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Sustainable public green finance under domestic and global policy uncertainties: Does environmental policy stringency matter? Evidence from OECD nations using method of moments quantile-based analysis

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ABSTRACT

This study fills the gaps by probing how policy uncertainties and the stringency of environmental policies (EPS), as well as their interactions, affect sustainable public green finance (PGF) in a sample of 19 OECD nations. The analysis employs a method of moments quantile-based analysis using fixed effects from 1996 to 2023. To accomplish these objectives, the present study focused on various policy uncertainties, including economic policy (DEPU) and energy-related uncertainties (DEUI) at the national level, alongside climate policy (GCPU) and world uncertainties (WUI) at the international level. Additionally, we utilized the EPS index and its sub-indices, which encompass market-based, non-market-based, and technology support policies, to assess the impact of environmental strategies thoroughly. Remarkably, the findings underscore that a rise in DEPU and WUI leads to an increase in PGF, while DEUI and GCPU have an adverse effect. Particularly, the findings show that the unfavorable impact of DEUI is more significant at higher levels of PGF, whereas GCPU has a more significant effect at lower levels of PGF. Furthermore, the findings reveal that the EPS index and its sub-indices have positive effects, and stricter environmental policies lead to stimulating PGF. Moreover, the interaction results indicate that the favorable impacts of the DEPU and WUI are intensified with increasing EPS, while the adverse effects of DEUI and GCPU are moderated. The findings are robust and have important implications for policymakers and investors.

1. Introduction

In light of escalating global climate change and worsening air quality, the importance of clean energy has intensified due to fluctuations in fossil fuel prices and increasing global warming. Shifting economies from conventional fossil fuels to clean and green energy sources aids in mitigating climate change and facilitates the pursuit of sustainable development goals (SDGs) (Shang et al., 2022). According to Doğan et al. (2020), renewable energy (RE) is more conducive to economic growth and should be encouraged to fulfill the objectives of the Paris Climate Conference (COP-21).

In recent years, in response to various challenges and to accelerate the conventional energy transition, policymakers have implemented various policies aimed at reducing climate change, decreasing greenhouse gas emissions (GHE), and promoting ecological sustainability. For example, policymakers are adopting incentive strategies to encourage green energy infrastructure and clean technological growth to decrease CO_2 (Lee et al., 2023). Several studies (Ferrer et al., 2021; Caglar and Ulug, 2022; Grafström et al., 2023) underscored that financial support strategies are also a suitable action to lower GHE, to convert from a high-carbon to a low-carbon economy, and to combat climate change.

Particularly, green finance by increasing funding for ecologically friendly initiatives and the development of greener energy sources will yield positive environmental effects and promote ecological sustainability (Aldakhil et al., 2018; Wang and Wang, 2021). Green finance promotes investments that contribute to environmental protection, mitigate climate change, spur economic development, and lower long-term financial risks related to ecological damage and climate change (Anser et al., 2024). Notably, Grubb (2014) contended that the primary competition within the RE sector stems from cost-effective

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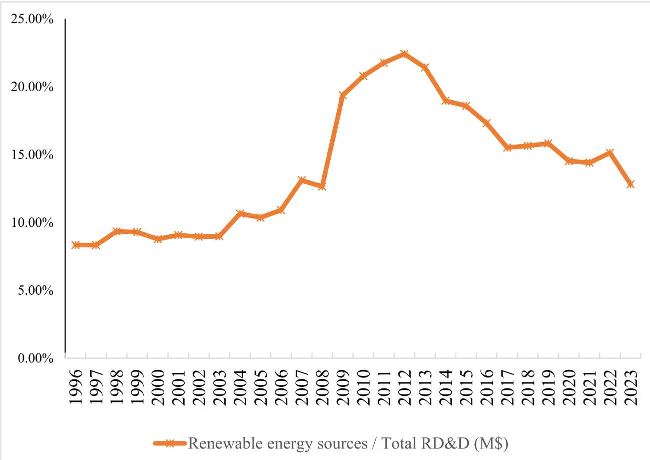

Fig. 1. Time series plot of renewable energy sources (% of total RD&D M$) for International Energy Agency (IEA) countries. Source: https://www.iea.org/data-and-statistics/data-tools/energy-technology-rdd-budgets-data-explorer.

technologies that emerge from investments in RE R&D. This raises the need for governments, especially due to the rise in global climate change and worsening air quality, to increase PGF to enhance the supply of RE and expedite the transition to greener energy sources. World Irena (2021) underscored that green financing for RE initiatives needs to be ramped up to $1.1 trillion between 2021 and 2030 to reduce GHE and fulfill the SDGs.

Fig. 1 displays the time series plot of RE sources (% of total RD&D[1] million dollars) for International Energy Agency (IEA) countries. As seen, the public RE RD&D considerably decreased after 2012, though the global spending on energy R&D rose from 14.40 % in 2021 to 15.12 % in 2022.

With the emergence of the importance of a green environment, studies have been encouraged to scrutinize the determinants of ecological quality and RE (e.g., Athari, 2024b). Particularly, some works attempted to explore which factors are crucial in promoting or decreasing sustainable PGF. Remarkably, increasing PGF can accelerate the transition to greener energy, help decrease CO_2 emissions, and attain SDG goals (Grafström et al., 2023). For example, Zhang et al. (2023) and Yuen et al. (2024) uncovered that an increase in CO_2 emissions leads to a rise in RE investments and an increase in PGF. Yuen et al. (2024) and Zhao et al. (2024) uncovered technological innovation positively impacts RE investment and is necessary for boosting public investment in RE R&D. Besides, some works (Liang et al., 2024; Wang et al., 2024b) revealed that environmental policies, trade, energy efficiency, human capital, and economic development significantly impact PGF in developing and OECD nations.

Moreover, some recent studies indicated that policy uncertainties such as economic policy uncertainty (Yuen et al., 2024), world uncertainty (Flouros et al., 2022), energy policy uncertainty (Pata, 2024), and climate policy uncertainty (Golub et al., 2020) significantly impact government decision-making about the distribution of resources for RE R&D. These uncertainties may hinder the progress of public investments in RE R&D, which are essential for tackling them for achieving sustainable environments.

How do domestic and international policy uncertainties influence PGF, and does PGF respond similarly or differently to various types of policy uncertainties? Additionally, do enhancements in environmental policies through strategies such as market and non-market-based approaches and technology support impact the promotion of PGF? Moreover, do environmental regulations influence the policy uncertainties-PGF nexus? Several studies corroborated the existence of the interaction between environmental policies and policy uncertainty and indicated that environmental policies play a positive role in reducing the adverse effect of global EPU on RE consumption. For example, Athari (2024b) revealed that the RE demand is less affected by global EPU in OECD nations with high EPS. AlAyoubi et al. (2025) also underscored that implementing stricter EPS leads to a decreased negative impact of global EPU on the demand for RE in BRICS nations.

Despite some studies on PGF, no thorough works have been identified in the existing literature that extensively explore PGF by comprehensively considering policy uncertainties both domestically and globally, as well as environmental policies through various approaches. Besides, the interactions between environmental policies and policy uncertainty variables are not explored in the literature. Conducting this research enables governments and policymakers to more effectively pinpoint the key determinants that encourage or hinder PGF. Increased investment in RE RD&D projects fosters RE production and accelerates the shift towards a sustainable environment (SDG 7 and SDG 13). Furthermore, by assessing the impact of policy uncertainties and environmental policies, governments can enhance their strategies to mitigate the negative consequences of uncertainties and implement stricter environmental regulations, which ultimately boost PGF and achieve SDGs in the future.

More specifically, identifying the factors that influence PGF is crucial in OECD countries, given that they accounted for 37 % of the total energy supply in 2018[2] and are projected to increase energy consumption by 15 % by 2050 (International Energy Outlook, 2021). These countries have an important role in global pollution emissions, and they need to shift to using green energies as an important step in tackling climate change. In 2019, fossil fuels, including oil (35 %), natural gas (29 %), and coal (15 %), comprised 79 % of the global energy supply from OECD countries, while renewable sources (9 %), nuclear power (10 %), and hydroelectricity (2 %) accounted for 21 %.[3] The significantly lower renewable energy supply by the OECD raises the importance of green financing, which enables OECD nations to shift faster to having green environments. A report by OECD (2022) stressed that these countries need to work towards the SDGs by decreasing the 35 % share of global energy-related carbon emissions attributed to OECD nations.

This research makes numerous significant contributions. Firstly, unlike previous research that focused solely on geopolitical and economic uncertainties (Yuen and Yuen, 2024), country risk (Wang et al., 2024), DEPU (Ahmed et al., 2021), and GCPU (Dong et al., 2024; Wang et al., 2024a), this investigation thoroughly explores how policy uncertainties at both domestic (DEPU and DEUI) and global (GCPU and WUI) levels influence PGF in the context of 19 OECD nations. Secondly, unlike the earlier research (e.g., Gu et al., 2023) that only examined environmental policies through the proxy of the EPS index, this research analyzes the effects of the EPS index along with three key sub-indices, namely the market-based (EPSM), non-market-based (EPSNM), and technology support (EPST) policies to provide a more comprehensive view. Thirdly, differing from previous works (e.g., Yuen and Yuen, 2024) that only assessed the impacts of policy uncertainties on PGF, this work investigates the interactions between policy uncertainties and environmental policies to determine if EPS acts as a moderator or exacerbator in the link between policy uncertainties and PGF. Fourthly, this research makes another contribution by utilizing unique panel data for 19 OECD nations from 1996 to 2023. Unlike the recent studies that used the panel quantile regression (Kaewsaeng-on and Mehmood, 2024; Mehmood and Kaewsaeng-on, 2025), this research uses an innovative method of moments quantile regression (MMQR) with fixed effects method to estimate models. This technique merges the robustness of quantile regression with the ability to handle unobserved heterogeneity

[1] RD&D stands for Research, Development, and Demonstration.

[2] https://www.iea.org/reports/key-world-energy-statistics-2020.

[3] https://www.iea.org/reports/key-world-energy-statistics-2020.

and cross-sectional dependence in the panel data. This method is beneficial for examining how covariates affect various points within the conditional distribution of the dependent element while also accounting for individual-specific effects.

