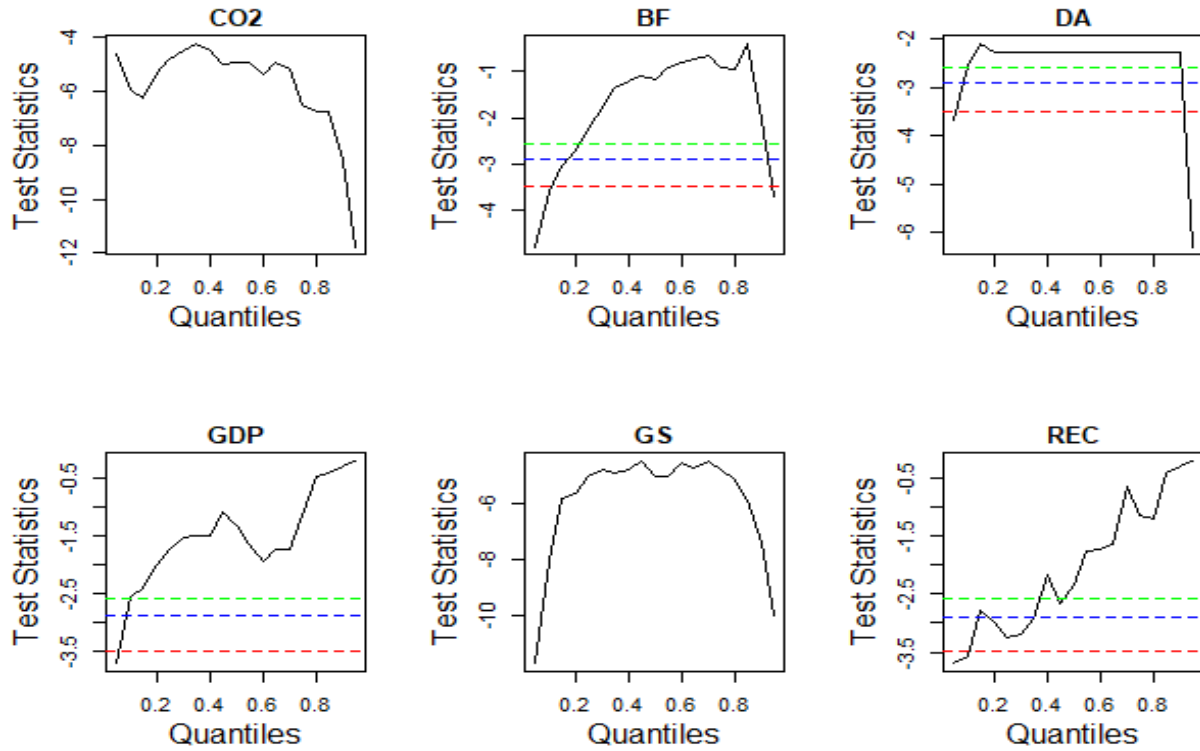


Figure 2: Quantile PP Result

Note: The green, blue, and red lines represent the critical values of -2.58 , -2.89 , and -3.49 , corresponding to the 10 %, 5 %, and 1 % significance levels, respectively.

4.4. Quantile-on-Quantile KRLS Results

The examination of the determinants of CO₂ in the United States employed the QQKRLS methodology recommended by Adebayo & Oktay (2022). The integration of regularization within QQKRLS is a preventative measure against overfitting, penalizing disproportionate coefficients and thus bolstering the model's adaptableness to novel data, as highlighted by Adebayo & Oktay (2022). This feature proves particularly valuable in improving predictive accuracy, especially in situations characterized by nonlinear dependencies among variables or deviations from normal distributions. As illustrated in Figure 3, the results reveal insights obtained through QQKRLS.

In Figure 3a, the impact of BF on CO₂ is presented. Across all tails (spanning from 0.05 to 0.95) of both CO₂ and BF, it is obvious that the effect of BF on CO₂ is statistically significant and negative. This signifies that the growth of biofuels is associated with CO₂ reduction, thereby contributing to the enhancement of the ecosystem in the United States. This further underscores the potential for achieving carbon neutrality in the United States through strategic biofuel investments. This outcome aligns with expectations because biofuels are commonly sourced from organic materials like crops, algae, or organic waste. During the growth phase of these feedstocks, CO₂ is absorbed from the atmosphere through photosynthesis (Xu et al., 2020). Subsequent utilization of biomass to produce biofuels, followed by combustion, results in the release of carbon dioxide, approximately offsetting the amount absorbed during growth.

