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Can Green Accounting Finance Promote Energy Resilience: Fresh Insights from New Estimation

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Abstract
Green accounting financing (GAF) is crucial for restructuring energy use, change, and efficiency. Few studies look at finance's role in facilitating energy transition despite the paucity of investigation on how GAF impacts energy safety. This study set out to analyse the impact of green accounting finance (GAF) on a nation's energy security (ES). By examining the nexus between GAF and ES, we investigated a sample of 66 nations from 2000 to 2023. Utilising Panel-Corrected Standard Errors (PCSE) and Feasible Generalized Least Squares (FGLS) and incorporating four explanatory variables, the study has found that green accounting finance significantly improves energy security. The Autoregressive Distributed Lag (ARDL) method was further implemented to understand both the long-run and short-run impacts on energy security. The findings of this method indicate that the influence of green accounting finance persists in the long horizon, highlighting the importance of focusing on green accounting finance initiatives. More importantly, maintaining GAF depends heavily on institutional quality. We test our hypothesis by combining green accounting finance variables with those that represent institutional excellence. The impacts of green accounting finance become more pronounced in countries with well-designed institutional systems. Our findings indicate that promoting green accounting finance is essential for countries to achieve and maintain energy security.

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1. Introduction
Due to its intricacy, the energy system is susceptible to hazards from various sources, including abrupt changes in energy costs, severe weather, imbalances in energy demand and supply, and geopolitical concerns (Endiana, Dicriyani, Adiyadnya, & Putra, 2020; Gonzalez & Peña-Vinces, 2023; Nepal, Zhao, Liu, & Dong, 2024). For instance, severe energy shortages brought on by the "Russia-Ukraine dispute" that began in February 2022 significantly increased social running expenses in Europe (Xin, Fan, Mbanyele, & Shahbaz, 2023). The energy grid was also upset in August 2023 by Typhoon "Doksuri," which caused persistently heavy precipitation in the Beijing-Tianjin-Hebei area of China (Xin, Xi, Sagir, & Wenbo, 2023). This resulted in power shortages and disrupted communications networks in various regions of Beijing and Hebei. Countries have put measures in place to lessen climate shifts in reaction to these occurrences and their adverse effects (Endiana et al., 2020; Gonzalez & Peña-Vinces, 2023; Nepal et al., 2024). Researchers and government officials are considering strengthening the energy system's resilience to prevent external hazards, maintain energy safety, and facilitate a green energy transition (Jamasb & Nepal, 2015).

In biological sciences, the term "resilience" was first used to characterise the compressive property of steel-like materials ("engineering resilience"). Resilience was first defined in biology by Holling (1973) and Hollnagel, Woods, and Leveson (2006) who described it as a system's ability to go beyond a certain point and maybe take a different developmental course in the wake of disruptions. Later, researchers concentrated on energy system resiliency. As stated by Gatto and Drago (2020) energy resilience is the system's capacity to tolerate shocks in various domains (such as the economy, society, environment, and institutions), respond to them, and bounce back by adapting and taking lessons from them. Although progress exists in evaluating energy durability (Perera, Zhao, Wang, Soga, & Hong, 2023) disagreements persist on its assessment and implications, especially in China, where additional research is required to gauge, examine, and contrast power resilience among various regions.

Green accounting financing (GAF) is crucial for restructuring energy use, change, and efficiency (Gonzalez & Peña-Vinces, 2023). However, researchers are divided on how to create a green accounting financial index. Numerous studies look at finance's role in facilitating energy transition despite the paucity of investigation on how GAF impacts energy safety. There are two ways that adequate finance can increase the use of green power. First, funding clean energy initiatives encourages people and companies to switch to non-fossil fuels, thereby reducing their reliance on conventional fossil energies. Second, the supply of these power sources is increased by raising research and development (R&D) expenditures for green energy. According to Paramati, Ummalla, and Apergis (2016) the EU, G20, and Organisation for Economic Co-operation and Development (OECD) countries' stock market-based financial growth is linked to higher utilisation of clean energy. According to Assi, Isiksal, and Tursoy (2020) creating financing can encourage sustainable development and lower gasoline usage.

The European Union (EU) has recently advanced green accounting finance through its financial policies (Rounaghi, 2019). Notably, the "G20 Green Accounting Finance Report," ratified during the 2016 G20 Summit, defines green accounting finance as an economic framework directing societal capital towards environmentally beneficial sectors, thereby promoting sustainable development. Since 2017, the EU has significantly promoted low-carbon development, exemplified by the establishment of pilot areas for green banking innovation across 10 cities spanning five provinces (Xueyang Wang, Sun, Zhang, & Xue, 2022; H. Zhang & Wei, 2024). This shift extends beyond the promotion of environmentally friendly financial products to encompass a broader agenda aimed at fostering sustainable economic growth.

The economic cycle—a term that describes the erratic swings of fiscal activity—must be considered when developing a financial product (Djennas, 2016). While commercial cycle shocks can cause disruptions in energy demand, such cyclical changes are expected in market systems and impact the supply of energy (Shahbaz, Nasir, & Roubaud, 2018). Besides, Khalifa, Caporin, and Hammoudeh (2015) state that these cycles impact energy pricing, supply, and demand. They also have an impact on energy resilience and financial instability. Research has shown that green accounting finance may efficiently promote clean energy as well as improve energy effectiveness, which has substantially impacted the energy sector (Du, Shen, Song, & Vardanyan, 2023). Energy system resilience is increased by increasing energy efficiency and switching to renewables (Banerjee, Smith, & Kumar, 2017). Enhancing energy vulnerability calls for significant and ongoing fiscal expenditures, and sustainable finance can supply the required capital, especially in the EU, which is proliferating. Because of this, it is imperative to investigate how ecological banking might improve the EU's energy durability, as this connection has received little attention.

