Politická ekonomie
2024, Volume 72 (2), Special Issue:
Achieving Energy Transition and Sustainable Development:
The Roles of Political Risk and Energy Technology Investments

Examining the Effects of Energy Efficiency R&D and Renewable Energy on Environmental Sustainability Amidst Political Risk in France

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Abstract

The urgent need to address climate change and the depletion of natural resources has led governments worldwide to allocate significant resources towards research and development in clean energy technologies and energy efficiency. This study evaluates the effectiveness of renewable energy and energy efficiency initiatives in reducing CO_2 emissions, taking into account the influences of natural resource availability and political risk. Using data from France spanning from 1985 to 2021, we employ the kernel-based regularized least squares (KRLS) methodology, complemented by quantile regression (QR), to analyse these relationships. Our findings indicate that policies promoting energy efficiency and green energy have a positive impact on reducing CO_2 emissions. However, the availability of natural resources and political risk exacerbate environmental challenges by increasing CO_2 emissions. Thus, our study underscores the importance of continued support from policymakers for renewable energy development and energy efficiency research to effectively pursue Sustainable Development Goals (SDGs). Additionally, as the world prepares for COP28, our findings emphasize the urgency of these initiatives in meeting global climate targets.

Keywords: France, energy efficiency R&D, renewable energy, political risks, natural resources, environmental sustainability

JEL Classification: C14, C53, Q55, Q42, Q58

Citation: Özkan, O., Eweade, B. S., Adebayo, T. S.: Examining the Effects of Energy Efficiency R&D and Renewable Energy on Environmental Sustainability Amidst Political Risk in France. *Politická ekonomie,* 2024, 72 (2), Special Issue, 331–356, https://doi.org/10.18267/j.polek.1437

1. Introduction

In the pursuit of achieving environmental sustainability, countries around the world are increasingly turning their attention to the dual objectives of advancing energy efficiency research and development (R&D) and promoting the integration of renewable energy sources into their energy portfolios (Alola *et al*., 2023; Wang *et al*., 2023; Eweade *et al*., 2024). This paradigm shift is particularly evident in the context of France, a country that has historically been at the forefront of global environmental initiatives. As the urgency to address climate change escalates, the role of innovation in mitigating environmental impact has become pivotal and a growing body of research suggests that investment in energy efficiency R&D and the widespread adoption of renewable energy technologies can significantly contribute to the reduction of greenhouse gas emissions (IEA, 2020).

Renewable energy, driven by sustainable processes and innovative strategies, shapes the global energy market, setting economic standards while addressing environmental concerns (Gielen *et al*., 2019; Adebayo *et al*., 2024). Intergovernmental commitments, such as the UNFCCC, persist in mitigating greenhouse gases, aligning with the IEA's call for collaborative efforts towards net-zero emissions by 2050 (IEA, 2020; Ibrahim *et al*., 2021; Adebayo *et al*., 2021; Adebayo *et al*., 2022; Ramzan *et al*., 2023). The shift to renewables aims for a 95% reduction in carbon emissions, marking a global transition from traditional fossil fuels. Energy efficiency R&D is a fundamental pillar, optimizing systems and pioneering technologies to diminish energy consumption, enhance efficiency and address environmental concerns. Beyond technological progress, such R&D influences broader ecological sustainability, reducing carbon emissions and fortifying energy infrastructure resilience (Eweade *et al*., 2023). Simultaneously, integrating renewable sources such as solar, wind, hydro and bioenergy provides cleaner, sustainable alternatives to traditional fossil fuels (Olanipekun *et al*., 2023; Eweade *et al*., 2022; Paraschiv and Paraschiv, 2023; Olabi *et al*., 2023).

Historically known for its commitment to nuclear energy, France is transforming towards a more diversified and sustainable energy portfolio that prominently includes renewable energy sources (IEA, 2021). This shift occurs amid a political landscape characterized by dynamic changes and uncertainties, presenting challenges and opportunities for sustainable energy initiatives. Understanding how energy efficiency R&D and renewable energy adoption navigate the multifaceted political risk realm is imperative for developing effective strategies that align with environmental sustainability objectives (Rehman *et al*., 2023; Usman *et al*., 2024; Zhang *et al*., 2024). However, amidst these endeavours towards ecological sustainability, political risks emerge as a complex and multifaceted challenge. Political factors, ranging from policy instability to geopolitical tensions, can significantly influence the trajectory and success of energy efficiency

R&D and renewable energy integration. The nuanced interplay between environmental sustainability goals and political risks necessitates a comprehensive examination to inform robust policy frameworks that can navigate these complexities effectively. Global energy market fluctuations and concerns about energy security have led countries, including France, to reevaluate their energy strategies. Furthermore, political risk (*POLR*) can significantly influence the adoption of renewable energy (*RENE*) and the mitigation of ecological sustainability. Evaluating political risks involves twelve institutional variables (Hsieh *et al*., 2022). Institutions are pivotal in advancing green energy technologies and enhancing environmental quality, given their central involvement in shaping and implementing energy and environmental policies (Lee and Chen, 2021).