This cyclic process establishes a closed carbon loop, rendering biofuels a carbon-neutral energy source. Moreover, biofuels can substitute conventional fossil fuels such as diesel and gasoline in industrial and transportation applications. This substitution effectively curtails the net emissions of CO₂, aligning with the recognition of biofuels as integral components of the natural carbon cycle. This finding aligns with the viewpoints of Bhat et al. (2022), Zaman (2017), and Al-Mulali (2015b), wherein both studies independently identified a connection between a decline in CO₂ and an increase in biofuel utilization. Their respective analyses underscore the pivotal role of biofuels in mitigating carbon emissions, reinforcing the viability of biofuel investments as a means to attain carbon neutrality.

Figure 3b displays the effect of DA on CO₂, with the result showing the effectiveness of DA in curbing CO₂ across all quantiles (0.05-0.95) of both DA and CO₂. Within a democratic framework, policymakers bear accountability to the electorate. The articulation of citizen concerns regarding ecological matters tends to elicit a responsive stance from elected officials, leading to the enacting and formulating policies targeting these issues (Güngör et al., 2021a). This responsiveness plays a pivotal role in shaping the landscape of ecofriendly regulations and policies. Furthermore, democratic systems underline the significance of openness and transparency in decision-making processes. This accessibility enables the public to comprehend, scrutinize, and engage in the evolution of policies impacting ecological quality. The resultant transparency nurtures trust and ensures that decisions are congruent with overarching ecological objectives. Our study validates the studies of Dai et al. (2023) and Güngör et al. (2021b), who reported the effectiveness of DA in curbing CO₂.

The impact of REC on CO₂ is illustrated in Figure 3c. Across all tails (spanning from 0.05 to 0.95) of both CO₂ and REC, the observed negative effect of REC on CO₂ implies that attaining carbon neutrality in the United States can be realized via strategic investments in RE sources. These outcomes accentuate the efficacy of RE in fostering clean ecological development. The implication is that an upsurge in the deployment of RE sources correlates with lessening CO₂, establishing a negative relationship between REC and CO₂, and vice versa. This outcome aligns with the theoretical premise articulated in the literature review, affirming that the advancement of RE contributes to ecological development by mitigating the impact of CO₂. These findings resonate with prior research by Acheampong et al. (2019) and Akram et al. (2020)

Figure 3d exemplifies the impact of Government Stability (GS) on CO₂ levels in the United States. Across the predominant range of quantiles (0.05-0.95) for both GS and CO₂, the observed effect of GS on CO₂ is positive. This indicates that low government stability is associated with increased CO₂, contributing to increased ecological deterioration. In instances of political instability, institutions and governance structures may become weakened. Under such circumstances, regulatory bodies may experience limitations in both authority and capacity to effectively implement ecological regulations and laws. This scenario can give rise to heightened ecological dilapidation, as individuals and industries may undertake practices detrimental to the ecosystem without encountering sufficient repercussions. This result aligns with prior studies (Adebayo & Ullah, 2023; Dai, Ahmed, Sinha, et al., 2023).