The three major objectives of the research are as follows: How can energy resilience in the EU's various areas be reliably and thoroughly evaluated? The second question is whether the EU's energy resilience is improved by the advancement of green banking and whether this influence differs depending on the location. Third, the particular channels via which the EU's energy independence is impacted by sustainable funding. The study utilises an entropy approach to evaluate energy resilience as well as green accounting finance, employing balanced panel data spanning. It conducts empirical and visual analyses to scrutinise the interplay between these factors, delving into the drivers of industrial restructuring and green technology innovation. Furthermore, the research examines how green accounting finance influences the economic, social, ecological, and energy endowment dimensions of energy durability.

This investigation makes three significant advances: To facilitate precise evaluations and interregional assessments, it first thoroughly evaluates energy robustness at the national level in the EU, considering fiscal, ecological, community, and endowment elements. Secondly, it closes a gap in the literature by empirically analysing how green accounting finance affects the nation's energy resilience in a sample of 66 nations between 2000 and 2023. It demonstrates that green accounting finance may effectively reduce the impact of external events on the power system. We collect the most up-to-date database. In this paper, we apply the PCSE method for the dynamic panel with the existence of cross-sectional dependence. This method requires strongly balanced data. Thus, the cleaning process must remove any country with missing observations and outliers. Lastly, it investigates the methods via the discovery of green technologies and upgrading the industrial structure, offering policymakers both theoretical understanding and valuable references. These contributions provide important insights for academic research and policy development and advance our knowledge of the link between power resilience and green banking.

The analyses of our study contribute substantially to the current papers. This is the first research evaluating the linkage of GAF and energy security (ES). Thus, our study improves and supplements the comprehension of the economic impact on the pattern of ES or on the environment (Abbasi, Lv, Radulescu, &

Shaikh, 2021; Boleti, Garas, Kyriakou, & Lapatinas, 2021; Jackman & Moore, 2021; Le, Hoang, & To, 2022). In our research, we assess the efficacy of GAF. The dataset used allows for an examination of various types of natural resources, offering an extensive view of the relationship between GAF adoption and ES. Our analysis covers the period between 2000 and 2023, employing a number of empirical methodologies and different strategies. The non-appearance of comprehensive GAF data in the area is why we selected this database. In the subsequent section, we examine the relationship between ES and GAF adoption by implementing the PCSE, the FGLS, and the ARDL method. The PCSE model is fitting for dynamic analysis, addressing cross-sectional dependence following longitudinal correlations and asymmetry tests of panel data. To enhance robustness, we employed the FGLS model to account for heteroscedasticity. Moreover, the ARDL – DFE estimator (Dynamic Fixed Effects) was utilised to capture both immediate and prolonged impacts. Ha (2022); Ha (2023) and Ha and Thanh (2022) posited that this method enables the identification of effects that are constant over time and specific to each country.

Below is the section arrangement of the study. Literature on the variables is disscussed in the second section. The study procedures, as well as the explanation of the variables and data, are presented in section number three. The last two sections cover the results and discussion, and then provides the last thoughts, the consequences of policy, and the limitations.

2. Literature review

2.1. Assessment of Energy Resilience

Scholars are particularly interested in determining how to evaluate power vulnerability thoroughly and reliably. Researchers have evaluated a country's energy resilience on a worldwide scale. For instance, Dong, Dong, Jiang, and Zhao (2021) assessed the energy endurance of 107 nations in 2016 using the entropy technique and 27 indicators divided into renewable power, energy access, and efficiency. Similarly, Gatto, Drago, Panarello, and Aldieri (2023) used intervals to build a blended indicator model to quantify global energy resilience. According to some research, various energy resources, governance, infrastructure, and R&D are all important for maintaining energy network resilience (Fan, Zhu, & Xu, 2023).

A number of academics have quantified energy resilience by examining how well power networks function both before and after disruptive events, taking recoverability, adaptability, and absorptive capacity into account. According to Jamali and Rasti-Barzoki (2022) the main way to evaluate energy resilience is to determine how well it recovers from shocks. Francis and Bekera (2013) suggested measuring resilience by assessing recovery time and system operation. Similarly, Henry and Ramirez-Marquez (2012) evaluated resilience by looking at how well a system could recover from and absorb different shocks. In addition, Hasselqvist, Renström, Strömberg, and Håkansson (2022) developed a thorough framework to evaluate households' energy resilience. The framework consists of four essential components: backup energy, energy adequateness, adaptability, and energy effectiveness.

2.2. The Connection between Energy Resilience and Green Accounting Finance

Academic studies on the effects of GAF on energy systems have proliferated recently due to the realisation that these studies are essential to advancing energy-related projects (Gonzalez & Peña-Vinces, 2023; Rounaghi, 2019). Sustainable financing for renewable energy has gained much recognition as an essential source of support; numerous studies have demonstrated how well it facilitates the transition to clean energy. Alharbi, Al Mamun, Boubaker, and Rizvi (2023) support conventional wisdom by demonstrating that funding for environmentally friendly initiatives promotes the growth of sustainable energy sources. After an empirical investigation into the causal relationships between sustainable energy initiatives, energy effectiveness, and GAF, Rasoulinezhad and Taghizadeh-Hesary (2022) discovered that sustainable bonds significantly increase expenditure on green energy initiatives. Promoting green energy projects strengthens the framework of the energy system, lessens reliance on natural gas, and increases resilience to fluctuations in fuel costs and scarcity.