Democracy, a critical institutional factor, substantially contributes to enhancing ecological sustainability. Hosseini Kaneko (2013) asserted that effectively controlling corruption is crucial in limiting environmental harm. Moreover, institutions are essential for sustainable growth, allowing countries with more vital institutions to attain economic progress at lower environmental costs. Consequently, countries can achieve significant growth while posing fewer ecological challenges in the long run. Strengthened institutions mitigate corruption, effectively enforcing stringent environmental laws and contributing to overall ecological quality (Ahmed *et al*., 2022). Improved institutions also enhance the dissemination of environmental information to the public, fostering cognizance and public burden for promoting ecological integrity (Rizk and Slimane, 2018). Uninfluenced by political considerations, institutions can effectively implement policy measures to enhance environmental quality and economic growth.

Conversely, countries with weak institutions often exhibit inefficiencies in bureaucracy, corruption and lax ecological regulations (Danish and Ulucak, 2020). Understanding how energy efficiency R&D and integrating renewable sources intersect with political risks is crucial for effective policies. As France stands at the crossroads of its energy transition, decisions made in the coming years will shape its environmental trajectory and resilience to geopolitical uncertainties. Incorporating renewable sources such as solar, wind and bioenergy holds promise for reducing reliance on fossil fuels and enhancing energy security (Jacobsson and Lauber, 2006). Additionally, investments in energy efficiency R&D can drive innovations optimizing energy consumption and overall system efficiency, aligning with sustainability and resilience goals.

The research examines the intricate interaction between energy efficiency R&D, renewable energy deployment, natural resources and environmental sustainability against the backdrop of political risks in France. To achieve the broad objective, the following research questions were raised: (i) To what extent has France successfully integrated renewable energy sources into its energy mix and what are the environmental implications of this transition, including reductions in reliance on fossil fuels and mitigations of climate change impacts? (ii) How do political risks, including policy instability, regulatory frameworks and geopolitical tensions, influence the effectiveness of energy efficiency R&D, the responsible utilization of natural resources and the widespread adoption of renewable energy sources for attaining environmental sustainability in France? (iii) What are the temporal dynamics and long-term impacts of energy efficiency R&D, natural resource utilization and green energy adoption on ecological excellence in France and how can strategies be developed to ensure the durability and resilience of these initiatives over time? The study uncovers crucial gaps in existing literature. The lack of in-depth exploration specific to the French context regarding energy efficiency R&D, renewable energy, political risk and environmental sustainability creates a gap in our understanding of these dynamics. Existing studies often need to pay more attention to integrating political risk factors, leaving a significant void in understanding how political dynamics influence the effectiveness of energy initiatives in France. The absence of comprehensive and practical policy implications for policymakers and stakeholders involved in shaping sustainability in France presents a gap, hindering the translation of research insights into viable measures.

The compartmentalization of environmental science, political science and economics in existing literature underscores a gap, as an interdisciplinary approach is crucial for a holistic understanding of sustainability dynamics. The oversight of the temporal perspective, considering the long-term consequences of energy measures and political risk, needs to be more comprehensive to understand the enduring impact of decisions over time. Previous studies may have focused more on specific aspects such as energy efficiency R&D or renewable energy, neglecting a holistic examination of the combined effects of these initiatives on environmental sustainability amid political risk in France. Addressing these research gaps will contribute to a more nuanced and comprehensive understanding of the intricate dynamics influencing sustainability efforts in the French context.

There is a need for more studies, specifically delving into this subject, utilizing recent data, accounting for relevant variables and employing rigorous econometric methodologies, especially in France. This research provides several noteworthy contributions to the existing literature. Firstly, it investigates the effects of energy efficiency research and development (R&D) and the adoption of renewable energy on CO_2 levels in France, considering natural resources and political risks. Secondly, the study introduces an innovative methodological approach, namely kernel-based regularized least squares (KRLS) and robustness tests using QR. This approach allows increased flexibility in capturing non-linear interrelationships and intricate patterns within the data. Thirdly, a substantial contribution lies in recognizing political dynamics, offering policymakers valuable insights to formulate resilient strategies capable of navigating fluctuations in the political climate. Lastly, the research contributes to the global conversation on reducing reliance on fossil fuels and addressing climate change by advocating for incorporating renewables into France's energy mix.

The remaining parts of the study are as follows: Section 2 reviews relevant literature on the subject. Section 3 outlines the data, model and methods used in the analysis. Section 4 presents and explains the study's findings and analysis. Ultimately, Section 5 synthesizes the conclusions derived from the research and explores potential policy recommendations based on these findings.

2. Literature Review

Over time, human-induced activities have increasingly strained the ecosystem, causing significant environmental harm. Consequences such as droughts, wildfires, heavy rainfall, bush burning and desert encroachment have prompted scholars and policymakers to address these issues in various forums, including at key intergovernmental meetings such as COP21, 26 and 27. The consensus from these gatherings emphasizes the urgent need for a shift towards sustainable energy as the primary solution to combat environmental degradation. Scholars have extensively explored economic factors influencing the environment, including economic growth, energy efficiency research and development and promotion of renewable energy. Despite numerous policy proposals based on these studies, establishing universally applicable policies has proven challenging. In energy and environmental literature, studies have delved into the impact of political risk on the ecosystem. For example, Kirikkaleli and Adebayo (2023) utilized a time-varying approach to examine CO_2 drivers, focusing on the role of political risk (*POLR*) in the Brazilian case. The results suggested that a decrease in CO_2 is linked to political stability in Brazil. Likewise, Awosusi *et al*. (2022) focused on the role of *POLR* in the ecosystem of the BRICS countries from 1990 to 2018, highlighting the role of *POLR* in exacerbating ecological damage.