Figure 3a: Impact of BF on CO₂

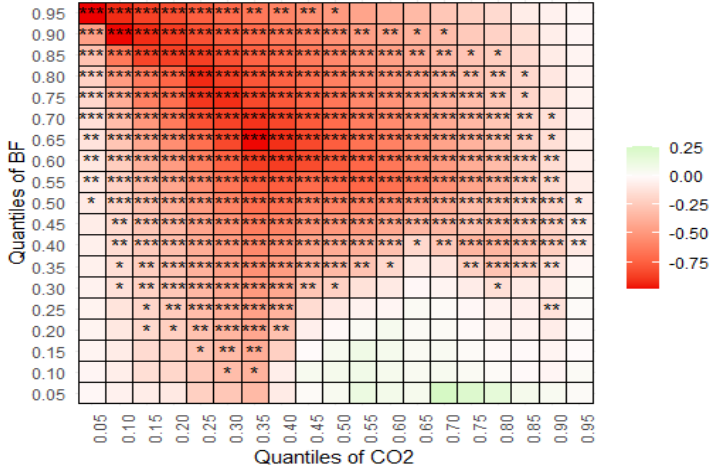


Figure 3b: Impact of DA on CO₂

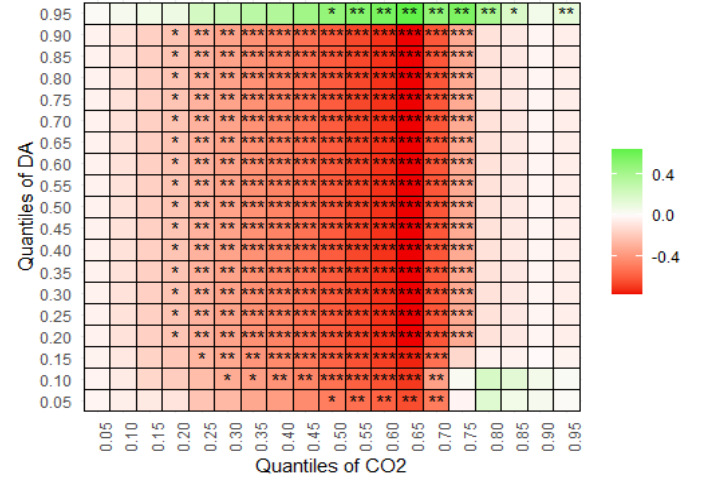


Figure 3c: Impact of REC on CO₂

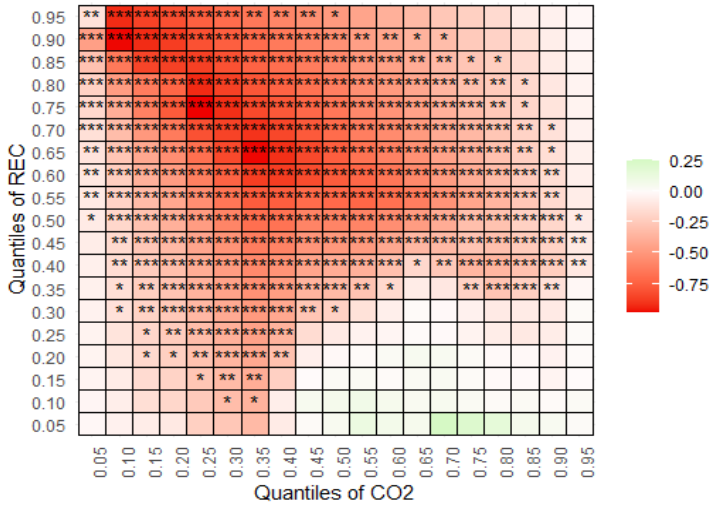


Figure 3d: Impact of GS on CO₂

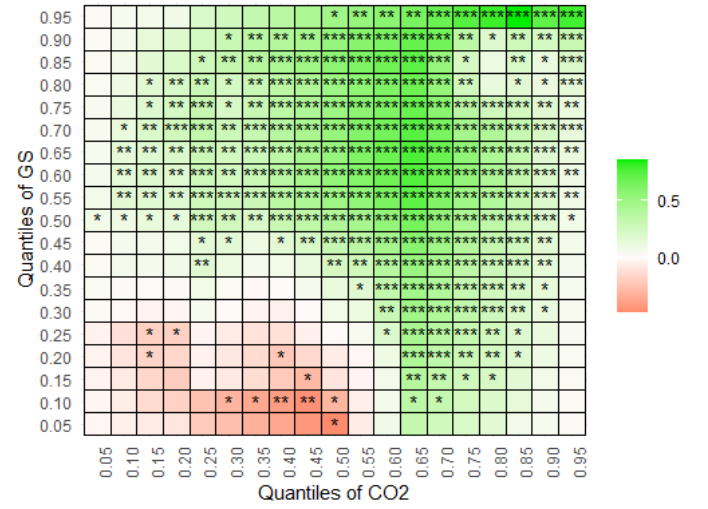


Figure 3e: Impact of GDP on CO₂

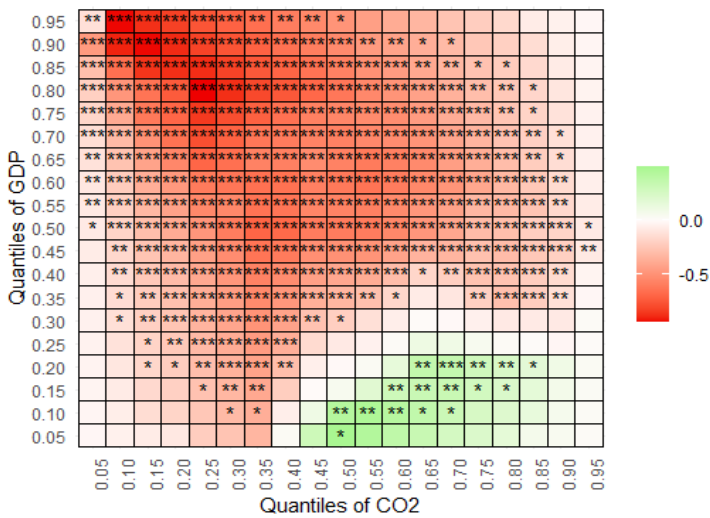


Figure 3: Quantile-on-Quantile KRLS Results

Note: The color bars illustrate the average pointwise marginal effect coefficients, with negative and positive coefficients denoted red and green. ***, ** and * signifies 1%, 5%, and 10% significance level, respectively.

Figure 3e depicts the impact of GDP on CO₂ in the United States. The outcomes reveal that, across all quantiles (0.05-0.95), the influence of GDP on CO₂ is negative and statistically significant. This implies that GDP benefits ecological integrity, indicating that the United States is progressing toward carbon neutrality. Furthermore, it underscores the sustainable energy utilized to fuel this growth. This discovery aligns with the findings of Dogan & Turkekul (2016) and Usman et al. (2020), who demonstrated that the United States experiences economic expansion without concurrent ecological weakening. This