Furthermore, increasing energy efficiency requires green money. GAF is an effective way to restructure energy consumption, according to Liu, Khan, Zakari, and Alharthi (2022). Similarly, Zhang et al. (2023) discovered that GAF predominantly increases energy effectiveness in Chinese prefecture-level cities through creativity in green technologies. Improving energy efficiency extends the longevity of power sources and lessens dependency on inefficient energy sources. High energy efficiency increases the energy system's resilience by ensuring that systems with restricted funds continue to function in the event of energy restriction or uncertain supply. We put out the following initial suggestion in light of this conversation:

H_1: Energy vulnerability is directly improved by GAF.

2.3. The Effect Process of Green Accounting Finance on Energy Resilience

In-depth research on the exact processes by which the development of sustainable financing affects energy vulnerability must be carried out. Nonetheless, there is no thorough analysis of this topic in the literature currently in publication. The beneficial impacts of finance on technical breakthroughs have been confirmed by several studies, including (Wang, Zhang, & Li, 2023a; Wang, Zhang, & Li, 2023b) investigation into digital finance. The positive impacts of green financial regulations on green technology innovation development have also been emphasised by academics. An example of a difference-in-differences evaluation is the work done by Lu, Wu, and Liu (2022); Zeng, Tong, and Yang (2023). Lu et al. (2022) focused on the policies that are in place in the EU's innovation and green accounting finance reform pilot zones. According to their outcomes, green accounting finance efforts greatly advance enterprises' green technology development, and this procedure requires reducing financial constraints. Other researchers agree with this conclusion, prominently Xu, Zhang, and Chen (2023). Sustainable technology enhancements involve energy storage, smart grids, and renewables. These helps increase the diversity of energy supplies, lessen dependency on fossil fuels, and increase the energy system's durability.

Several scholars have studied the effects of green accounting finance on enhancing industrial structural strengthening. By integrating capital and allowing resource reallocation, green accounting finance shifts funding toward low-pollution or sustainable sectors while decreasing aid for high-pollution or excessive industries (Xinyue Wang & Wang, 2021). Based on empirical research, green accounting finance efforts help with industrial structural adjustment by increasing the tertiary sector's value-added output and reducing the primary and secondary sectors' growth rates. One may legitimately contend that this kind of institutional modernisation creates a more adaptable and diverse energy system, which increases the system's durability. As a result, we have put out the following theory regarding the mechanics behind the effects of sustainable finance:

H_2: Green accounting finance could indirectly improve energy vulnerability by promoting green technology development.

H_3: Green accounting finance could indirectly improve energy resilience by promoting the modernisation of industrial infrastructure.

2.4 Research Gaps

A literature study on this subject has shown several unmet research needs. First, there is no industry-wide standard for evaluating energy durability despite numerous research studies suggesting methods. Furthermore, the quantification of energy resilience in both developed and developing countries has still remained silent. Second, there is evidently lacking empirical research on the connection between energy robustness and green accounting finance, even though the literature currently in publication focuses mainly on the effects of green accounting finance growth on encouraging the switch to sustainable energy sources and enhancing energy effectiveness. Lastly, little paper has been completed to determine how green technical advances and enhancing of industrial structures moderate this relationship, leaving the processes underpinning the impact of sustainable finance ambiguous.

3. Empirical Methodology

To investigate the linkages between GAF and ES, we have employed a model presented as follows.

$$ES_{it} = \beta_0 + \beta_1 GAF_{it-1} + \beta_2 INC_{it-1} + \beta_3 GE_{it-1} + \beta_5 POP_{it-1} + \beta_5 SAV_{it-1} + \varepsilon_{it} \quad (1)$$

Where *i*, *t* represents nation *i* in year *t*. φ_t and ω_i accounts for the nation and year-fixed effects of the model and $\varepsilon_{ijt,}$ is the disturbance.

3.1. Indicators of Energy Security (ES)

There are six proxies of ES used in this study to analyse the interrelationship between ES and GAF, representing the faucets of "acceptability", "develop-ability", and "sustainability". First, *Availability*, ES1, quantified by the share of non-fossil-source consumption in the final consumption, characterises a nation's energy mix. It exhibits the "acceptability" aspect, revealing the supply and demand impacts of non-fossil fuels on economic and environmental aspects (Liwen Fang et al., 2018). With data sourced from the U.S. EIA, ES1 is a positive proxy, given the rise of non-fossil fuels leads to stronger and more sustained energy security (Fang et al., 2018). Second, *Acceptability*, ES2, is measured by the per capita energy consumption rate. As a higher energy consumption rate puts greater threats and weights on energy security, this is an adverse proxy. The sustainable advancement of a country's energy system (i.e., efficient, eco-friendly, and low-carbon) is shown through the nation's ability to measure how secure and reliable its energy is (Liwen Fang et al., 2018).