Saud *et al*. (2023) studied the impact of natural resource abundance, economic complexity and environmental sustainability in the Middle East and North Africa (MENA) from 1980 to 2020. Their findings revealed that higher economic complexity is linked to reduced carbon dioxide emissions and ecological footprint. Additionally, the study notes an unfavourable relationship between natural resource abundance and both CO_2 emissions and the ecological footprint. Furthermore, Saud *et al*. (2019) and Saud *et al*. (2020) examined the impact of financial development, electricity consumption and trade openness on environmental quality for 59 Belt and Road Initiative (BRI) countries from 1980 to 2016. Their findings indicated that elevated financial development, foreign direct investment and trade openness positively influence the environmental quality, while increased economic growth and electricity consumption are associated with a decline. Similarly, according to Saud *et al*. (2022), the findings indicate that economic growth and electricity consumption are positively associated with CO_2 emissions, posing a threat to environmental sustainability. Xiao Gu *et al*. (2023) studied the relationships between the political risk index, renewable electricity output and renewable energy consumption in China from 1984 to 2022 using Granger causality. They found stationary variables at differences, indicating long-run equilibrium. Their empirical findings suggested that economic growth would reduce renewable energy consumption in China over both short and long term. In a separate study, Yu *et al*. (2023) explored connections among economic growth, renewable energy transition and carbon footprint in the top 10 emitters from 1992 to 2020, using the method of moment quantile regressions. Their results showed that transitioning to renewable energy significantly reduces the carbon footprint. They emphasized that expanding this transition benefits sustainable development and carbon footprint reduction, with improvements in the political environment, notably the reduction of political risk, playing a crucial role.

Energy efficiency R&D and the integration of renewable energy play key roles in cutting CO_2. They achieve this by reducing our dependence on fossil fuels, improving how efficiently we use energy and shifting towards sustainable, cleaner energy sources. When combined, these approaches substantially affect curbing GHGs, ultimately easing the detrimental effects of climate change. Likewise, using the Danish case, the study of Adebayo and Alola (2023) using the wavelet tools highlighted the effectiveness of energy efficiency R&D and *RENE* in bolstering ecological excellence. The survey of Bilgili *et al*. (2023) also aligns with Adebayo and Alola (2023), who affirmed the influential role of energy efficiency R&D and *RENE* in dampening the growth of CO_2. The existing literature needs to be more comprehensive in assessing the interplay between political risks and the effects of energy efficiency R&D, natural resource utilization and renewable energy adoption on environmental sustainability in France. More attention should be paid to the pivotal role of natural resources in influencing sustainability objectives amidst political risks. Empirical analyses quantitatively assessing the impact of energy efficiency R&D, *NATR* and renewable energy integration on CO_2 reduction in France are deficient. Geographical disparities within France concerning the effects of energy efficiency R&D, natural resources and renewable energy on environmental sustainability should be addressed more.

Furthermore, there needs to be more research on exploring these initiatives' temporal dynamics and long-term impacts. Additionally, the literature requires a comprehensive and integrated framework that concurrently considers the interactions of energy efficiency R&D, natural resources, renewable energy adoption and political risks. Addressing these gaps with further research is imperative for a more nuanced understanding and effective policy formulation.

3. Data, Model and Methodological Framework

3.1 Data

This study examines the impact of energy efficiency research and development (R&D), renewable energy, political risks and natural resources on environmental sustainability in France, utilizing annual data from 1985 to 2021. Similar to Olasehinde-Williams and Özkan (2023), carbon emissions serve as a measure of environmental sustainability. Detailed information on the variables and their data series is provided in Table 1. As in Alola *et al*. (2023c), Özkan *et al*. (2023a, 2023c, 2023d) and Pata *et al*. (2023b), all raw data series are transformed into natural logarithms to minimize potential heteroscedasticity effects.

Table 1: Variables and data sources

Variable	Abbreviation	Data description	Data source
Carbon emissions	*CARE*	Per capita *CARE* (metric tonnes)	Our World in Data (2023)
Energy efficiency R&D	*EER&D*	Public *EER&D* spending in million USD	IEA (2023)
Renewable energy	*RENE*	Per capita *RENE* consumption (kWh)	Our World in Data (2023)
Political risks	*POLR*	*POLR* index	PRS Group (2023)
Natural resources	*NATR*	Total *NATR* rents (% of GDP)	WB (2023)

Source: Authors' own elaboration

3.2 Model and methodological framework

This study reveals the connections between energy efficiency research and development (R&D), renewable energy, political risks, natural resources and carbon emissions in France by using the following model:

$$\ln CARE = f\left(\ln EER\,\&\,D,\ \ln RENE,\ \ln POLR,\ \ln NATR\right) \tag{1}$$

In Equation (1), f represents a function, ln*CARE* signifies the logarithm of carbon emissions, ln*EER&D* denotes the logarithm of energy efficiency research and development, ln*RENE* represents the logarithm of renewable energy, ln*POLR* implies the logarithm of political risks and ln*NATR* indicates the logarithm of natural resources. The study employs a machine learning approach, specifically the kernel regularized least-squares (KRLS) method proposed by Hainmueller and Hazlett (2014) and Ferwerda *et al*. (2017) to estimate the effects of energy efficiency research and development (*EER&D*), renewable energy (*RENE*), political risks (*POLR*) and natural resources (*NATR*) on carbon emissions (*CARE*) in France. The KRLS method is chosen for its capability to address regression and classification issues without relying on specific assumptions and specifications (Ferwerda *et al*., 2017).