The research questions of the current study can be shortened as follows: i) What key elements influence PGF, and which determinants have a positive or negative effect on PGF? ii) How do the domestic and global policy uncertainties impact PGF? iii) Does EPS have a moderator or catalyst role? iv) Do the EPS sub-indices significantly impact PGF? Remarkably, the results reveal that environmental technology, human capital, economic growth, and trade positively impact PGF. Besides, the results underscore that an increase in DEPU and WUI causes an upsurge in PGF, while DEUI and GCPU have an opposite effect. Particularly, the results show that the adverse impact of DEUI is more significant at higher levels of PGF, whereas GCPU has a more significant effect at lower levels of PGF. Furthermore, the findings suggest that the EPS index and its sub-indices are significant, and stricter environmental policies lead to stimulating PGF. Moreover, the interaction results indicate that EPS serves both as a moderator for DEUI and GCPU and as a catalyst for DEPU and WUI in the sample nations. Particularly, the results underline that the effects of the DEPU and WUI are more positive in nations with high EPS, whereas the effects of the DEUI and GCPU are more negative in low EPS nations and vice versa. The findings are robust and have significant implications for governments, policymakers, and investors.

The remainder of this research is organized as follows. Section 2 elucidates the earlier works. Section 3 unveils the data and the research methods. Section 4 explains the findings and robustness checks. Section 5 is the conclusion.

2. Literature review

Previous studies have indicated that implementing effective sustainability practices by governments is essential for promoting environmental sustainability and triggering companies to engage more in ecological activities (Athari, 2024a). Green finance has emerged as an effective means of encouraging eco-friendly initiatives and fostering sustainability in various industries. Green finance influences the development of financial systems by prompting financial institutions to incorporate ecological elements into their decision-making and investment approaches. This is consistent with the principles of sustainable finance, which focus on creating long-term value and environmental responsibility. Increasing PGF (e.g., government budget for RE R&D initiatives) could serve as a potential strategy to enhance a country's sustainability performance (Dong et al., 2023) and can accelerate the transition to cleaner energy and help reduce CO_2 emissions, leading to the attainment of SDG goals (Grafström et al., 2023; Zhan et al., 2023). In this section, we review recent studies that pinpoint the crucial factors that can adversely or favorably influence PGF. Understanding these factors is vital for policymakers and can help them adjust their policies accordingly.

2.1. Public green finance (PGF)-policy uncertainties nexus

Public green investments and RE rely on having a stable economic situation and strict environmental regulations (Pata, 2024). Consequently, a rise in policy uncertainties could have an unfavorable effect on public expenditure to invest in RE R&D initiatives and lead to diminished RE production and consumption. Based on the findings of previous works, domestic economic policy uncertainty (DEPU), world uncertainty (WUI), domestic energy policy uncertainty (DEUI), and global climate policy uncertainty (GCPU) are the most important policy uncertainties that influence public budgets for R&D green initiatives.

Several studies reveal that DEPU has a mixed effect on PGF. On one hand, governments, in response to the DEPU, decide to change their expenditure policies by funding the short-term financial goals and reallocating their funding from RE R&D initiatives to tackle immediate economic swings. Wang et al. (2024b) support this view by revealing that green finance decreased (or increased) when countries are more (or less) exposed to country risk (e.g., economic uncertainty). On the other hand, while some studies revealed a negative effect, DEPU could have a positive effect on the public green budget. The rise in investment in RE R&D projects amid domestic policy uncertainty can be explained as a strategy for governments to demonstrate their commitment to long-term environmental goals and to bolster their policy credibility during times of uncertainty. Consistently, Yuen et al. (2024) revealed that a rise in domestic uncertainties (e.g., DEPU) positively affects public investment in RE R&D in 15 developed countries in the long run. Gu et al. (2023) also documented that a rise in vulnerabilities (e.g., increasing economic uncertainty) leads to an uprising in PGF in OECD countries. DEPU has also adversely impacted the RE supply (Yi et al., 2023) and consumption (Shafiullah et al., 2021; Zhang et al., 2021; Yi et al., 2023). However, Liu et al. (2020) and Lei et al. (2021) revealed a positive link between DEPU and RE consumption in China.

Furthermore, prior works revealed that WUI has a mixed impact on PGF. On one hand, a rise in WUI may lead to postponing public investment in green energy R&D projects. An increase in global policy uncertainties (e.g., global EPU) may lower the income levels of investors and households, resulting in a deceleration of the transition to a clean country and decreasing green public expenditure in the long run (Alsagr and Van Hemmen, 2021; Wang et al., 2024c). Consequently, Flouros et al. (2022) using the ARDL method unearthed that a rise in WUI (e.g., rising geopolitical risk) negatively impacts green investment in the short and long run. On the other hand, while some studies revealed a negative effect, a rise in WUI leads to increased uncertainty in non-RE prices, stimulating governments to finance greater investments in RE. Sweidan (2021) documented that increasing world uncertainty encourages economies to increase PGF and rely on RE sources to mitigate the risk of fossil fuel inflows. Yuen et al. (2024) also underscored a positive correlation between WUI (measured by geopolitical risk) and the level of government investment in RE R&D in the long run. Rising geopolitical tensions stimulate governments to decrease their dependency on energy imports and instead increase their investments in RE sources. Besides, increasing world policy uncertainties raise investment costs for the private sector, resulting in a reduction in the supply of RE (Gozgor et al., 2022). Zhao et al. (2023) and Athari (2024b) also uncovered that increasing WUI (e.g., rising geopolitical risk and global EPU) causes a decrease in the demand for RE in OECD nations, while Cai and Wu (2021) found a positive effect.

Besides, the findings of some works revealed that DEUI significantly impacts PGF. Pata (2024) underscored that a rise in DEUI delays RE R&D investments and decreases PGF. However, while Pata (2024) identified a negative effect, Işık et al. (2024) demonstrated that the high volatility of global EUI necessitates a transition from fossil fuels to RE and a clean nation. This transition is vital for attaining SDGs and requires increased PGF and clean energy production. Remarkably, some research (e.g., Zhang et al., 2022; Dai and Wu, 2024; Zhan and Guo, 2024) revealed that the DEUI could foresee oil price volatility, helping to promote ecological protection and sustainable development. Several works also highlighted the considerable effect of DEUI on RE. Shafiullah et al. (2021) and Pata (2024) showed that a rise in DEUI leads to a decrease in RE consumption. However, Saliba (2024) indicated that the higher DEUI causes the promotion of RE consumption globally.

Moreover, some works uncovered that GCPU has a mixed impact on PGF. On one hand, companies and governments with a rise in GCPU might reduce or delay investments in green finance as the worth of postponed investment opportunities rises with greater uncertainty (Golub et al., 2020). Consequently, Engle et al. (2020) documented that GCPU impacts firms' investment decision policy. On the other hand, in contrast to previous studies, a rise in GCPU may stimulate the importance of green energies and result in a shift of investment towards sustainable energy sectors (Lee et al., 2023). Raza et al. (2024) and Dong et al. (2024) stressed that a rise in GCPU resulted in increasing volatility in green finance markets, and GCPU has both positive and negative effects on the green finance market. GCPU also has an impact on the supply and consumption of RE. For instance, works (e.g., Shang et al., 2022; Dutta et al., 2023; Zhou et al., 2023; AlAyoubi et al., 2025) showed that GCPU uncovered that a rise in GCPU leads to an increase in demand for green energy (demand side) and triggers green investments. However, Syed et al. (2023), using a Fourier augmented ARDL, showed that GCPU inhibits RE consumption in the USA. The previous works (e.g., Pommeret and Schubert, 2018; Antoniuk and Leirvik, 2024) also uncovered that a rise in GCPU encourages companies to invest more in clean energy plans (supply side), leading to a boost in the green energy sector as a result of climate change. Taken together, the literature suggests that the influence of policy uncertainties on PGF is mixed, underscoring the need to examine the role of policy uncertainties in determining PGF, which is the focus of the present study.

2.2. Control variables

Several studies suggested that some other factors, such as CO_2 emissions and environmental technologies, impact RE investments and financing. For example, Chen et al. (2021), using fixed-effect quantile regression, showed that a rise in CO_2 emissions leads to increasing RE investments globally. Zhang et al. (2023), using the FMOLS method, revealed that an increase in CO_2 emissions leads to a rise in investments in RE R&D projects in Asian economies. Similarly, Yuen et al. (2024) indicated that CO_2 emissions positively impact PGF.

Furthermore, Khan and Su (2023) revealed that technological innovation has a significant role in RE in countries (e.g., Germany, Sweden) with a strong innovative base and huge spending on R&D. Zhao et al. (2024) using the bootstrap rolling-window subsample Granger causality test showed that technological innovation positively influences RE investment in China; however, the negative effect may be expected because of rising the demand for non-RE. Yuen et al. (2024) unearthed that technological innovation positively impacts PGF, and RE technological innovation is crucial for boosting public investment in RE R&D initiatives. Moreover, Zhou and Li (2022), Chen et al. (2023), and Athari (2024b, c) revealed a positive and significant role of technological innovations in rising RE consumption and developing a clean economy in the long run.

Besides, some works indicated that environmental policies have a significant role in the transition to energy and sustainable development. Adopting strict ecological regulations (e.g., environmental tax) could accelerate the energy transition and help achieve environmental sustainability (Bashir et al., 2021; Dong et al., 2023; Hou et al., 2023; Ullah et al., 2023). This led to an increase in RE investments and triggered PGF. Consistently, Gu et al. (2023) found that environmental policies promote PGF in OECD nations. Remarkably, Jenner et al. (2013) uncovered that environmental policies are effective in boosting RE capacity growth. Also, Acemoglu et al. (2016) indicated that ecological regulations increase the necessity for RE sources. Furthermore, Athari (2024b) showed that adopting stricter green ecological strategies leads to encouraging RE consumption. Besides, the author showed that environmental policies have a beneficial role in lessening the unfavorable effect of global EPU on RE consumption, particularly in nations with stricter ecological policies. Saliba (2024) underlines that the impact of the DEUI on RE consumption is more positive in nations with stricter environmental policies. AlAyoubi et al. (2025) underscored that ecological strategies have a significant positive effect on the demand for RE, and implementing stricter environmental policies leads to an intensified positive impact of GCPU and a decreased negative impact of global EPU on the demand for RE.

Moreover, Gu et al. (2023) found that trade and natural resource extraction adversely affect PGF in OECD countries, whereas energy efficiency has the opposite effect. Wang et al. (2024b) demonstrated that financial inclusion, energy efficiency, and foreign trade significantly enhance PGF in OECD nations in the long term, while human capital has a negative effect. Liang et al. (2024) also uncovered a positive link between economic growth, trade, natural resource rents, and PGF in developing countries.