Third, *Develop-ability*, there are two proxies, ES3 and ES4, reflecting the linkage between the energy structure and fossil fuel combustion emission (Le & Nguyen, 2019). They are, according to Liwen Fang et al. (2018) the proportions of CO_2 emissions to Gross Domestic Product (GDP) and primary energy usage, and thus, are negative proxies. Fourth, *Sustainability*, the ES5 proxy is quantified through the ratio of renewables to total final energy usage, and the ES6 proxy is quantified through per capita renewables consumption, respectively.

Sources of energy can be classified into fossil fuels, non-renewables, and renewables by the U.S.EIA definition. Renewable energy includes hydroelectricity, natural-resource energy (i.e., geothermal, solar, and wind), and biomass, all of which significantly influence energy security and sustainability. In contrast, fossil fuels comprise coal, natural gas, and petroleum. Unlike ES1, which encompasses a broad view of energy security, ES5 and ES6 specifically focus on renewable energy usage to more accurately reflect the sustainability of energy security.

Nuclear energy and hydroelectric power are also included in ES1, but their effects on the sustainability of energy structures are still being debated (Lee, Ayoub, & Agrawal, 2016). Specifically, for nuclear, there is complexity in the environmental profile, according to the U.S. EIA. The mining, ore refining, and reactor fuel production operations require a significant amount of energy, even though uranium produces the same amount of pollution as fossil fuels. Additionally, the manufacturing of metal and concrete for nuclear infrastructure involves significant energy use, contributing to pollution and carbon emissions. The potential for environmental contamination and long-term radioactive hazards further complicates the sustainability of nuclear power.

3.2. Key Explanatory Variable: Green Accounting Finance (GAF)

In this article, green accounting finance is measured. Material flows, as well as resource productivity indicators, are central to monitoring the altering patterns of resource usage as global economies grow (ton). This variable was sourced from the UNEP IRP Global Material Flows Database. The sample consists of 66 countries from 2000 to 2023.

3.3. Control Variables

After reviewing existing literature on the topic, the selected set of explanatory variables is as follows. Table 1 describes the definitions, sources, and specific statistics of the variables to be employed in our analysis – definition and summary statistics. The explanatory variables are the degree of democratisation (*GE*), total population (*POP*), economic growth (*INC*), and national annual savings (as a percentage of GDP) (*SAV*). Table 2 displays the correlation matrix. GAF is negatively correlated with dimension 4 of ES, with the remaining being positive.

To determine if there exists cross-sectional dependence (CD), Pesaran (2021) methodology is used to conduct the CD test. The stationarity of variables displaying CD is then investigated with unit root tests. Table A.1 illustrates the information of included countries.Table 3 summarises the results for all variables—which, aside from GE—show cross-sectional dependence and are stationary at their values. When one applies the first difference, every variable becomes stationary. Then, in order to ascertain whether ES and GAF show cointegration, we ran the Kao (1999); Pedroni (2004) and Westerlund (2005) cointegration tests. The cointegration feature of GAF with each dimension of ES was validated by the results shown in Table 4.

Given cross-sectionally dependent, first-differenced stationary data, the PCSE model is utilised to assess the linkage between GAF and ES following the methodologies of Beck and Katz (1995); Ha (2022) and Le et al. (2022). Equation 1 specifies that all independent variables are taken as their lagged-one values in order to mitigate potential endogeneity resulting from the interactions between GAF and ES. We also repeat our analysis with the two-step General Method of Moment (GMM) methodology and FGLS. In order to address any heterogeneity and endogeneity problems, these models are used, as explained by Sweet and Eterovic (2019); Gala, Camargo, Magacho, and Rocha (2018); Ha (2023) and Sweet and Eterovic Maggio (2015).

Table 1. Definition and summary statistics.

Variable	Definition	Measure	Source	Obs.	Mean	SD	Min.	Max.
ES1	Energy security 1 (Acceptability of energy security)	Non-fossil energy consumption=1-Fossil energy consumption to total (%)	U.S. EIA	1.518	20.28	16.21	0.00	55.63
ES2	Energy security 2 (Develop-ability of energy security)	Primary energy consumption/Population	U.S. EIA	1.518	0.04	0.04	0.00	0.15
ES3	Energy security 3 (Develop-ability of Energy Security)	CO2 emissions	U.S. EIA	1.518	0.24	0.14	0.06	0.82
ES4	Energy security 4 (Develop-ability of energy security)	CO2 emissions/Primary energy consumption	U.S. EIA	1.518	188.44	43.05	109.00	304.00
ES5	Energy security 5 (Acceptability of Energy Security)	Sustainable energy consumption (%)	U.S. EIA	1.518	0.48	1.07	0.00	7.06
ES6	Energy security 6 (Sustainability of energy security)	Sustainable energy consumption per capita	U.S. EIA	1.518	6.66	8.43	0.01	33.30
GAF	Creditor reporting system	Material flows and resource productivity indicators are central to monitoring the changing patterns of resource use as global economies grow (Ton)	UNEP IRP global material flows database	1,518	1.12	3.39	1.35	3.49
INC	Economic growth	The real GDP per capita (Constant 2010 US dollars).	WDI	1.518	8.78	1.39	5.57	11.39
GE	Level of democratisation	The index of democratisation	FSSDA	1.518	0.16	0.93	-1.89	2.11
POP	Population	Total of population.	WDI	1.518	4.15	1.44	0.98	7.57
SAV	Saving	Annual saving to total GDP (%).	WDI	1.518	23.34	12.55	-29.26	65.55

Note: EIA: Energy information administration, UNEP IRP: United nation environment programme international resource panel; WDI: World development indicator.
FSSDA: Federated semi-supervised domain adaptation.