In simpler terms, the kernel regularized least-squares (KRLS) serves as a valuable tool for addressing complex estimation challenges in regression and classification, mitigating issues such as misspecification bias that may arise from inconsistent functional forms in empirical models (Sarkodie *et al*., 2023). An advantageous feature of KRLS is its ability to adapt to the functional forms of the data series under investigation, automatically safeguarding against specification errors. By estimating the partial derivatives of the dependent variable concerning each independent variable, KRLS provides pointwise marginal effects (PME), showcasing the impact of each independent variable on the dependent variable. These PME unveil whether the relationship between X and Y is uniform (linear) or diverse (nonlinear). Importantly, KRLS accommodates nonnormality, nonlinearity and data series instability. For statistical inference, KRLS further offers average pointwise marginal effects (APME) for each independent variable on the dependent variable (Ferwerda *et al*., 2017). Given these advantages, we opt for KRLS in this study, aligning with recent empirical literature (Balcilar *et al*., 2023; Özkan *et al*., 2023b; Pata *et al*., 2023a).

To test the study model presented in Equation (1), the KRLS can be specified as follows:

$$\ln CARE_t = \partial_0 + \partial_1 \ln EER\&D_t + \partial_2 \ln RENE_t + \partial_3 \ln POLR_t + \partial_4 \ln NATR_t + u_t \quad (2)$$

where ∂_0 denotes the intercept, $\partial_1, \ldots, \partial_4$ are the estimated APME of ln*EER&D*, ln*RENE*, ln*POLR*, and ln*NATR*, respectively and u_t symbolizes the error term.

In order to test the validity of the KRLS findings, we employ Koenker and Bassett's (1978) quantile regression (QR) method. In the study, we test our model given in Equation (1) with the QR as follows:

$$\ln CARE_t(q) = \partial_0(q) + \partial_1(q)\ln EER\&D_t + \partial_2(q)\ln RENE_t + \partial_3(q)\ln POLR_t + \\ + \partial_4(q)\ln NATR_t + u_t(q) \quad (3)$$

where q represents the quantiles of ln*CARE*, $\partial_0(q)$ and $u_t(q)$ indicate the intercept and error term for the q-th quantile, respectively and $\partial_1(q), \ldots, \partial_4(q)$ are the estimated slope coefficients corresponding ln*EER&D*, ln*RENE*, ln*POLR*, and ln*NATR*, respectively, in the q-th quantile.

4. Findings and Discussion

4.1 Preliminary analysis

To ensure unbiased statistical inferences, it is essential to assess the multicollinearity among the independent variables (Asumadu-Sarkodie and Owusu, 2017). In this context, the study examines the presence of multicollinearity among ln*EER&D*, ln*RENE*, ln*POLR* and ln*NATR* using the correlation matrix and variance inflation factor (VIF). The results presented in Table 2 indicate that the correlation among these series does not exceed ±0.8 and the VIF values for these series are below 5 (Caglar *et al*., 2023). These findings demonstrate that the independent variables in our study are not affected by multicollinearity.

Table 2: Correlation matrix and VIF results

	ln*CARE*	**ln*EER&D***	**ln*RENE***	**ln*POLR***	**ln*NATR***
ln*CARE*	1		–	–	–
ln*EER&D*	−0.749	1	–	–	–
ln*RENE*	−0.803	0.388	1	–	–
ln*POLR*	0.747	−0.689	−0.574	1	–
ln*NATR*	0.720	−0.633	−0.514	0.457	1
	VIF	**1/VIF**	–	–	–
ln*EER&D*	2.650	0.377	–	–	–
ln*RENE*	1.782	0.561	–	–	–
ln*POLR*	2.478	0.404	–	–	–
ln*NATR*	1.998	0.500	–	–	–

Note: VIF is estimated for the model: ln*CARE* = *f*(ln*EER&D*, ln*RENE*, ln*POLR* and ln*NATR*).

VIF: variance inflation factor, ln: logarithm; *CARE*: carbon emissions; *EER&D*: energy efficiency R&D; *RENE*: renewable energy; *POLR*: political risks; *NATR*: natural resources.

Source: Authors' own calculations

Table 3 provides statistical information for the log series. The mean values suggest that, during the sample period, the annual averages of *CARE*, *EER&D*, *RENE*, *POLR* and *NATR* are approximately 1.8, 4.5, 8.2, 4.3 and −2.8, respectively. The standard deviation results indicate higher volatility for *EER&D* (lower for *POLR*) compared to the other variables. The skewness results show negative skewness for *CARE*, *EER&D* and *POLR*, while *RENE* and *NATR* exhibit positive skewness. The kurtosis results reveal that *NATR* has a leptokurtic distribution, while other variables have a platykurtic distribution. Finally, the Jarque–Bera results indicate that *CARE* and *POLR* have a nonnormal distribution, while other variables have a normal distribution.