2.3. Literature gap

Although some works have attempted to probe the determinants of PGF, a limited number of works have comprehensively explored PGF in the framework of OECD nations under the impact of domestic and global policy uncertainties. The mixed findings regarding policy uncertainties underscore the need to specifically examine how policy uncertainties at both the national and global levels affect PGF in OECD nations, which is the focus of the current work.

The findings of this work could provide significant insight into the literature, as there is no consensus among scholars on the impacts of policy uncertainties on PGF. Furthermore, despite the earlier works that only considered environmental policies as a control variable, the current research aims to explore whether ecological policies play a moderator or catalyst role between policy uncertainties and PGF. Moreover, unlike earlier studies, the present work uses the novel MMQR with fixed effects approach to explore the research questions. Fig. 2 illustrates the summary of the literature. To fill the gaps, the present study selected policy uncertainties at the domestic (DEPU and DEUI) and global (GCPU and WUI) levels by focusing on 19 OECD nations from 1996 to 2023.

3. Data and methodology

3.1. Data

This research originally focused on entire OECD nations. However, the final country samples are reduced because of the following reasons. First, since public green financing (PGF) is a dependent variable, we excluded economies such as Colombia, Costa Rica, Iceland, Israel, Latvia, Lithuania, Luxembourg, and Slovenia from the sample list due to the lack of a PGF dataset on the OECD website. Second, since domestic and global policy uncertainties are the primary independent variables of interest, economies such as Austria, Czechia, Estonia, Finland, Hungary, Norway, Poland, Portugal, the Slovak Republic, Switzerland, and

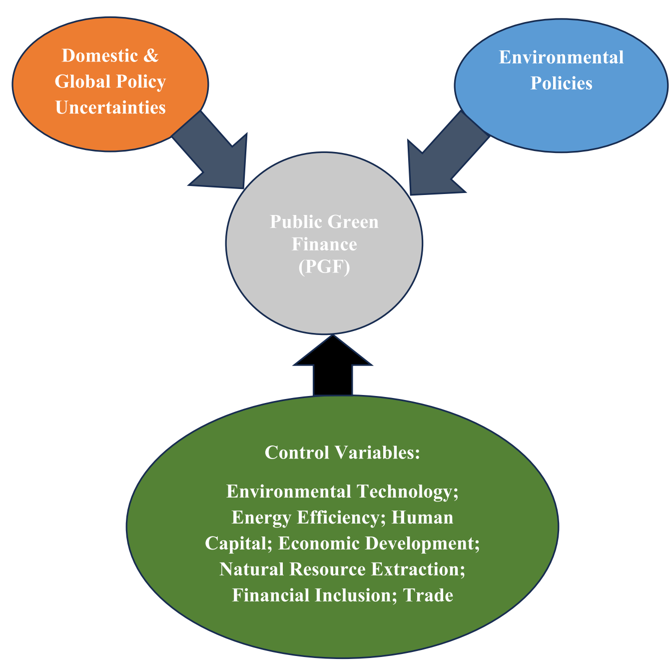

Fig. 2. Summary of the literature.

Turkey, for which EPU data at the national level were not available, were excluded. Therefore, this work selected the final sample size and duration based on the accessibility of data and matching between different data sources, which ultimately includes 19 countries. It's noteworthy to mention that although some OECD member states were excluded due to incomplete data, the risk of systematic selection bias is limited. The OECD constitutes a relatively homogeneous group of advanced nations, and the remaining sample continues to cover all major regions (North America, Europe, and Asia-Pacific) as well as both large and small economies. Additionally, missingness is attributable to data availability rather than substantive characteristics of the countries themselves. Moreover, robustness checks in sub-section 4.4 yield similar results, suggesting that the potential bias is limited. Therefore, the final sample can reasonably be considered representative of the OECD as a whole, and the results are generalizable to the broader population of advanced economies.

Additionally, the timeframe for this research was chosen from 1996 to 2023, during which all variables of the study have available data. This allows us to gather a substantial number of observations to estimate models and achieve robust results. Table A1 reveals the list of samples of countries used in this work.

The present work chose the variables based on the current literature explained in Section 2. The data was collected for the variables from reliable secondary sources. For example, the data for the dependent factor, namely PGF, and independent elements, including environmental technology (ET), energy efficiency (EE), and environmental policies (EPS), were gathered from the OECD website. This study also collected the data of EPS sub-indices, namely EPSM, EPSNM, and EPST, from the OECD website. Furthermore, the data for human capital (HC) was collected from the Penn World Table, while the data for economic development (ED) and Trade (Trade/GDP) were collected from the World Bank, respectively. Moreover, the data for the policy uncertainties, including the domestic energy-related uncertainty (DEUI), domestic economic policy uncertainty (DEPU), global climate policy uncertainty (GCPU), and world uncertainty (WUI), were gathered from the policy uncertainty website. The elucidations of the factors are displayed in Table 1.

Table 1
Factors explanations.

Factors	Symbols	Measurements	Sources
Dependent factor			
Public green finance	PGF	Renewable energy public RD&D budget (% of public energy RD&D budget)	https://stats.oecd.org/
Independent factors			
Environmental technology	ET	Development of environment-related technologies (% of domestic inventions)	https://stats.oecd.org/
Energy efficiency	EE	Renewable energy supply (% of energy supply)	https://stats.oecd.org/
Environmental policies	EPS	Environmental policy stringency index	https://stats.oecd.org/
Human capital	HC	Human capital index	Penn World Table
Economic development	ED	GDP per capita (current US$)	World Bank
Trade	Trade/GDP	Trade (% of GDP)	World Bank
Domestic and global uncertainty factors			
Domestic energy-related uncertainty	DEUI	Domestic energy-related uncertainty index	www.policyuncertainty.com
Domestic economic policy uncertainty	DEPU	Domestic economic policy uncertainty index	www.policyuncertainty.com
Global climate policy uncertainty	GCPU	Climate policy index	www.policyuncertainty.com
World uncertainty	WUI	World uncertainty index	www.policyuncertainty.com

Note: Table 1 explains the symbols, measurements, and sources of factors.

3.2. Research methodology

Eq. (1) is particularly used to probe the impact of domestic and global policy uncertainties on PGF by incorporating the explained control factors shown in Table 1.

Fig. 3 reveals a scatterplot matrix between the elements. It is noted that the scatterplot matrix plots the pairwise scatter between different elements in the form of a matrix.

$$PGF_{it} = \alpha_0 + \alpha_1 ET_{it} + \alpha_2 EE_{it} + \alpha_3 EPS_{it} + \alpha_4 HC_{it} + \alpha_5 ED_{it} + \alpha_6 Trade/GDP_{it} + \alpha_7 DEUI_{it} + \alpha_8 DEPU_{it} + \alpha_9 GCPU_t + \alpha_{10} WUI_t + \varepsilon_{it} \quad (1)$$

Fig. 4 displays the time series plot of PGF, domestic policy uncertainties (DEUI and DEPU) (Panels A and B), and global policy uncertainties (GCPU and WUI) (Panels C and D) from 1996 to 2023. As seen, PGF exhibited a rising trend from 1996 to 2014 and soared to its highest level in 2014. However, PGF subsequently experienced a declining trend from 2014 to 2023. Furthermore, DEPU and GCPU showed an increasing trend throughout the study period. In contrast, DEUI demonstrated a downward trend from 1998 to 2010, followed by an upward trend from 2010 to 2015. Panel (D) also shows that WUI had an increasing trend from 1996 to 2019, but it then transitioned to a decreasing trend, suggesting a reduction in global policy uncertainties.

Fig. 5 shows the time series graph of the EPS index along with its sub-indices. It denotes that the EPS has experienced a positive trend throughout the work period. Notably, the EPSNM reveals the strongest positive trend, followed by EPST and EPSM, respectively.

Table 2 uncovers the correlation analyses between the factors. As indicated, the Pearson correlation matrix and VIF measurements show no signs of multicollinearity. Consequently, all independent factors can be incorporated into the estimation models.

where $_{it}$ symbolises country and time, respectively. ε_{it} is an independent error term.

Initially, we winsorized and normalized each variable. Winsorization is applied to avoid the effect of outliers on the estimation. Logarithmic normalization is also used to convert data exhibiting skewed distributions into a more symmetrical and manageable format for analysis, especially when dealing with large ranges of values. In estimating Eq. (1), this research performs the fixed effects (FE) approach. This technique model helps to estimate the impact of intrinsic features of individuals in a panel data set that are not directly observable or measurable. In addition, the present work uses the MMQR with FE. This approach combines the robustness of quantile regression with the capacity to manage unobserved heterogeneity and cross-sectional dependence in the panel data. This method is beneficial for comprehension of how covariates influence various positions within the conditional distribution of the dependent factor, while simultaneously considering individual-specific effects.

Mathematical model:

In a panel dataset with $i = 1, \ldots, N$ individuals (here, OECD nations) and $t = 1, \ldots, T$ periods, the quantile regression model with fixed effects can be identified as:

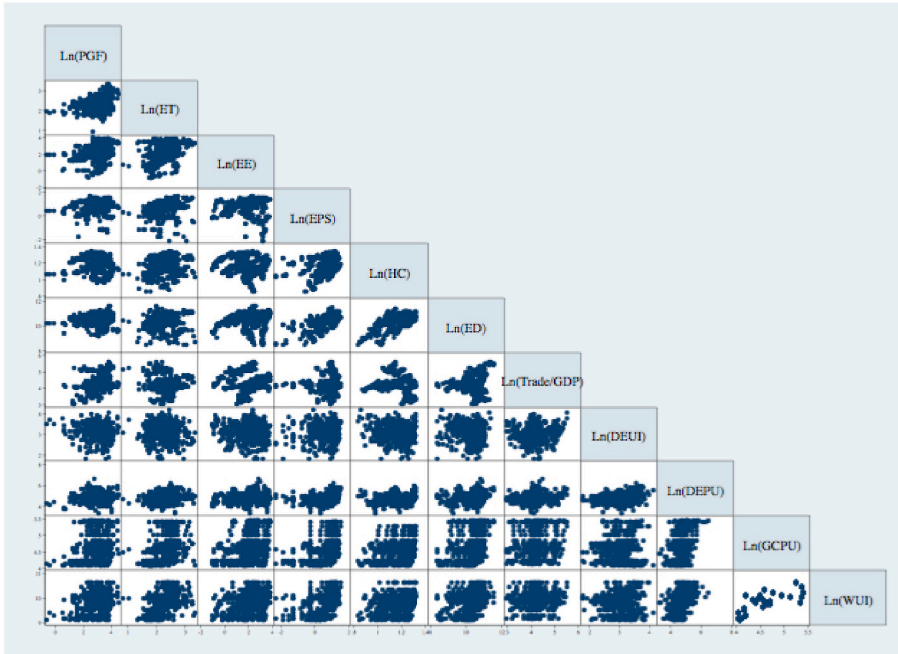

Fig. 3. Scatterplot matrix. Source: Author's calculation.