Table 2. Correlation matrix.

Variable	ES1	ES2	ES3	ES4	ES5	ES6	LGAF	INC	GE	POP	SAV	EXP	INFL
ES1	1												
ES2	0.154*	1											
ES3	-0.418***	0.496***	1										
ES4	-0.771***	-0.154*	0.586***	1									
ES5	0.410***	0.266***	0.178*	-0.293***	1								
ES6	0.554***	0.745***	0.0910	-0.505***	0.498***	1							
LGAF	0.0448	0.179*	0.0544	-0.0699	0.0237	0.350***	1						
INC	0.479***	0.735***	0.111	-0.323***	0.0898	0.578***	0.0224	1					
GE	0.419***	0.718***	0.0123	-0.288***	0.0393	0.614***	0.181*	0.423***	1				
POP	-0.0952	-0.516***	-0.622***	-0.230**	-0.395***	-0.414***	-0.139	-0.369***	-0.274***	1			
SAV	-0.276***	-0.119	-0.182*	0.0495	-0.314***	-0.131	0.0135	-0.0395	0.0467	0.473***	1		
EXP	0.404***	0.690***	0.128	-0.330***	-0.0794	0.485***	-0.0165	0.437***	0.446***	-0.175*	0.105	1	
INFL	-0.362***	-0.232**	0.160*	0.184*	-0.0840	-0.286***	0.0206	-0.376***	-0.403***	0.0492	0.103	-0.297***	1

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Cross-Dependence (CD) tests and stationarity tests.

Variable (in level)	Im-Pesaran-Shin test (Z-bar)	CD-test, Pesaran (2021)	Variable (in difference)	Im-Pesaran-Shin test (Z-bar)
GAF	-9.32***	18.22***	DGAF	-11.47***
ES1	-5.91***	6.22***	DES1	-6.67***
ES2	-5.16***	6.13***	DES2	-6.22***
ES3	-5.31***	6.22***	DES3	-6.67***
ES4	-5.32***	6.13***	DES4	-6.55***
ES5	-5.21***	6.22***	DES5	-6.83***
ES6	-6.22***	5.17***	DES6	-6.43***
INC	-6.46***	8.13***	DINC	-6.66***
EXP	-7.31***	4.36***	DEXP	-4.29***
GE	3.007	42.070***	DGE	-3.698***
POP	-12.21***	8.64***	DPOP	-16.43***
NR	-14.21***	3.54***	DNR	-17.15***
SAV	-7.32***	8.30***	DSAV	-15.43***
INFL	-12.21***	12.64***	DINFL	-16.93***

Note: The CD test null hypothesis is "data are not correlated across panel groups". Unit root tests follow (Im, Pesaran, & Shin, 2003) and Levin, Lin, and Chu (2002). The null hypothesis is "All panels contain unit root".
***$p < 0.001$

Table 4. Cointegration test.

Model: f (GAF and ES)	Pedroni test	Kao test	Westerlund test
	Phillips-Perron t	Dickey-Fuller test	Variance ratio
ES1	-2.51***	-3.11***	5.26***
ES2	-2.56***	-4.17***	5.11***
ES3	-2.64***	-5.18***	5.24***
ES4	-3.77***	-3.12**	6.34***
ES5	-2.46***	-3.26***	4.41***
ES6	-2.46***	-5.18***	6.51***

Note: The null hypothesis of all three tests is "No cointegration". Regarding the first two tests, the alternative hypothesis is "All panels are cointegrated", whereas for the Westerlund test, it is "Some panels are cointegrated". ***$p < 0.001$

4. Empirical Results

4.1. Energy Transition and Green Accounting Finance: Benchmark Results

Employing PCSE and FGLS methods, Table 5 compares the regression results between the two for the benchmark model. Here, we use GAF as the key independent variable, as mentioned above. It can be seen that the PCSE and FGLS regressions do not differ in coefficient magnitudes, suggesting a strong and consistent empirical analysis. In using the PCSE method, GAF is found to exert significant beneficial effects on ES5 and ES6 (sustainable energy consumption share and sustainable consumption per capita, respectively) and a significant adverse effect on ES4 (primary energy consumption). Moreover, further analysis using FGLS identified an additional significant negative effect of GAF on ES3 (CO_2-to-GDP ratio). In general, a 1% increase in the past values of GAF brings about a rise in the usage of renewables (ES5, ES6) and a decline in the emission of CO_2 (with respect to GDP and primary energy consumption, ES3, ES4). As such, evidence has pointed out that green accounting finance ensures the energy transition, or in other words, energy security.

Interestingly, all control variables display a significant influence on the dimensions of ES. First, economic growth positively affects a nation's energy security by enhancing the ES1 (non-fossil fuel structure) and ES6 (renewable energy consumption per capita), while effectively reducing the threats of negative ES3 and ES4 indicators. However, economic growth presents a side effect of reducing a positive indicator, ES5, which hinders the energy transition. The level of democratisation positively induces an increase in every dimension, implying that democracy-related policies might need more attention if geared toward energy security. The total population has a positive influence on ES1 and negative impacts on the remaining dimensions, having a net positive effect on energy security. The saving ratio appears to negatively impact energy security, with negative coefficients for positive indicators and positive coefficients for negative indicators. It is worth noting that all variables have little to no influence on the ES2 (the rate of primary energy consumption per capita). GAF's impact on ES2 is effectively zero for both the PCSE and FGLS methods.