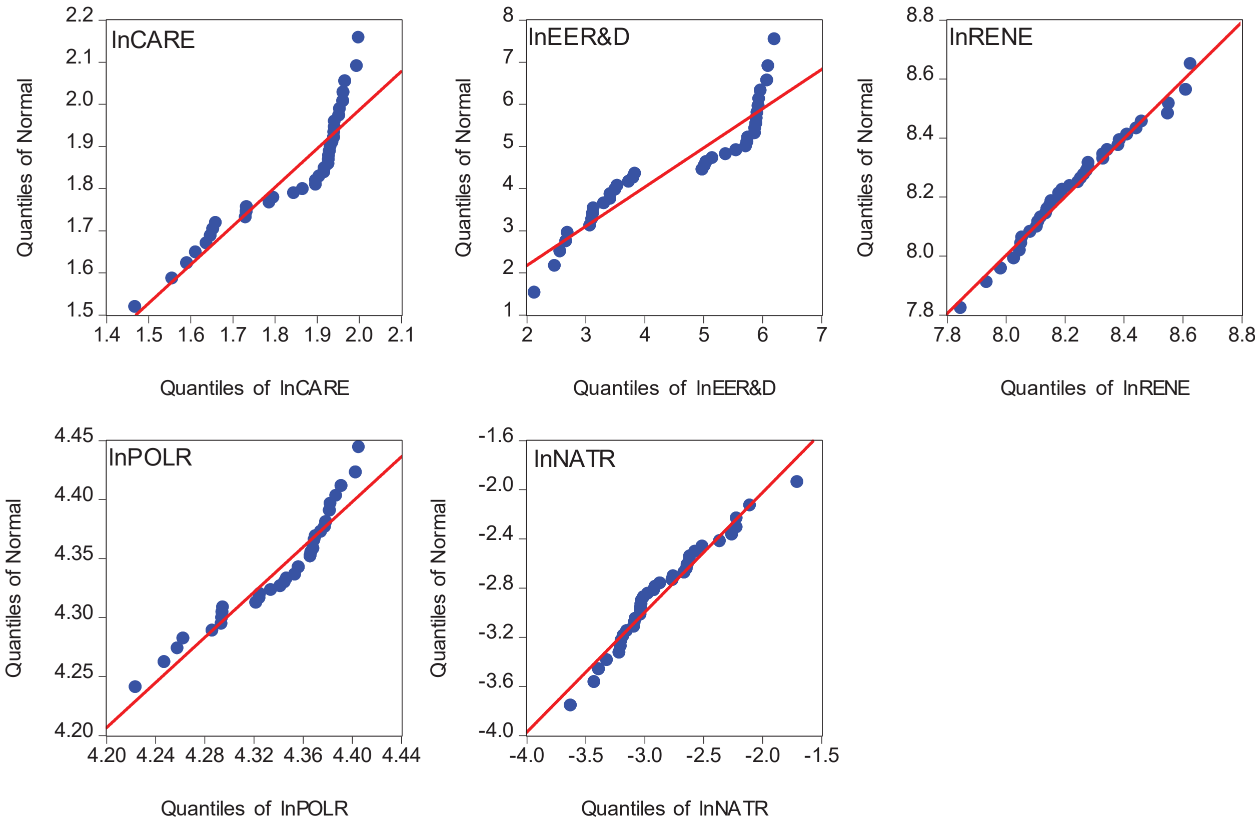
Table 3: Descriptive statistics

	ln*CARE*	ln*EER&D*	ln*RENE*	ln*POLR*	ln*NATR*
Mean	1.838	4.532	8.237	4.342	–2.848
Median	1.917	5.018	8.218	4.357	–2.971
Maximum	2.000	6.206	8.627	4.406	–1.704
Minimum	1.469	2.138	7.848	4.224	–3.626
Std. dev.	0.145	1.359	0.187	0.046	0.411
Skewness	–0.946	–0.232	0.284	–0.908	0.668
Kurtosis	2.624	1.426	2.599	2.910	3.232
J–B	5.740*	4.152	0.745	5.099*	2.833
Prob	0.057	0.125	0.689	0.078	0.243

Note: J–B: Jarque–Bera (1980) test. Statistical significance at the 10% level is indicated by *.
Source: Authors' own calculations

Additionally, we explore the normal distribution of the log series for variables using a visual tool, the quantile–quantile (Q–Q) diagram, which provides a more detailed picture (Xu and Lin, 2023). The Q–Q diagrams presented in Figure 1 reveal that the blue dots deviate from the red diagonal line representing the normal distribution. Unlike the J–B results, the Q–Q diagrams suggest that all variables have a nonnormal distribution.

Figure 1: Q–Q diagrams



Source: Authors' own elaboration

After determining the nonnormality of the studied series, we use the BDS test (Broock *et al*., 1996) to determine whether they are linear or nonlinear in the sample period by considering Alola *et al*. (2023b), Olasehinde-Williams *et al*. (2023a), Özkan *et al*. (2023b) and Pata *et al*. (2023c). The BDS test results are reported in Table 4. Evidently, the H_0 (linearity) is rejected across all dimensions (from D[2] to D[6]) for the log series of *CARE*, *EER&D*, *POLR* and *NATR* and it is rejected for ln*RENE* at D[2], D[3] and D[4]. These findings empirically prove that our all variables have nonlinearity in the sample period.