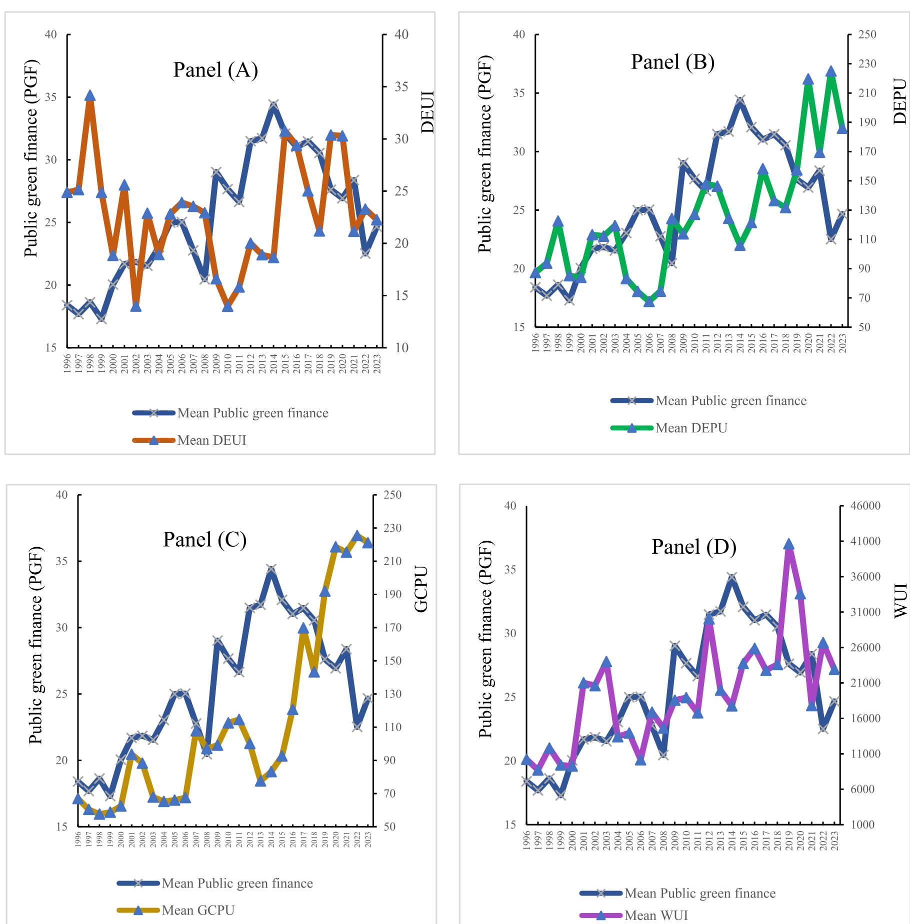

Fig. 4. Time series plot of public green finance (PGF), domestic policy uncertainties (DEUI and DEPU), and global policy uncertainties (GCPU and WUI). Source: Author's calculation.

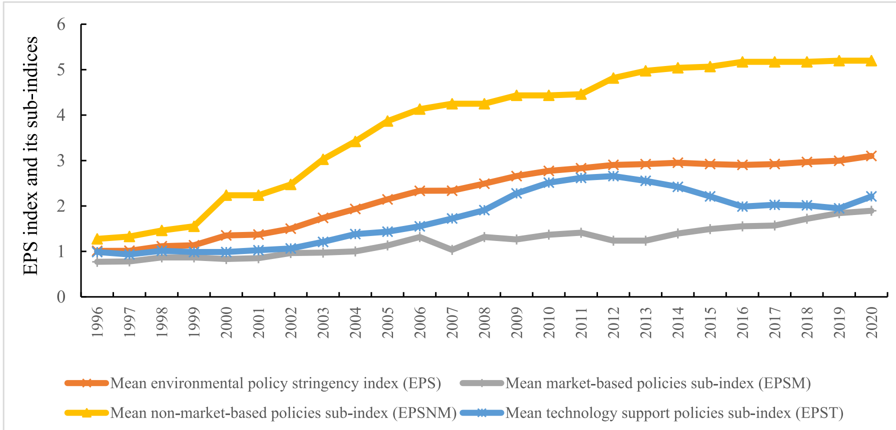

Fig. 5. Time series plot of EPS index and its sub-indices (EPSM, EPSNM, EPST). Source: Author's calculation.

Table 2
Pearson correlation matrix.

	ET	EE	EPS	HC	ED	Trade/GDP	DEUI	DEPU	GCPU	WUI	VIF
ET	1.000										2.23
EE	0.362*	1.000									2.20
EPS	0.389*	−0.063	1.000								2.12
HC	0.178*	0.021	0.396*	1.000							1.97
ED	0.158*	0.104	0.326*	0.387*	1.000						1.72
Trade/GDP	−0.092	−0.029	0.135*	−0.151*	0.373*	1.000					1.53
DEUI	−0.127*	−0.105	0.042	−0.107	−0.072	0.095	1.000				1.51
DEPU	0.259*	0.087	0.368*	0.182*	0.245*	0.071	0.275*	1.000			1.43
GCPU	0.336*	0.283*	0.247*	0.235*	0.386*	0.141*	0.112	0.307*	1.000		1.30
WUI	0.359*	0.211*	0.292*	0.221*	0.291*	0.085	0.141*	0.368*	0.383*	1.000	1.16

Note: * is statistically significant at 1 %.

$$Qy_{it}(\tau|x_{it},\alpha_i) = x'_{it}\beta(\tau) + \alpha_i \tag{2}$$

Where y_{it} is the dependent factor for individual i at time t. $Qy_{it}(\tau|x_{it},\alpha_i)$ denotes the conditional τth quantile of y_{it} given the covariates x_{it} and the fixed effect α_i. x_{it} is a vector of covariates for individual i at time t. $\beta(\tau)$ is a vector of quantile-specific coefficients. α_i is the fixed effect for individual i.

To remove the fixed effects α_i, we use the within transformation:

$$\tilde{y}_{it} = y_{it} - \bar{y}_{it}$$

$$\tilde{x}_{it} = x_{it} - \bar{x}_{it} \tag{3}$$

where $\bar{y}_{it}$ and $\bar{x}_{it}$ are the individual-specific means of y_{it} and x_{it} over time.

The transformed model is:

$$Q\tilde{y}_{it}(\tau|\tilde{x}_{it}) = \tilde{x}'_{it}\beta(\tau) \tag{4}$$

The following model for the work is formulated as:

$$\begin{aligned} Q\tilde{y}_{it}(\tau|\tilde{x}_{it}) = {} & \beta_0(\tau) + \beta_1(\tau)\ln(ET_{it}) + \beta_2(\tau)\ln(EE_{it}) + \beta_3(\tau)\ln(EPS_{it}) \\ & + \beta_4(\tau)\ln(HC_{it}) + \beta_5(\tau)\ln(ED_{it}) + \beta_6(\tau)\ln(Trade/GDP_{it}) \\ & + \beta_7(\tau)\ln(DEUI_{it}) + \beta_8(\tau)\ln(DEPU_{it}) + \beta_9(\tau)\ln(GCPU_t) \\ & + \beta_{10}(\tau)\ln(WUI_t) \end{aligned} \tag{5}$$

The method of moments for quantile regression includes solving moment conditions originating from the quantile regression objective function. For the τ th quantile, the objective function is:

$$min_{\beta(\tau)} = \sum_{i=1}^{N}\sum_{t=1}^{T}\rho_\tau(\tilde{y}_{it} - \tilde{x}'_{it}\beta(\tau)) \tag{6}$$

where $\rho_\tau(u) = u(\tau - 1\{u < 0\})$ is the check function for quantile τ.

The moment conditions for quantile regression originate from the first-order conditions of this objective function. For $Z_{it} = \tilde{y}_{it} - \tilde{x}'_{it}\beta(\tau)$, the moment conditions are:

$$E[\psi\tau(Z_{it})\tilde{x}_{it}] = 0 \tag{7}$$

where $\psi\tau(Z_{it}) = \tau - 1\{Z_{it} < 0\}$

4. Empirical analysis and findings

4.1. Univariate analysis

The descriptive statistics of the elements are detailed in Table 3. As indicated in Panel (A), the mean (median) of Ln(PGF) in the entire OECD sample countries is 3.013 (3.110). Furthermore, among domestic policy uncertainty factors, LnDEPU has a higher mean of 4.730 than LnDEUI, which has a mean of 3.065. Additionally, regarding global policy uncertainty factors, LnWUI, with a mean of 9.798, has a higher score than LnGCPU, with a mean of 4.619. Overall, Panel (A) shows that OECD nations face greater exposure to LnDEPU and LnWUI compared with LnDEUI and LnGCPU. Panel (B) further provides a descriptive summary of the EPS sub-indices. Panel (B) shows that Ln(EPSNM) has the highest mean value at 1.191, followed by Ln(EPST) at 0.450, and Ln(EPSM) at −0.013.

4.2. Multivariate results

Initially, we check the cross-sectional dependence, slope heterogeneity, normality, stationarity, and causality pre-estimation tests.

Table 4 shows the cross-sectional dependency test results using Friedman (1937), Frees (1995), and Pesaran (2004). In all tests, the results are statistically significant, suggesting that any variation in one

Table 3
Descriptive summary (1996–2023).