is attributed to stringent ecological strategies and technological advancements that mitigate the intensity of energy usage. Nevertheless, it contrasts with the conclusions drawn by Abbasi et al. (2021) and Bekun et al. (2019), who established a positive correlation between ecological contamination and GDP.

4.4. Quantile-on-Quantile Granger Causality (QQGC) Results

Next, we employed the novel Quantile-on-Quantile Granger causality method suggested by Adebayo & Oktay (2024), with the results shown in Figure 4. The results indicate that across all quantiles of CO₂ and BF distributions, BF can significantly forecast CO₂ (see Figure 4a). Figure 4b reveals the predictive power of DA over CO₂ across all quantiles of DA and CO₂. The causality analysis from REC to CO₂ shows that REC can predict CO₂ (see Figure 4c). Similarly, Figure 4d demonstrates that across all quantiles of GS and CO₂, changes in GS can be attributed to changes in CO₂. Figure 4e shows that across all quantiles of GDP and CO₂, shifts in CO₂ can be attributed to changes in GDP. These results are consistent with prior studies (Acaroğlu & Aydoğan, 2012; Ahmed et al., 2022b; Al-Mulali, 2015b; AlNemer et al., 2023; Dai, Ahmed, Sinha, et al., 2023; Saidi & Ben Mbarek, 2016).