Examining further by employing three green accounting finance alternatives, Table 6 concerns the influence of these measures on ES1, ES4, and ES6. Similar to the previous findings on GAF and ES, both PCSE and FGLS produced matching regression outputs. The three measures have a consistent effect on each of the dimensions: positive for ES1 and ES6, and negative for ES4. Notably, all three measures have a significant impact on ES6 at the 5% significance level, while there is insignificant impact on ES1. Two alternative measures, public investment in green energy and green energy debt flows, significantly reduce ES4 (environmental waste) at the 10% significance level. We can, therefore, assume that green accounting finance can act as a catalyst to strengthen the energy transition or energy security, which is in line with the above result using GAF.

Table 6 also presents the effects of the control variables corresponding to each green accounting finance measure. Overall, the control variables' coefficient signs in the GPI (Public Investments in Green Energy), DEBT, and SECU models do not deviate from those in the GAF model, with the only exception of economic growth exerting a negative influence on ES6 instead of a positive like in the GAF model.

Table 5. The influences of green accounting finance on energy transition: Benchmark models.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	PCSE						FGLS					
Variables	**ES1**	**ES2**	**ES3**	**ES4**	**ES5**	**ES6**	**ES1**	**ES2**	**ES3**	**ES4**	**ES5**	**ES6**
L.LGAF	0.10	0.00*	-0.01	-5.60***	0.16***	1.15***	0.10	0.00	-0.01**	-5.60***	0.16***	1.15***
	(0.427)	(0.000)	(0.008)	(2.112)	(0.041)	(0.268)	(0.538)	(0.001)	(0.004)	(1.338)	(0.041)	(0.253)
L.INC	6.72***	0.00***	-0.05***	-31.82***	-0.54***	0.15	6.72***	0.00*	-0.05***	-31.82***	-0.54***	0.15
	(0.693)	(0.001)	(0.008)	(2.150)	(0.093)	(0.352)	(1.987)	(0.003)	(0.016)	(4.945)	(0.150)	(0.936)
L.GE	1.34	0.01***	0.03***	15.30***	0.55***	4.76***	1.34	0.01***	0.03	15.30***	0.55***	4.76***
	(0.911)	(0.001)	(0.010)	(2.359)	(0.103)	(0.437)	(2.230)	(0.003)	(0.018)	(5.547)	(0.168)	(1.050)
L.POP	2.97***	-0.01***	-0.07***	-18.83***	-0.30***	-1.08***	2.97***	-0.01***	-0.07***	-18.83***	-0.30***	-1.08***
	(0.215)	(0.000)	(0.005)	(1.242)	(0.031)	(0.124)	(0.683)	(0.001)	(0.006)	(1.700)	(0.051)	(0.322)
L.SAV	-0.65***	0.00***	0.01***	3.08***	0.07***	-0.06**	-0.65***	0.00	0.01***	3.08***	0.07***	-0.06
	(0.064)	(0.000)	(0.001)	(0.289)	(0.011)	(0.028)	(0.106)	(0.000)	(0.001)	(0.264)	(0.008)	(0.050)
Observations	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452
Number of nations	66	66	66	66	66	66	66	66	66	66	66	66

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6. The influences of green accounting finance on energy transition: Alternative measures of green accounting finance.

Panel A: PCSE

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	PCSE								
Variables	**ES1**	**ES4**	**ES6**	**ES1**	**ES4**	**ES6**	**ES1**	**ES4**	**ES6**
L.LGPI	0.14	-1.78	0.52**						
	(0.332)	(1.306)	(0.214)						
L.LDEBT				0.39	-2.09*	0.68***			
				(0.364)	(1.158)	(0.240)			
L.LSECU							2.08	-3.25	1.55*
							(1.577)	(4.492)	(0.790)
L.INC	6.54***	-24.06***	-1.50**	6.44***	-23.98***	-1.55**	6.48***	-24.62***	-1.37***
	(0.753)	(2.393)	(0.591)	(0.793)	(2.366)	(0.605)	(0.705)	(2.011)	(0.474)
L.GE	1.51*	7.16***	6.47***	1.59*	7.06***	6.52***	1.57*	7.52***	6.39***
	(0.877)	(2.510)	(0.747)	(0.922)	(2.501)	(0.763)	(0.830)	(2.259)	(0.615)
L.POP	2.92***	-16.90***	-1.49***	2.93***	-17.05***	-1.44***	2.84***	-16.92***	-1.51***
	(0.159)	(0.646)	(0.086)	(0.165)	(0.701)	(0.083)	(0.190)	(0.751)	(0.086)
L.SAV	-0.65***	2.90***	-0.03	-0.66***	2.96***	-0.05	-0.64***	2.82***	-0.00
	(0.064)	(0.269)	(0.028)	(0.069)	(0.278)	(0.031)	(0.059)	(0.233)	(0.024)