Variables	Mean	Median	St.dev	Minimum	Maximum	First quartile	Third quartile
Panel (A): Summary statistics of factors							
Ln(PGF)	3.013	3.110	0.784	−0.562	4.597	2.616	3.556
LnET	2.308	2.326	0.374	0.880	3.368	2.043	2.564
LnEE	2.064	2.083	1.028	−0.942	3.883	1.593	2.812
LnEPS	0.650	0.894	0.676	−2.197	1.587	0.329	1.130
LnHC	1.164	1.178	0.107	0.842	1.328	1.089	1.256
LnED	10.345	10.478	0.586	8.396	11.573	10.077	10.763
LnTrade/GDP	4.227	4.164	0.501	2.973	5.522	3.992	4.454
LnDEUI	3.065	3.079	0.411	1.783	4.184	2.814	3.376
LnDEPU	4.730	4.710	0.448	3.296	6.506	4.427	4.980
LnGCPU	4.619	4.558	0.440	4.053	5.418	4.210	4.836
LnWUI	9.798	9.839	0.397	9.074	10.613	9.533	10.071
Panel (B): Environmental policy stringency (EPS) sub-indices							
Ln(EPSM)	−0.013	0.000	0.768	−1.792	1.427	−0.405	0.511
Ln(EPSNM)	1.191	1.558	0.691	−1.386	1.792	0.864	1.705
Ln(EPST)	0.450	0.560	0.689	−0.693	1.792	0.000	1.012

Note: Table 3 presents the descriptive statistics of factors. EPSM: Market-based policies index; EPSNM: Non-Market-based policies index; EPST: Technology support policies index.

Table 4
Cross-sectional dependence (CD).

Test	PGF	ET	EE	EPS	HC	ED	Trade/GDP	DEUI	DEPU
Panel (A): Variable CD test									
Pesaran (2004)	18.796*	46.5501*	45.810*	52.088*	49.080*	22.548*	27.016*	19.957**	30.305*

Panel (B): Model CD test

	Test-value	P-value
Pesaran (2004)	0.330*	0.001
Friedman (1937)	31.651*	0.007
Frees (1995)	0.896***	0.092

Note: * and *** denote statistical significance at the 1 % and 10 % levels, respectively.

Table 5
Testing for slope heterogeneity.

Diagnostic test	Δ (Delta)	Δ $(\text{Delta})_{\text{adj.}}$	Decision
Pesaran and Yamagata (2008)	1.836*** (0.066)	3.508* (0.000)	Slope coefficients are heterogeneous
Blomquist and Westerlund (2013)	−4.696* (0.000)	−8.972* (0.000)	Slope coefficients are heterogeneous

Note: * and *** denote statistical significance at the 1 % and 10 % levels, respectively.

Table 6
Normality test.

Test	chi2(2)	Prob > chi2
Joint test for Normality on e	43.44*	0.000
Joint test for Normality on u	32.51*	0.000

Note: * denotes statistical significance at the 1 % level, respectively.

nation will significantly influence the others in the sample.

Table 5 shows the slope heterogeneity test using Pesaran and Yamagata (2008) and Blomquist and Westerlund (2013). The findings of Δ(delta) and adjusted Δ(delta) confirm that slope coefficients are heterogeneous. This implies that significant variations exist in the slope coefficients among the panels, necessitating the use of the MMQR with fixed effects to address this heterogeneity.

The normality test presented in Table 6 indicates non-normality, as evidenced by a statistically significant p-value at the 1 % significance level. This emphasizes the presence of outliers and deviations from a Gaussian distribution within the panel data, leading to the use of the quantile regression method.

Table 7 presents panel unit root test methods proposed by Levin et al. (2002) (Panel A), Im et al. (2003) (Panel B), and Karavias and Tzavalis (2014) (Panel C). We performed the second-generation panel unit root tests due to the presence of cross-sectional dependence and the possibility of structural breaks in the panel data. The findings displayed in Table 7 indicate that all elements are stationary, indicating that they do not comprise a unit root.

Table 8 reveals the Granger causality test using Dumitrescu and Hurlin (2012) (Panel A) and Juodis et al. (2021) (Panel B) methods. The findings displayed in Table 8 denote no inverse direction between the elements, and there is less likelihood of having endogeneity issues.

Table 9 uncovers the estimation findings of Eq. (1) using FE and MMQR with FE analysis because of heterogeneity and non-linearity in the panel data. Table 9 reveals the impacts of different factors of PGF across various quantiles.

The findings uncover that the coefficients for LnET are positive but not statistically significant at any quantile. In contrast, the coefficient of LnEE is negative and statistically significant. This implies that a rise in energy efficiency resulted in a decrease in public investment in green R&D projects (PGF) in OECD nations. As energy efficiency improves, the necessity for government assistance (such as subsidies) for green initiatives may decrease, given their improved cost-effectiveness and better returns on investment. Additionally, as energy efficiency advances, governmental priorities might shift, redirecting green finance budgets toward more challenging sectors to decarbonize. Furthermore, enhanced energy efficiency could encourage private investment by lowering risks and uncertainties for investors, thus diminishing dependence on PGF. Yuen et al. (2024) supported this finding, denoting that a decrease in energy efficiency (increase in CO_2 emissions) positively impacts PGF.

Furthermore, Table 9 reveals that the coefficients of LnEPS, LnHC,

Table 7
Panel unit root test.

Variables	Panel (A): LLC (2002)		Panel (B): IPS (2003)		Panel (C): Karavias and Tzavalis (2014)
	With trend	With CD	With trend	With CD	With structural breaks
LnPGF	−7.548*	−10.438*	−3.508*	−4.576*	−8.969*
LnET	−4.986*	−9.935*	−11.443*	−12.384*	−5.076**
LnEE	−4.368*	−6.371*	−12.249*	−11.252*	−7.608*
LnEPS	−6.832*	−10.743**	−11.327*	−11.494*	−6.516*
LnHC	−1.356***	−1.512***	−1.753**	−2.345**	−4.641*
LnED	−8.106*	−8.513*	−10.151*	−9.645*	−12.655*
LnTrade/GDP	−3.775*	−8.555*	−5.441*	−11.259*	−10.422*
LnDEUI	−4.849**	−6.411*	−8.016*	−6.831*	−8.762*
LnDEPU	−1.925**	−7.188*	−7.137*	−2.851**	−8.839*
LnGCPU	−2.206**	−6.317*	−1.552***	−5.262**	−5.497*
LnWUI	−7.257*	−4.465*	−9.663*	−6.627*	−12.716*

Note: *, **, and *** denote statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

Table 8
Granger causality test.

Panel (A): Dumitrescu and Hurlin's (2012) approach					
H_0			Zbar-Stat	[Probability]	Decision
LnET	→	LnPGF	7.151*	[0.000]	✓
LnEE	→	LnPGF	5.138*	[0.000]	✓
LnEPS	→	LnPGF	3.236*	[0.001]	✓
LnHC	→	LnPGF	1.851***	[0.064]	✓
LnED	→	LnPGF	3.731*	[0.000]	✓
LnTrade/GDP	→	LnPGF	2.292*	[0.000]	✓
LnDEUI	→	LnPGF	1.653***	[0.082]	✓
LnDEPU	→	LnPGF	3.118*	[0.000]	✓
LnGCPU	→	LnPGF	5.584*	[0.000]	✓
LnWUI	→	LnPGF	4.405**	[0.036]	✓
Panel (B): Juodis et al. (2021) approach with cross-sectional heteroskedasticity-robust standard errors					
H_0			**Wald-test**	**[Probability]**	**Decision**
All variables	→	LnPGF	30.736*	[0.000]	✓

Note: *, **, and *** imply 1 %, 5 %, and 10 % statistical significance levels, respectively.

Table 9
The impacts of domestic and global policy uncertainties on PGF (1996–2023).

Independent factors	MMQR with FE				FE
	Q.25	Q.50	Q.75	Q.95	Coefficients
LnET	0.010	0.044	0.073	0.099	0.042
	(0.07)	(0.41)	(0.55)	(0.53)	(0.35)
LnEE	−0.426*	−0.473*	−0.511*	−0.545*	−0.469*
	(-3.06)	(-4.87)	(-4.39)	(-3.35)	(-5.32)
LnEPS	0.392**	0.355*	0.324**	0.297***	0.358*
	(2.46)	(3.19)	(2.43)	(1.61)	(3.01)
LnHC	3.902**	3.871*	3.844*	3.821***	3.873*
	(2.25)	(3.20)	(2.65)	(1.89)	(2.72)
LnED	0.367***	0.397*	0.422**	0.445***	0.395*
	(1.81)	(2.81)	(2.50)	(1.88)	(2.68)
LnTrade/GDP	1.443*	1.395*	1.356*	1.321*	1.399*
	(4.07)	(5.55)	(4.50)	(3.14)	(6.30)
LnDEUI	−0.054	−0.109**	−0.155**	−0.195**	−0.105***
	(-0.71)	(-2.06)	(-2.44)	(-2.21)	(-1.92)
LnDEPU	0.138	0.122***	0.109**	0.097	0.123***
	(1.52)	(1.93)	(2.14)	(0.92)	(1.88)
LnGCPU	−0.333**	−0.299*	−0.272**	−0.247**	−0.302*
	(-2.59)	(-3.34)	(-2.53)	(-1.65)	(-3.15)
LnWUI	0.186	0.159***	0.136*	0.116	0.161***
	(1.55)	(1.90)	(4.36)	(0.83)	(1.90)
CD-test	–	–	–	–	(0.228)
Time dummy	✓	✓	✓	✓	✓
Country dummy	✓	✓	✓	✓	✓

Note: Table 9 particularly displays the impacts of domestic and global policy uncertainties on PGF. P-values are reported in parentheses. *, **, and *** reveal the significance level at 1 %, 5 %, and 10 %, correspondingly.

LnED, and LnTrade/GDP are positive and statistically significant in the various quantiles, suggesting a robust positive nexus between these determinants and PGF. Focusing on the FE results, a 1 % change in EPS, HC, ED, and Trade/GDP leads to a 0.358 %, 3.873 %, 0.395 %, and 1.399 % change in PGF, respectively. Similarly, Liang et al. (2024) and Wang et al. (2024b) revealed that trade and economic development (GDP) significantly enhance PGF in developing and OECD countries. Cherniwchan (2017) discussed that trade acts to distribute sustainable activities and innovations globally. Trade of ecologically friendly technology and goods catalyzes investment in sustainable sectors, stimulating green finance growth. However, Gu et al. (2023) found that trade adversely affects PGF in OECD countries. Furthermore, human capital is a significant driver for increasing green finance, as a workforce with advanced skills actively contributes to creating and growing ecologically sustainable technology (Lin et al., 2021). However, the findings are contradicted by Wang et al. (2024b), who revealed that human capital adversely impacts PGF in OECD nations. Also, the findings support earlier research (e.g., Gu et al., 2023) showing that adopting stricter environmental policies promotes PGF in OECD nations. Remarkably, this mechanism is likely to be observed in countries with comparable political conditions and financial stability. According to earlier studies (Chen and Liu, 2020; Wang and Yu, 2024; Chiou et al., 2025), EPS considers the political climate and financial stability of a country, as these elements greatly affect its capacity and readiness to carry out and enforce environmental initiatives. EPS are inherently political. Factors such as governmental ideology, political stability, and international agreements (such as the Paris Agreement) are key political conditions that can influence EPS. For example, in the US, EPS often shifts between Republican and Democratic administrations. Furthermore, fiscal constraints created by substantial deficits (debt) and the trade-offs between costs and benefits significantly influence EPS. For instance, numerous developing nations depend on fossil fuel sectors due to economic limitations, making the transition to clean energy potentially difficult without financial assistance. Overall, EPS are usually influenced by political circumstances, economic limitations, and international agreements. An effective EPS balance between ecological objectives and financial realities, along with political viability. Overall, the findings are crucial and suggest meaningful policy implications for decision-makers to acknowledge the significant roles of EPS, HC, ED, and Trade in stimulating the growth of green finance.