Figure 4a: Causality from BF to CO₂

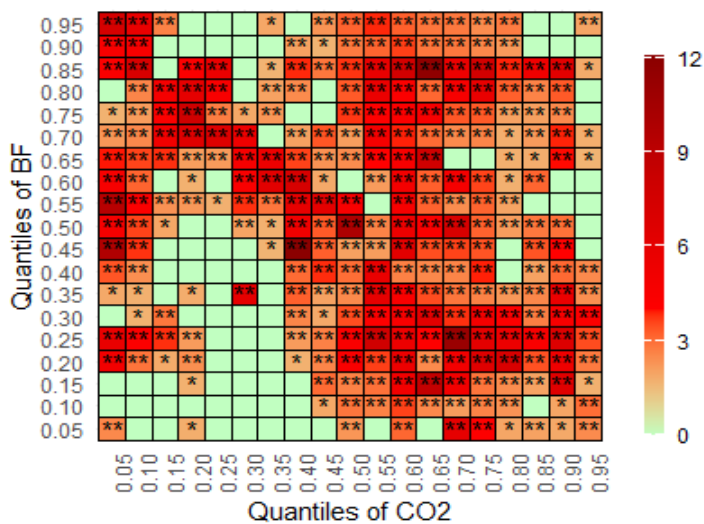


Figure 4b: Causality from DA to CO₂

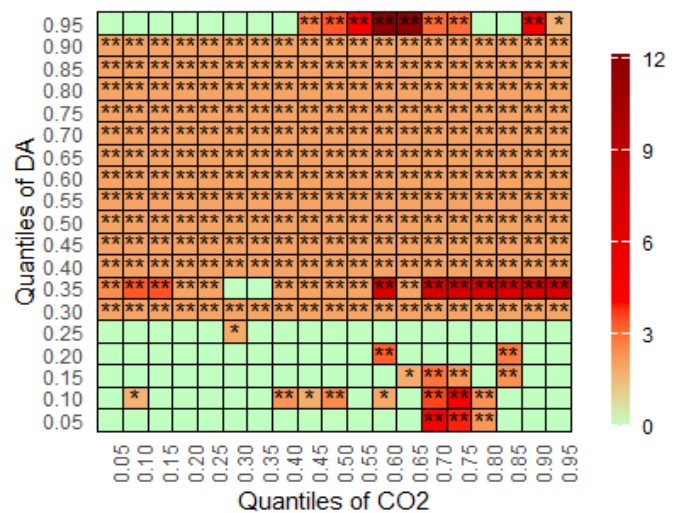


Figure 4c: Causality from REC to CO₂

Figure 4d: Causality from GS to CO₂

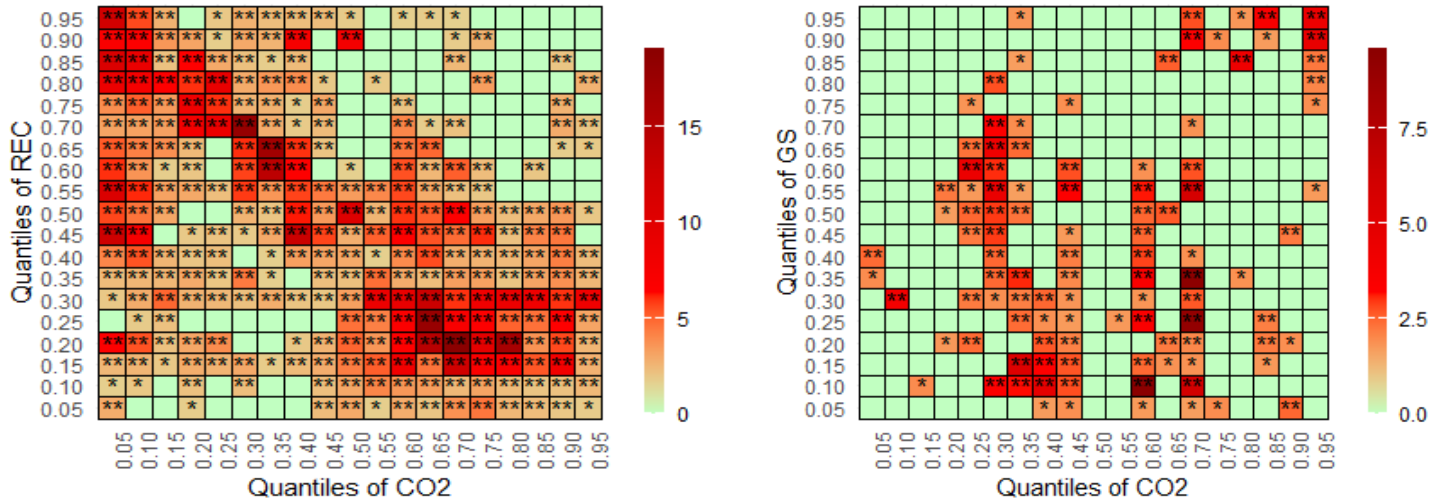


Figure 4e: Causality from GDP to CO₂

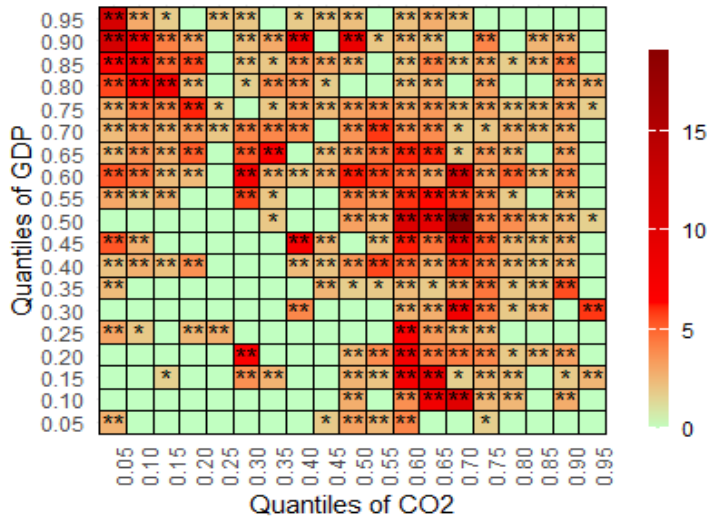


Figure 4: Quantile-on-Quantile Granger Causality Results

Note: Notes: This plot exhibits the estimated test statistics for each pairwise quantile series. Test statistics are colored in ascending order from dark green to red. ** and * symbols denote statistical significance at the 5 % and 10 % levels.