Observations	224	224	224	224	224	224	224	224	224
Number of nations	14	14	14	14	14	14	14	14	14
Panel B: FGLS									
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
	FGLS								
Variables	**ES1**	**ES4**	**ES6**	**ES1**	**ES4**	**ES6**	**ES1**	**ES4**	**ES6**
L.LGPI	0.14 (0.369)	-1.78* (0.946)	0.52*** (0.178)						
L.LDEBT				0.39 (0.424)	-2.09* (1.089)	0.68*** (0.204)			
L.LSECU							2.08 (1.341)	-3.25 (3.476)	1.55** (0.655)
L.INC	6.54*** (1.876)	-24.06*** (4.809)	-1.50* (0.906)	6.44*** (1.874)	-23.98*** (4.811)	-1.55* (0.902)	6.48*** (1.862)	-24.62*** (4.825)	-1.37 (0.910)
L.GE	1.51 (2.108)	7.16 (5.403)	6.47*** (1.018)	1.59 (2.105)	7.06 (5.404)	6.52*** (1.013)	1.57 (2.095)	7.52 (5.430)	6.39*** (1.024)
L.POP	2.92*** (0.663)	-16.90*** (1.699)	-1.49*** (0.320)	2.93*** (0.661)	-17.05*** (1.696)	-1.44*** (0.318)	2.84*** (0.661)	-16.92*** (1.714)	-1.51*** (0.323)
L.SAV	-0.65*** (0.105)	2.90*** (0.268)	-0.03 (0.051)	-0.66*** (0.106)	2.96*** (0.273)	-0.05 (0.051)	-0.64*** (0.103)	2.82*** (0.267)	-0.00 (0.050)
Observations	224	224	224	224	224	224	224	224	224
Number of nations	14	14	14	14	14	14	14	14	14

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2. Robustness Checks

4.2.1. The Short-Term and Long-Term Impact of Energy Transition

In examining the effects of different time horizons on the link between green accounting finance and energy security, the results of the ARDL method, as presented in Table 7, reveal significant long-run impacts of GAF on all indicators of energy security. In the short run, however, all impacts are found to be insignificant. These results suggest that attention to green accounting finance will contribute to enhancing a nation's energy security, particularly in terms of sustainable energy usage (ES5 and ES6), in the long term. The EC terms are significant for all variables, indicating that imbalances caused by previous shocks will converge to equilibrium in the long term. Thus, promoting green accounting finance is beneficial to energy security in the long term, with over 63% of instability because of previous shocks being restored to equilibrium.

Specifically, long-term positive impact coefficients range from 0.27 and 0.29 for ES1 and ES2 to 1.52 and 1.73 for ES5 and ES6, respectively, while negative impact coefficients are -0.23 and -0.26 for ES3 and ES4. Given that ES1, ES5, and ES6 are positive indicators and ES2, ES3, and ES4 are negative indicators, the above results show that promoting green accounting finance will significantly reduce CO_2 emissions and increase consumption of sustainable energy or GAF would have a net constructive effect on energy transition and energy security in longer horizons.

Table 7. The effect of green accounting finance on energy transition: Short-term and long-term impacts.

Variables	(1) GAF-ES1	(2) GAF-ES2	(3) GAF-ES3	(4) GAF-ES4	(5) GAF-ES5	(6) GAF-ES6
Short-term impact						
EC term	-0.67* (0.016)	-0.63*** (0.013)	-0.68*** (0.015)	-0.64*** (0.014)	-0.66*** (0.016)	-0.66* (0.012)
D.LGAF	0.21 (0.04)	0.13 (0.001)	0.24 (0.019)	0.26 (0.001)	0.27 (0.001)	0.26 (0.04)
Long-term impact						
LGAF	0.27*** (0.012)	0.29*** (0.001)	-0.23** (0.002)	-0.26** (0.009)	1.52** (0.001)	1.73*** (0.012)
Observations	1.452	1.452	1.452	1.452	1.452	1.452

Note: *** p<0.01, ** p<0.05, * p<0.1

4.2.2. What is the Importance of Institutional Quality?

Maintaining GAF depends heavily on institutional quality. Empirical analysis is done on institutional quality. We test our hypothesis by combining green accounting finance variables with those that represent institutional excellence. VA, PV, GE, RQ, RL, and CC[1] are the main criteria used to evaluate a quality system. These variables were chosen using ICG. Tables 8 and 9 display the estimates.

Table 8 displays the moderating effect of InstQ in examining green accounting finance and pollutant emission, GAF, and ES4. Adding institutional quality dimensions into the model results in the negative impacts of GAF, InstQ, and the interaction term InstQ*GAF on ES4, with the exception of the corruption control (CC) variable and individual RQ effect. Given that ES4 is a negative indicator, the negative coefficients altogether confirm the positive impact of GAF on ES in the context of good institutional quality. This finding is consistent with previous analyses using PCSE, FGLS, and ARDL and further reinforces the role of green accounting finance in securing the energy sector.

Table 9 displays the moderating influence of InstQ in examining green accounting finance and sustainable energy usage, GAF, and ES6. Surprisingly, the inclusion of institutional variables has led to a negative individual effect of GAF on ES6, except for corruption control (CC). The sole effect of institutional variables on ES6 is divided into two groups: positive for VA, CC (significant), and RQ, and significantly negative for PV, GE, and RL. Because ES6 positively contributes to the energy transition/energy security, the positive coefficients of the interaction terms might be able to offset the above adverse outcomes. The interaction term is significant for VA, PV, RQ, and RL. Depending on the magnitude of the coefficients, the net effect of GAF with institutional quality may be positive (VA, CC) or negative (PV, GE, RQ, RL). Therefore, it remains inconclusive whether good institutional quality as a whole can facilitate or hinder renewable usage in energy security, but governments can focus on the VA and, presumably – due to insignificance, the CC aspects to limit the negative influence and endorse the role of green accounting finance.