Focusing on the domestic policy uncertainty factors, the coefficient of LnDEUI is negative but only significant in some quantiles Q50 ($\alpha = -0.109^{**}$), Q75 ($\alpha = -0.155^{**}$), and Q95 ($\alpha = -0.195^{**}$). The results uncover that the DEUI has an essential role in decreasing PGF, and the negative effect of DEUI is more pronounced as we move to the higher quantiles. Focusing on the FE results, a 1 % change in DEUI leads to a −0.105 % change in PGF. A work by Pata (2024) argued that a rise in DEUI leads to delaying investments in RE R&D projects and ultimately decreases PGF. Consequently, Shafiullah et al. (2021) and Pata (2024) also highlighted that the demand for RE is adversely impacted by a rise in DEUI. In contrast, Işık et al. (2024) revealed that because of the high volatility of global EUI, a move from fossil fuels to RE and a clean nation is crucial for attaining SDGs, requiring an increase in PGF and clean energy production.

In contrast, the coefficient of LnDEPU is positive but only significant in some quantiles Q50 (α = 0.122***) and Q75 (α = 0.109**). This indicates that a rise in DEPU leads to an increase in PGF in OECD nations. The rise in investment in RE R&D plans and PGF amid rising DEPU can be elucidated as a policy for governments to demonstrate their commitment to long-term ecological goals and bolster their policy credibility during times of uncertainty. In addition, this tactical decision is intended to bridge the investment gaps and protect the environment by supplying RE, creating a leading position in the market, and upholding control over the intellectual property related to RE technologies. Similarly, Yuen et al. (2024) supported this finding and showed that a rise in domestic uncertainties (e.g., EPU) positively impacts public investment in RE R&D in 15 developed countries in the long run, which in turn leads to increasing PGF. Gu et al. (2023) also highlighted that a rise in a country's vulnerabilities (e.g., increasing economic uncertainty) causes an increase in PGF in OECD nations. However, Wang et al. (2024b) uncovered that green finance decreased when countries are more exposed to country risk (e.g., economic uncertainty).

For the global policy uncertainty factors, the coefficient of LnGCPU is negative and significant in the different quantiles Q25 (α = −0.333**), Q50 (α = −0.299*), Q75 (α = −0.272**), and Q90 (α = −0.247**). This suggests that PGF is significantly decreased by a rise in GCPU. Focusing on the FE results, a 1 % change in GCPU leads to a −0.302 % change in PGF. Golub et al. (2020) argued that governments with a rise in GCPU might reduce or postpone investments in clean projects as the worth of postponed investment opportunities rises with greater uncertainty. Syed et al. (2023) also underscored that the demand for RE is adversely influenced by increasing GCPU. This is contradicted by a work by Lee et al. (2023) denoting that a rise in GCPU may stimulate the importance of green energies and result in a shift of investment toward sustainable energy sectors.

However, the coefficient of LnWUI is positive but only significant in some quantiles, Q50 (α = 0.159***) and Q75 (α = 0.136*). This denotes that a rise in LnWUI results in an increase in PGF. Focusing on the FE results, a 1 % change in WUI leads to a 0.161 % change in PGF. The positive effect could be explained since a rise in WUI causes an increase in uncertainty in non-RE prices. This may stimulate governments to finance greater investments in RE to accelerate the shift towards RE and attain the SDGs. Sweidan (2021) implied that increasing global uncertainty encourages nations to rely on RE sources to mitigate the risk of fossil fuel inflows

by increasing PGF. Similarly, Yuen et al. (2024) showed a positive correlation between global uncertainty (e.g., increasing geopolitical risk) and the level of government investment in RE R&D in the long run. However, Flouros et al. (2022) unearthed that a rise in WUI (e.g., rising geopolitical risk) negatively impacts green investment in the short and long run. Overall, the results provide significant insights for

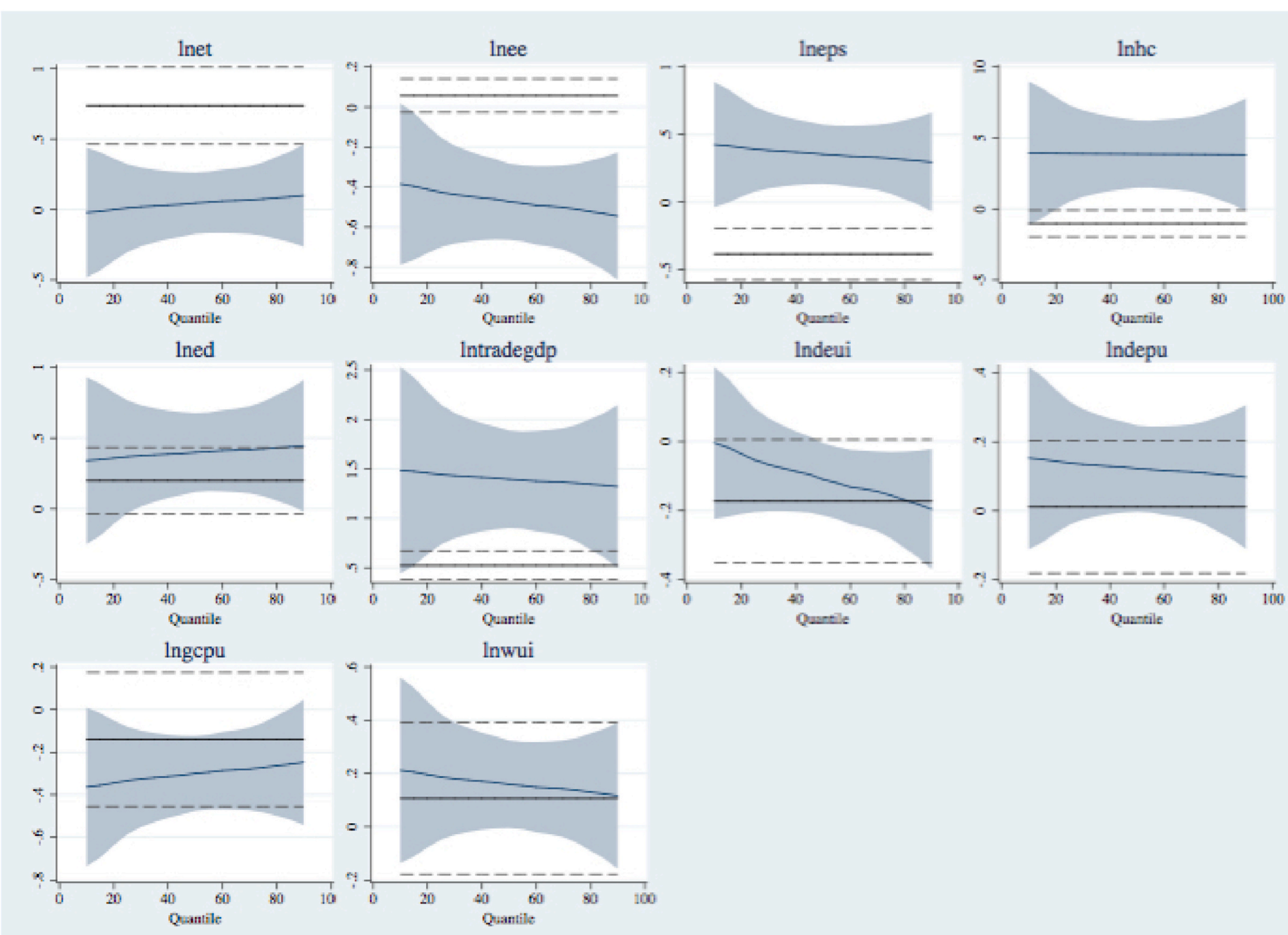

Fig. 6. Estimated coefficients using the method of moments quantile regression with fixed effects (Blue lines) and OLS (Black lines) methods. Source: Author's calculation.

policymakers, highlighting that policy uncertainties have varying impacts on PGF. Remarkably, it recommends developing specific strategies to mitigate the decrease in PGF when there is an increase in DEUI and GCPU.

Fig. 6 displays the estimated coefficients across quantiles using the MMQR with FE. The quantile regression coefficients are depicted by the blue lines, with the shaded regions representing the confidence intervals, while the OLS regression is illustrated with black lines. Remarkably, Fig. 6 shows that the negative slope for DEUI becomes steeper in the higher quantiles, suggesting that the adverse effect of DEUI is more significant at higher levels of PGF. However, the adverse effect of GCPU is less severe in the higher quantiles, with its effect being more significant at lower levels of PGF. It also shows that ET has a negligible effect as the slope is close to zero.

4.3. Further analysis: the role of EPS

Table 10 specifically illustrates how the EPS sub-indices impact PGF. The findings are consistent with those displayed in Table 9, denoting that LnHC, LnED, and LnTrade/GDP have significant positive effects on PGF, whereas LnEE has a significant negative impact. Besides, LnDEUI and LnGCPU negatively influence PGF, while LnDEPU and LnWUI positively impact it.

Furthermore, the findings specifically show that the EPS sub-indices, namely EPSM, EPSNM, and EPST, are statistically significant and positively impact PGF. This suggests that an increase in the stringency of ecological policies, particularly by market-based policies (taxes on CO_2, Nitrogen oxides (NO_X), Sulphur oxides (SOx), and Diesel, CO_2 and RE trading schemes), non-market policies (performance standards by emission limit value NO_X, SO_X, and sulphur), and technological support policies (upstream support by low-carbon R&D expenditures, adaption support (e.g., wind and solar energy support), leads to increase PGF and boosts investments in RE R&D projects. Earlier studies (e.g., Athari, 2024b) confirmed that environmental policies have an important role in increasing the supply and demand of RE, and implementing stricter environmental policies leads to accelerated shifting of countries to sustainable environments. Overall, the findings indicate to policymakers that enhancing ecological policies encourages the government to increase PGF, which can be accomplished by focusing on EPSM, EPSNM, and EPST strategies.