Table 4: Nonlinearity results

		ln*CARE*	ln*EER&D*	ln*RENE*	ln*POLR*	ln*NATR*
D[2]	*z*-stat Prob	12.187*** 0.000	18.943*** 0.000	6.554*** 0.000	12.188*** 0.000	12.594*** 0.000
D[3]	*z*-stat Prob	11.336*** 0.000	18.456*** 0.000	4.675*** 0.000	11.699*** 0.000	12.386*** 0.000
D[4]	*z*-stat Prob	11.031*** 0.000	19.593*** 0.000	2.741*** 0.006	11.512*** 0.000	13.481*** 0.000
D[5]	*z*-stat Prob	10.666*** 0.000	21.214*** 0.000	0.317 0.751	11.628*** 0.000	15.749*** 0.000
D[6]	*z*-stat Prob	10.014*** 0.000	23.120*** 0.000	1.008 0.313	12.073*** 0.000	17.658*** 0.000

Note: The table demonstrates the BDS test estimates across dimensions (D) from 2 to 6. Statistical significance at the 1% level is indicated by ***.

Source: Authors' own calculations

In this study, we also investigate whether the log series of the variables are stable or unstable in the sample period by employing the parameter stability test first developed by Andrews (1993) and later modified by Andrews and Ploberger (1994) and Hansen (1997), respectively, similar to papers by Khan *et al*. (2023), Lee *et al*. (2023), Olanipekun *et al*. (2023) and Olasehinde-Williams *et al*. (2023b). The parameter stability test results are given in Table 5. The estimates (supF, expF and aveF) imply that the H_0 (stability) is rejected for all the variables at the 1% level. This result reveals that, empirically, the study variables exhibit instability in the sample period. The variables' nonnormality, nonlinearity and instability justify using the KRLS and QR methods in this study.

Table 5: Instability results

	ln*CARE*	ln*EER&D*	ln*RENE*	ln*POLR*	ln*NATR*
supF	166.184***	311.182***	57.416***	84.247***	69.536***
Prob	0.000	0.000	0.000	0.000	0.000
expF	79.927***	152.333***	25.819***	39.448***	31.959***
Prob	0.000	0.000	0.000	0.000	0.000
aveF	61.563***	64.499***	18.267***	25.574***	37.877***
Prob	0.000	0.000	0.000	0.000	0.000

Note: The table demonstrates the parameter stability test estimates. Statistical significance at the 1% level is indicated by ***.

Source: Authors' own calculations

4.2 Kernel-based regularized least squares (KRLS) outcomes

The research conducted in this study represents a pioneering effort in utilizing advanced statistical techniques, specifically kernel-based regularized least squares (KRLS) and quantile regression (QR), to investigate the multifaceted relationship between various factors and CO_2 levels in France. By analysing the influence of energy efficiency R&D (*EER&D*), renewable energy (*RENE*), natural resources (*NATR*) and political risks (*POLR*), the study sheds light on how different variables affect carbon emissions in a complex socio-economic and environmental context. One of the key findings of the study is the consistently negative average pointwise marginal effects of energy efficiency research and development (*EER&D*) on CO_2 levels across different quantiles (ranging from 0.05 to 0.70). This indicates that as investments in *EER&D* increase, there is a corresponding reduction in carbon emissions. The robustness and statistical significance of this relationship underscore its reliability, implying that strategic initiatives aimed at advancing energy efficiency research and development can effectively contribute to achieving and sustaining environmental goals in France.

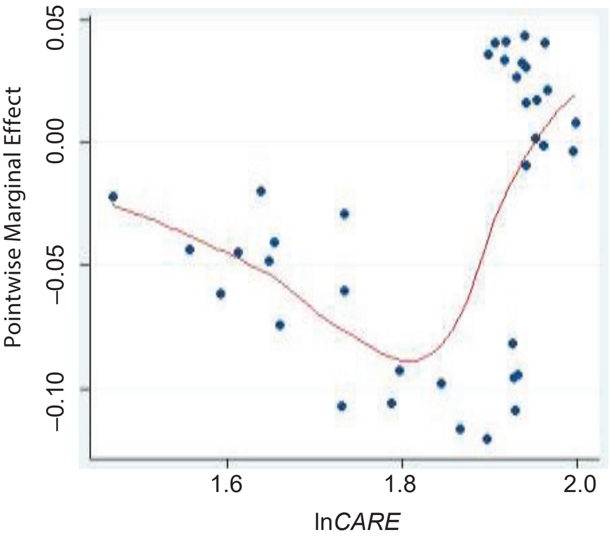
Moreover, the alignment of these findings with prior research by Bilgili *et al*. (2023) and Wang *et al*. (2023) reinforces the significance of energy efficiency research and development investments (EERDI) in mitigating carbon emissions. Additionally, the study supports the viewpoint presented by Pata *et al*. (2023), which emphasizes the role of R&D investments in driving the development of innovative technologies geared towards enhancing energy efficiency. These technological advancements encompass a wide range of areas, including energy-efficient appliances, advanced insulation materials, low-energy lighting and smart grids. By improving energy efficiency across industries, transportation and households, these technologies contribute to reducing overall energy consumption and dependence on fossil fuels. Subsequently, this leads to a decline in CO_2 emissions, aligning with the objectives of environmental sustainability and climate change mitigation.