5. CONCLUSIONS AND POLICY RAMIFICATIONS

5.1. Conclusions

Given the conflicting findings regarding the interplay between the environment and democracy and recognizing the potential influence of biofuel energy consumption on environmental quality, this study delved into an empirical examination of the impact of democratic accountability and government stability on CO₂ in the United States over the period spanning from 1990 to 2019. The empirical investigation employed innovative quantile-based methodologies, including Quantile-on-Quantile Kernel Regularized Least Squares (QQKRLS), Quantile-on-Quantile Granger Causality (QQGC), Quantile Augmented Dickey-Fuller (QADF), and Quantile Philip-Perron (QPP), to provide a detailed understanding of the interrelationships at different quantiles of the data distribution. The application of the BDS test

supported the use of nonlinear techniques in the analysis, underscoring the need for a comprehensive approach to understanding the complex dynamics involved. The findings stemming from the QKRLS analysis revealed that government stability, democratic accountability, economic growth, and biofuel energy consumption collectively contribute to environmental sustainability in the United States. Notably, the positive contributions of government stability, economic growth, and biofuel energy use signify their potential to foster ecological well-being. However, the analysis also indicated that democratic accountability dampens ecological sustainability, suggesting a more nuanced relationship between democratic processes and environmental outcomes. Lastly, the QKGC results show that all the regressors can significantly predict CO₂ across all quantiles.

5.2. Policy Directions

Building upon the aforementioned conclusions, the paper encapsulates significant policy implications.

Firstly, prioritizing biofuels as an energy source is imperative for the United States in its battle against pollution. Notably, in 2021, the United States produced approximately 17.5 billion gallons of biofuels, surpassing the 16.8 billion gallons consumed (EIA, 2022). Fuel ethanol dominated both gross and net biofuel exports, accounting for a net export of 0.8 billion gallons from the United States. The United States government should sustain its support for biofuel production, diversify the renewable energy mix by incorporating wind, solar, and hydropower, and leverage innovative technologies to bolster environmental sustainability. Implementing tax breaks for businesses could catalyze the increased production of renewable energy.

Secondly, there is a critical need to enhance democratic accountability and governmental transparency. Our findings suggest that democratic accountability fosters the formulation of environmental policies that contribute to improving ecological quality. To fortify the accountability of government departments, a comprehensive review of responsibilities at their foundational levels is warranted. Upholding government integrity necessitates imposing stringent penalties for corrupt officials. Leveraging the public's oversight role to ensure the implementation of pertinent policies and prevent abuse of power by unscrupulous regulators is also instrumental.

Thirdly, it is crucial for the United States government to systematically analyze the impact of political stability on CO₂ and implement necessary measures. Enhancing political stability plays a central role in the collective endeavor to mitigate CO₂. In pursuit of the ambitious target to achieve carbon neutrality by 2050, the United States can strategically integrate considerations of the interconnection between political stability and carbon emissions into its policy formulation and implementation processes. This involves recognizing potential interventions that can be employed to foster political stability, thereby advancing ecological integrity and realizing the all-encompassing goal of carbon neutrality. This all-inclusive tactic aligns with the broader agenda of aligning political stability with ecological integrity, highlighting the intricate interplay between environmental outcomes and governance stability from an economic standpoint.

5.3. Caveat and Future Directions

Like many empirical studies, this one faces certain limitations that warrant acknowledgment. The sample size of our investigation was notably constrained by data availability. As we look ahead, we recommend that future research, conducted when data becomes more readily accessible, expands on both individual nations or groups of nations and spans a more extended timeframe. This broader scope will facilitate drawing more pragmatic conclusions regarding the intricate interrelationships between democratic accountability, government stability, and their impact on the environment. In this research, a time series method was employed. For more robust conclusions, subsequent studies could consider incorporating panel analysis to comprehensively capture the influence of biofuel energy consumption, democratic accountability, and government stability on ecological deprivation or quality. Additionally, it is advisable for future research to adopt a more comprehensive measure of environmental degradation or quality, such as ecological footprint and load capacity factor, for a thorough understanding of the dynamics at play.

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