Table 10
The impacts of EPS sub-indices on PGF (1996–2023).

Independent factors	Environmental policy stringency (EPS) sub-index		
	EPSM	EPSNM	EPST
LnET	0.103	0.095	0.131
	(0.96)	(0.82)	(1.08)
LnEE	−0.421*	−0.442*	−0.479*
	(-5.06)	(-4.96)	(-5.15)
LnEPS	0.123***	0.181**	0.039*
	(1.66)	(2.09)	(3.75)
LnHC	3.053**	3.806*	3.283*
	(2.20)	(2.64)	(2.81)
LnED	0.665*	0.464*	0.621*
	(5.59)	(3.09)	(4.89)
LnTrade/GDP	1.317**	1.403*	1.329*
	(2.02)	(6.23)	(5.85)
LnDEUI	−0.103**	−0.101***	−0.085
	(-2.01)	(-1.82)	(-1.53)
LnDEPU	0.147**	0.157**	0.126***
	(2.38)	(2.37)	(1.82)
LnGCPU	−0.373*	−0.304*	−0.288*
	(-4.01)	(-3.13)	(-2.90)
LnWUI	0.182**	0.143***	0.167***
	(2.27)	(1.67)	(1.91)
Adj. R^2	0.374	0.351	0.344
Time dummy	✓	✓	✓
Country dummy	✓	✓	✓

Note: Table 10 particularly displays the impact of EPS sub-indices on public green finance. P-values are reported in parentheses. *, **, and *** reveal the significance level at 1 %, 5 %, and 10 %, correspondingly.

Furthermore, Table 11 presents the results of the interaction effects between EPS and policy uncertainties on PGF. By splitting countries based on EPS level in Panels (A) and (B), we find that interaction effect coefficients are negative at low EPS levels but turn positive at high EPS levels. The findings specifically indicate that with increasing EPS levels from low to high, the negative influence of LnDEUI and LnGCPU is moderated (LnEPS*LnDEUI >0, LnEPS*LnGCPU >0), whereas the positive impacts of LnDEPU and LnWUI become more pronounced (LnEPS*LnDEPU >0, LnEPS*LnWUI >0). This finding highlights that EPS serves as both a moderator for diminishing the negative effects of DEUI and GCPU and a catalyst for increasing the positive effects of DEPU and WUI on PGF. During times of uncertainty, strong environmental policies can reassure both public and private investors, encouraging them to commit to long-term green initiatives, mitigate the financial risks associated with these projects, and direct public resources toward sustainable green initiatives. Consequently, this led to ESP promoting PGF in situations where policy uncertainties occur. The findings of several studies also highlighted that the level of EPS has a vital role in promoting the demand for green energies during policy uncertainty periods. For example, Athari (2024b) revealed that the RE demand is less affected by global EPU in OECD nations with high EPS. AlAyoubi et al. (2025) also underscored that implementing stricter EPS leads to a decreased negative impact of global EPU on the demand for RE in BRICS nations.

Moreover, by selecting the whole sample in Panel (C), the results demonstrate that the interaction effect coefficients are significant and positive. This indicates that an increase in EPS alleviates the adverse impacts of LnDEUI and LnGCPU on PGF in OECD nations, while the influences of LnDEPU and LnWUI become more favorable. Fig. 7 shows the interaction effects for Panel (C).

4.4. Robustness checks

This work conducts numerous robustness tests to assess the reliability of the findings. First, a new variable, "stock market capitalization (% of GDP) ratio" (LnSM), was incorporated into the estimation model to account for the potential effect of financial development on PGF.

Second, this study estimates Eq. (1) through the use of MMQR with FE and FE. Additionally, we applied GMM-SYS to estimate Eq. (1) to address possible endogeneity concerns. To validate the statistical model, the over-identifying restrictions (Sargan and Hansen) and serial correlation (M_2) tests were applied. The test results indicate that the null hypothesis cannot be rejected, meaning that the instruments are valid and the model does not suffer from serial correlation. Finally, the CD post-estimation test was implemented to assess whether the estimated model is influenced by dependency problems. Remarkably, in all estimation models, the standard errors are robust to heteroskedasticity.

Table 12 presents the findings of the robustness test. In line with Table 9, LnDEUI and LnGCPU have a negative effect on PGF, whereas LnDEPU and LnWUI positively influence it. Furthermore, LnET significantly and positively affects PGF, implying that advancements in environmental technology encourage public investment in green initiatives and trigger PGF. A work by Yuen et al. (2024) corroborated this finding and revealed that technological innovation promotes PGF, and RE technological innovation is vital for boosting public investment in RE R&D. Moreover, the results underscore that LnEE, LnEPS, LnHC, LnED, and LnTrade/GDP significantly impact PGF, while no significant evidence was found for LnSM.

5. Conclusion and policy implications

5.1. Conclusion

Some studies explored the determinants of PGF. However, there is a

Table 11
The interaction effects between EPS and policy uncertainties on public green finance (1996–2023).

Independent factors	Panel (A): Low EPS				Panel (B): High EPS				Panel (C): Whole Sample			
LnEPS*LnDEUI	−0.068**	–	–	–	0.035***	–	–	–	0.013**	–	–	–
	(-2.41)	–	–	–	(1.90)	–	–	–	(2.02)	–	–	–
LnEPS*LnDEPU	–	−0.044**	–	–	–	0.049**	–	–	–	0.018*	–	–
	–	(-2.39)	–	–	–	(2.85)	–	–	–	(3.64)	–	–
LnEPS*LnGCPU	–	–	−0.046**	–	–	–	0.035****	–	–	–	0.024***	–
	–	–	(-2.43)	–	–	–	(1.85)	–	–	–	(1.79)	–
LnEPS* LnWUI	–	–	–	−0.017**	–	–	–	0.018**	–	–	–	0.007*
	–	–	–	(-1.99)	–	–	–	(2.19)	–	–	–	(3.07)
Control variables	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time dummy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Country dummy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Note: Table 11 particularly displays the interaction effects between EPS and domestic and global policy uncertainties on public green finance. P-values are reported in parentheses. *, **, and *** reveal the significance level at 1 %, 5 %, and 10 %, correspondingly.

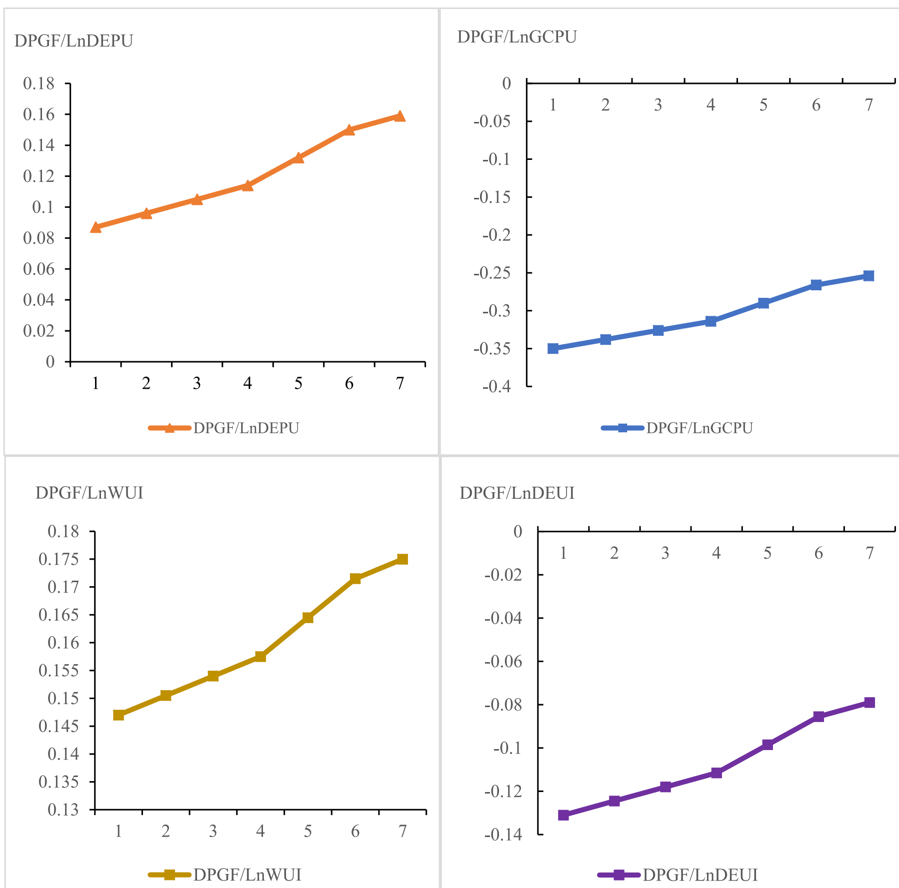

Fig. 7. Interaction effects between policy uncertainties and EPS.

significant gap in research to delve considerably into the impacts of domestic and global policy uncertainties on PGF and to probe the role of ecological plans in determining the policy uncertainties-PGF relationship. To do so, this research selected domestic (DEPU and DEUI) and global (GCPU and WUI) policy uncertainties in 19 OECD nations between 1996 and 2023. We also used the novel proxy of EPS and its sub-indices, namely EPSM, EPSNM, and EPST, to measure the impact of ecological policies on PGF.

Using robust models, the results indicate that a rise in DEPU and WUI has a positive effect on PGF, while a rise in DEUI and GCPU results in a decrease in PGF. Particularly, the findings show that the adverse impact of DEUI is more significant at higher levels of PGF, whereas it has a more significant effect at lower levels of PGF. Furthermore, the findings reveal that the EPS index and its sub-indices have positive effects on PGF, denoting that implementing stricter ecological policies promotes PGF. Moreover, the interaction results underscore that the favorable impacts of the DEPU and WUI on PGF are intensified with increasing EPS (catalyst role), whereas the adverse effects of DEUI and GCPU are moderated (moderator role). The results also underline that the impacts of the DEPU and WUI are more (less) positive in nations with high (low) EPS, whereas the effects of the DEUI and GCPU are more (less) negative in low (high) EPS nations.