[1] Voice and accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory of Quality, Rule of Law, Corruption Control

Table 8. An analysis of the moderating impacts of institutional quality on the link between pollution emissions and green accounting finance.

	(1)	(2)	(3)	(4)	(5)	(6)
	ES4					
Variables	**VA**	**PV**	**GE**	**RQ**	**RL**	**CC**
L.LGAF	-0.55*** (0.029)	-0.57*** (0.055)	-0.55 (0.110)	-0.54*** (0.046)	-0.44*** (0.020)	0.22 (0.047)
L.InstQ	-0.64*** (0.029)	-0.62*** (0.070)	-0.68*** (0.061)	0.69 (0.116)	-0.64*** (0.037)	0.61*** (0.145)
L.InstQ* LGAF	-0.96*** (0.052)	-0.73** (0.082)	-0.75 (0.212)	-0.92*** (0.074)	-0.93*** (0.035)	-0.91 (0.118)
L.INC	-0.14* (0.001)	-0.25*** (0.003)	-0.35* (0.002)	-0.31* (0.004)	0.32* (0.006)	-0.031* (0.005)
L.GE	0.24*** (0.003)	0.26*** (0.003)	0.023*** (0.003)	0.041*** (0.003)	0.023*** (0.003)	0.013*** (0.003)
L.POP	-0.13*** (0.051)	-0.24 (0.043)	-0.26 (0.053)	-0.25*** (0.056)	-0.11 (0.034)	-0.043 (0.045)
L.SAV	-0.17*** (0.012)	-0.24*** (0.014)	-0.22 (0.015)	-0.24*** (0.012)	-0.08*** (0.013)	-0.04*** (0.015)
Observations	1.452	1.452	1.452	1.452	1.452	1.452
Number of nations	66	66	66	66	66	66

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1.

Table 9. An analysis of the moderating impacts of institutional quality on the link between renewable energy consumption and green accounting finance.

	(1)	(2)	(3)	(4)	(5)	(6)
	ES6					
Variables	**VA**	**PV**	**GE**	**RQ**	**RL**	**CC**
L. LGAF	-0.65*** (0.029)	-0.67*** (0.055)	-0.35 (0.110)	-0.66*** (0.046)	-0.62*** (0.020)	0.72 (0.047)
L.InstQ	0.28*** (0.029)	-0.41*** (0.070)	-0.33*** (0.061)	0.29 (0.056)	-0.44*** (0.037)	0.46*** (0.145)
L.InstQ* LGAF	0.76*** (0.052)	0.71** (0.082)	0.24 (0.212)	0.72*** (0.074)	0.83*** (0.035)	0.95 (0.118)
L.INC	-0.01* (0.007)	-0.02*** (0.008)	-0.01* (0.007)	-0.01* (0.006)	0.01 (0.006)	-0.01* (0.007)
L.GE	0.04*** (0.003)	0.04*** (0.003)	0.03*** (0.003)	0.03*** (0.003)	0.03*** (0.003)	0.03*** (0.003)
L.POP	-0.19*** (0.051)	-0.06 (0.043)	-0.06 (0.053)	-0.15*** (0.056)	-0.01 (0.034)	-0.03 (0.045)
L.SAV	-0.03*** (0.012)	-0.05*** (0.014)	-0.02 (0.015)	-0.04*** (0.012)	-0.08*** (0.013)	-0.04*** (0.015)
Observations	1.452	1.452	1.452	1.452	1.452	1.452
Number of nations	66	66	66	66	66	66

Note: Standard errors in parentheses
*, **, *** are significant levels at 10%, 5%, and 1%, respectively.

5. Conclusions

The rationale of the current paper is to answer the question of whether or not green accounting finance measures improve the energy security of a nation. Denoted by six indicators, energy security was examined over the period of 23 years for a sample of 66 countries. In the employed model, GAF was considered the key independent variable, alongside the remaining control variables of the level of democratisation, economic growth, population, and savings. Results have identified that green accounting finance significantly enhances energy security by increasing renewables consumption and reducing CO_2 emissions, specifically in the long term and in the presence of a better institution. However, a better institution moderates the relationship through inconclusive influences on renewables consumption, but it can be promoted through the voice and accountability (VA) and corruption control (CC) aspects.

Our findings indicate that promoting green accounting finance is essential for countries to achieve and maintain energy security. To ensure an equitable transition to renewables, governments should invest in research and development within the green accounting finance sector. Additionally, implementing incentive policies to support green accounting finance approaches is crucial. Businesses should align with government policies and increase investment in early-stage green energy initiatives. The government's role is vital in helping green accounting finance curb the emission of greenhouse gases. To encourage the usage of sustainable energy in society, governments should prioritise enhancing voice and accountability (VA) and corruption control (CC).

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Appendix

Table A.1. Nations in the sample.

EU nations		
Austria	Hungary	Portugal
Belgium	Iceland	Slovak Republic
Bulgaria	Ireland	Slovenia
Czech Republic	Italy	Sweden
Denmark	Lithuania	
Spain	Luxembourg	
Estonia	Latvia	
United Kingdom	Malta	
Greece	Netherlands	
Croatia	Poland	