The negative average pointwise marginal effect (−0.150) observed between renewable energy (*RENE*) and CO_2 emissions (*CARE*) in Table 6 signifies a crucial relationship: as the utilization of renewable energy increases, there is a corresponding decrease in CO_2 emissions. This finding underscores the potential of increased investment in renewable energy sources to significantly mitigate carbon emissions in France, aligning with broader objectives related to environmental sustainability and climate change mitigation. From an economic perspective, this shift towards greater reliance on renewable energy represents a fundamental transition away from conventional, carbon-intensive methods of energy generation. By reducing dependence on fossil fuels and promoting the adoption of clean energy sources such as wind, solar, hydroelectric and biomass, France can not only decrease its carbon footprint but also realize various economic benefits.

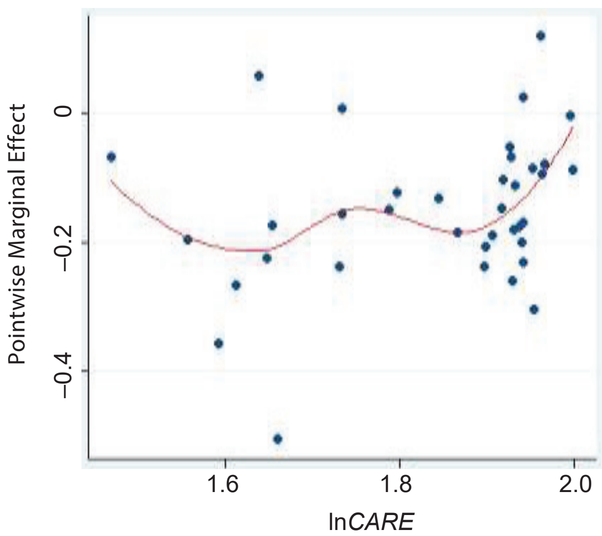
Firstly, fostering the growth of the renewable energy sector can stimulate economic activity and create new job opportunities. Investments in renewable energy infrastructure, research and development can lead to job creation across various sectors, including manufacturing, construction, engineering and maintenance. Secondly, by reducing reliance on imported fossil fuels, France can enhance its energy security and resilience to external supply disruptions. This can lead to cost savings and reduce vulnerability to fluctuations on global energy markets. Thirdly, transitioning towards renewable energy aligns with the global trend towards sustainable and green economies. As countries worldwide commit to reducing greenhouse gas emissions and transitioning to renewable energy sources, France's leadership in embracing clean energy technologies can enhance its reputation as an environmentally conscious country and attract investment and partnerships from other countries and international organizations. These findings align with the conclusions drawn by Pata *et al*. (2023), Omri and Saidi (2022), Özkan *et al*. (2023) and Adebayo and Ullah (2023). Inversely, Doğan *et al*. (2021) indicated that the negative relationship between renewable energy utilization and CO_2 emissions is not significant or not consistently observed across different contexts. Their research might emphasize the need for a more nuanced understanding of the interplay between renewable energy and carbon emissions. The positive 0.116 average pointwise marginal effect of political risks (*POLR*) on CO_2 emissions (*CARE*) suggests that an increase in political risks corresponds to higher CO_2 emissions. Political stability is vital for establishing regulatory frameworks supporting clean energy adoption and emissions reduction. Enhancing political stability through transparent policies, international collaboration and measures for continuity can positively affect environmental sustainability by fostering a conducive environment for sustainable initiatives. This result resonate with studies of Su *et al*. (2021), Benlemlih *et al*. (2022) and Eweade *et al*. (2023). An increase in *NATR* is associated with a corresponding rise in CO_2 emissions. The positive average pointwise marginal effect suggests a potential relationship where the greater use of *NATR* may contribute to ecological impacts, possibly through increased industrial activities, extraction processes or energy consumption. This aligns with the findings of Danish *et al*. (2019), Balsalobre-Lorente *et al*. (2018) and Balsalobre-Lorente *et al*. (2023).