5.2. Policy implications

Firstly, the findings reveal that rising DEPU and WUI trigger PFG. This might have occurred due to a reduction in private investment in green energy R&D projects and a shift in funds from RE R&D initiatives

Table 12
Robustness checks.

Independent variables	MMQR with FE				FE	GMM-SYS
	Q.25	Q.50	Q.75	Q.95	Coefficients	Coefficients
Lag dependent variable (PGF)	–	–	–	–	–	0.102
	–	–	–	–	–	(0.58)
LnET	0.193	0.238***	0.264***	0.291	0.231***	0.241
	(0.96)	(1.85)	(1.69)	(1.33)	(1.61)	(0.89)
LnEE	−0.421**	−0.491*	−0.531*	−0.571*	−0.480*	−0.078
	(-2.41)	(-4.39)	(-3.93)	(-3.03)	(-4.29)	(-0.90)
LnEPS	0.254	0.238**	0.228***	0.219	0.241***	0.451**
	(1.36)	(2.11)	(1.64)	(1.09)	(1.75)	(2.09)
LnHC	3.958**	3.616*	3.416*	3.222***	3.668*	0.561
	(2.35)	(3.44)	(2.72)	(1.86)	(2.75)	(0.43)
LnED	0.374	0.445*	0.486**	0.527***	0.434**	0.347***
	(1.49)	(2.78)	(2.51)	(1.95)	(2.49)	(1.65)
LnTrade/GDP	1.347*	1.396*	1.425*	1.453*	1.389*	0.089
	(3.55)	(5.76)	(4.86)	(3.55)	(5.76)	(0.55)
LnSM	0.016	0.032	0.041	0.049	0.029	0.043
	(0.14)	(0.42)	(0.45)	(0.39)	(0.35)	(0.37)
LnDEUI	−0.013	−0.052**	−0.092*	−0.129**	−0.042	−0.044
	(-0.16)	(-2.13)	(-4.33)	(-2.03)	(-0.68)	(-1.04)
LnDEPU	0.085	0.077	0.073**	0.069*	0.078	0.251***
	(0.79)	(1.13)	(2.18)	(5.60)	(1.02)	(1.71)
LnGCPU	−0.244**	−0.259*	−0.268**	−0.277**	−0.257**	−0.112
	(-1.61)	(-2.67)	(-2.29)	(-1.69)	(-2.37)	(-0.94)
LnWUI	0.197	0.198**	0.198***	0.199	0.198**	0.046
	(1.44)	(2.27)	(1.88)	(1.35)	(2.11)	(0.41)
CD-test *(p-value)*	–	–	–	–	(0.317)	–
M_1-test	–	–	–	–	–	(0.000)
M_2-test	–	–	–	–	–	(0.193)
Sargan-test	–	–	–	–	–	(0.327)
Hansen-test	–	–	–	–	–	(0.312)
Time dummy	✓	✓	✓	✓	✓	✓
Country dummy	✓	✓	✓	✓	✓	✓

Note: Table 12 presents the robustness test results. The standard errors for the estimation models are robust to heteroskedasticity using Fixed effects with clustered standard errors, cluster-robust variance estimation for MMQR, and robust standard errors (heteroskedasticity and autocorrelation consistent standard errors) for GMM. *, **, and *** denote the significance level at 1 %, 5 %, and 10 %, respectively.

by raising DEPU and WUI, which prompted governments to compensate and increase PGF. This finding suggests that governments, by increasing DEPU, should allocate sufficient green funds to bridge the investment gaps, aiming to support long-term investments in RE R&D projects and sustain innovation ecosystems. This is crucial to avert a slowdown in RE production, stimulate investment in RE, and ultimately accelerate the transition towards achieving the SDGs. Additionally, the findings suggest that governments should raise green budgets when WUI increases, aiming to reduce reliance on non-RE sources since energy prices are influenced by changes in WUI. Overall, the findings imply that as DEPU and WUI rise, governments should boost their public investments in green initiatives and PGF to compensate for a decline in private investments in green projects, strengthen their commitment to long-term ecological goals, and enhance their policy credibility.

Secondly, the findings reveal that PFG is adversely impacted by rising DEUI and GCPU. This might have happened because of higher volatility in green finance markets, causing governments to delay investments in green finance and decrease expenditures on green initiatives. Besides, banks and other financial institutions become less willing to provide loans for green finance projects due to the delays in their development and execution caused by rising DEUI and GCPU, which ultimately leads to a decline in both the production and consumption of RE. This finding implies that governments and policymakers should adopt policies and strategies that encourage investment in green and sustainable plans (e.g., financial incentives and subsidies) by addressing the challenges posed by rising DEUI. Specifically, it suggests that policymakers should establish plans to swiftly shift from fossil fuels to clean energy sources to alleviate the undesirable impacts of DEUI and expedite the movement toward greener environments. Additionally, policymakers should reinforce ecological regulations and develop incentive programs to decrease the detrimental impacts of policy uncertainties on PGF and stimulate green investments. environmental policy frameworks can act as a buffer against policy uncertainty by enhancing investor confidence through reducing investment risk, preventing market shocks, and allocating public funds strategically. Additionally, studies (e.g., Athari, 2024b) have revealed the significant role of strong ecological strategies in mitigating the negative consequences of global policy uncertainties and promoting RE globally.

Thirdly, the positive and statistically significant effect of EPS implies that stricter ecological plans trigger the government to increase PGF. In other words, governments tend to increase budgets for RE RD&D to supply more green energy when environmental policies are stricter. Notably, the studies conducted in various regions highlighted that the demand for green energy differs depending on the EPS levels of nations, especially during periods of uncertainty. Athari (2024b) revealed that, in OECD countries with high EPS levels, the consumption of RE tends to increase during times of rising global EPU, in contrast to low-EPS nations. Additionally, AlAyoubi et al. (2025) found that implementing stricter EPS reduces the adverse effects of global EPU on the demand for RE in BRICS nations. Given the significance of EPS levels, this finding indicates that representatives and governments should strengthen environmental policies to enhance public investment in RE R&D plans and stimulate RE demand during uncertain times. Governments can improve ecological policies through various policies such as EPSM (e.g., CO_2 taxes and RE trading schemes), EPSNM (e.g., emission limit value for NO_X and SO_X), and EPST (e.g., low-carbon R&D expenditures, wind and solar energy support).

Fourthly, the findings indicate that governments and policymakers ought to enhance human capital, stimulate economic growth, promote trade, and foster innovations in environmental technology, all of which positively influence PGF. Policymakers could consider implementing strategies aiming to encourage economic development and trade, providing incentives for companies to invest in environmental technologies and activities, and raising support for educational programs and plans that focus on sustainability and ecological protection.

Overall, understanding the elements affecting PGF in OECD economies provides insight for governments, executives, and investors, enabling them to apply certain interventions and make informed investment decisions. Particularly, the comprehension of the interplay between policy uncertainties and PGF is vital for policymakers and investors to devise policies that mitigate the unfavorable effects of policy uncertainties and promote green investments instead. The findings also hold significant implications for policymakers and governments across different nations and regions. By grasping the influences and essential impacts of policy uncertainties, environmental regulations, human capital, economic growth, trade, energy efficiency, and environmental technologies on PGF, stakeholders can more effectively support PGF and expedite investments in green initiatives.

5.3. Limitations and further studies

It would be noteworthy for further research to conduct this study in different countries or regions to determine if the findings are consistent. Besides, this study excluded some potential factors due to a lack of data. Future studies would benefit from examining the influence of these potential factors, such as natural resource extraction, financial inclusion, and green FDI, on PGF within OECD countries to reduce omitted variable bias. It is also suggested that further studies incorporate excluded countries by verifying the data availability for EPS and policy uncertainty variables. Furthermore, it would be beneficial for future research to implement alternative approaches, such as 2SLS, to address endogeneity issues in the estimation models, which is a limitation of MMQR. Besides, it would be useful to probe the potential effect of institutional quality and explore the interaction effects of the EPS subindex (EPSM, EPSNM, EPST) and policy uncertainties (e.g., DEUI, DEPU, GCPU, and WUI) on PGF for OECD and other regions, as it could offer valuable insights for researchers and readers. Moreover, this study excluded the possible effects of political conditions and financial circumstances in performing the analyses. It would be useful for further work to control the impacts of these two factors, particularly during times of heightened uncertainty.

Table A1
List of samples of countries and the average of factors (1996–2023)

Sample countries	Ln(GF)	LnET	LnEE	LnEPS	LnHC	LnED	LnTrade	LnDEUI	LnDEPU
Australia	2.953	2.314	1.837	0.446	1.250	10.608	3.747	2.782	4.599
Belgium	1.962	2.185	1.232	0.798	1.117	10.551	5.041	3.019	4.696
Canada	2.372	2.368	2.821	0.639	1.281	10.541	4.200	2.931	4.994
Chile	4.298	2.783	3.277	−0.370	1.074	9.179	4.179	2.850	4.786
Denmark	3.718	2.691	2.927	1.062	1.226	10.824	4.601	2.813	4.726
France	1.928	2.331	2.063	1.070	1.106	10.464	4.102	3.347	5.006
Germany	3.195	2.476	1.974	0.955	1.286	10.562	4.286	3.180	4.993
Greece	3.605	2.327	2.111	0.686	1.060	9.864	4.136	3.089	4.760
Ireland	3.617	1.847	1.474	0.672	1.094	10.838	5.247	3.173	4.774
Italy	2.834	2.154	2.389	0.984	1.074	10.336	3.990	3.103	4.696
Japan	2.066	2.375	1.424	1.126	1.238	10.553	3.409	3.027	4.666
Korea	3.046	2.336	−0.149	0.751	1.223	9.954	4.369	3.158	4.833
Mexico	2.780	2.337	2.231	0.001	0.937	9.094	4.135	3.277	4.410
Netherlands	3.446	2.165	1.330	0.908	1.175	10.685	4.942	3.102	4.516
New Zealand	3.687	2.150	3.556	−0.670	1.188	10.297	4.037	2.937	4.572
Spain	3.682	2.313	2.273	0.693	1.017	10.123	4.097	3.120	4.731
Sweden	3.250	2.291	3.498	1.045	1.193	10.726	4.456	3.009	4.550
United Kingdom	3.016	2.206	1.193	0.815	1.288	10.561	4.060	3.253	4.751
United States	2.495	2.201	1.758	0.582	1.296	10.795	3.275	3.093	4.723

Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose.

Data availability

Data will be made available on request.

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