Figure 2: Impact of PME of *EER&D*, *RENE*, *POLR* and *NATR* on *CARE*

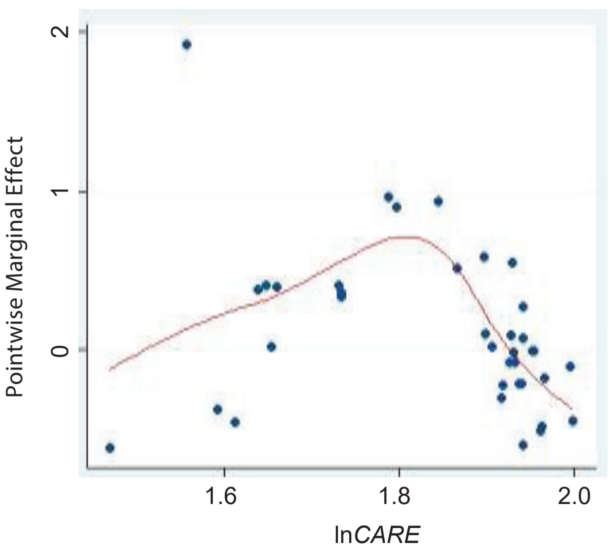
(a) PME of *EER&D* on *CARE*



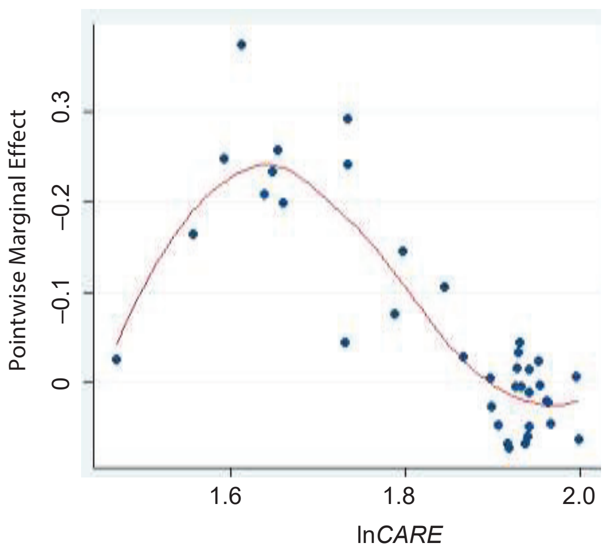
(b) PME of *RENE* on *CARE*



(c) PME of *POLR* on *CARE*



(d) PME of *NATR* on *CARE*



Source: Authors' own elaboration

Table 6: APME results

	APME	SE	*t*-stat	Prob	1st quartile	2nd quartile	3rd quartile
ln*EER&D*	−0.029***	0.004	−7.207	0.000	−0.081	−0.022	0.022
ln*RENE*	−0.150***	0.027	−5.661	0.000	−0.207	−0.156	−0.085
ln*POLR*	0.116***	0.133	0.871	0.000	−0.214	0.018	0.394
ln*NATR*	0.060***	0.015	4.126	0.000	−0.023	0.016	0.145
Diagnostics							
R^2	0.986	Lambda	0.071	Sigma	4	Looloss	0.519

Note: The table demonstrates the estimated APME ∂_1, ∂_2, ∂_3, and ∂_4 by the KRLS for the model: ln*CARE* = *f*(ln*EER&D*, ln*RENE*, ln*POLR* and ln*NATR*). APME: average pointwise marginal effects. Statistical significance at the 1% level is indicated by ***.

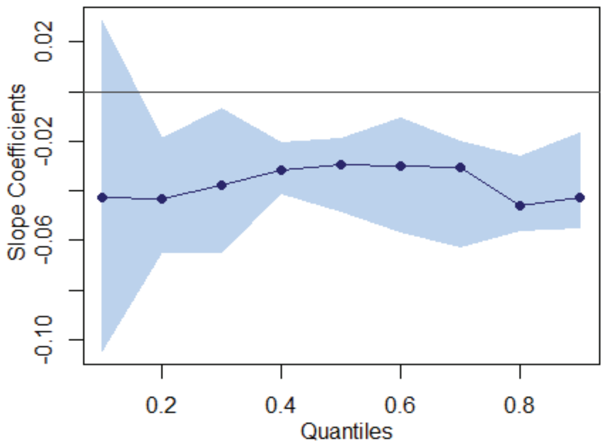
Source: Authors' own calculations

4.3 Robustness check

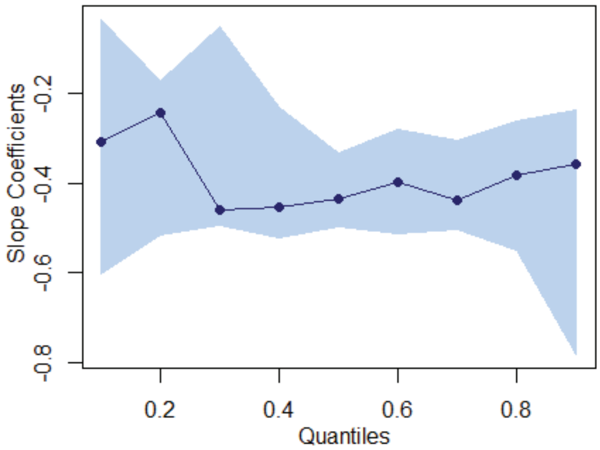
Conducting a robustness check with quantile regression is a methodological approach aimed at evaluating the robustness and consistency of primary research findings by scrutinizing the variability in the relationship between variables across various quantiles of the distribution of the dependent variable. Quantile regression, a statistical technique introduced by Koenker and Bassett (1978) and further developed by Koenker (2005), proves particularly advantageous for discerning heterogeneity in the impacts of independent variables across the entirety of the distribution. This approach enhances analytical depth, offering a nuanced comprehension beyond the limitations of traditional mean-based regression models (Koenker, 2005). Hence, Figure 2(a) substantiates the findings from the KRLS analysis outlined below. The results of the quantile regression (QR) indicate that, across all quantiles, the effect of energy efficiency research and development (*EER&D*) on CO_2 is consistently negative, aligning with the conclusions drawn from the KRLS regression. Conversely, Figure 2(b) exhibits that the QR results harmonize with the KRLS results, showcasing a negative impact of CO_2 emissions on renewable energy. Additionally, in Figure 2(c), the QR outcomes reveal that political risks positively influence CO_2 in all the quantiles, echoing the trends observed in the KRLS analysis. Conversely, in Figure 2(d), the positive impact of CO_2 on natural resources across all the quantiles is affirmed by both QR and KRLS outcomes. This finding underscores the mutual validation of results between QR and KRLS analyses. The estimates derived from quantile regression (QR) are depicted in Figure 3.

Figure 3: Impact of *EER&D*, *RENE*, *POLR* and *NATR* on *CARE*

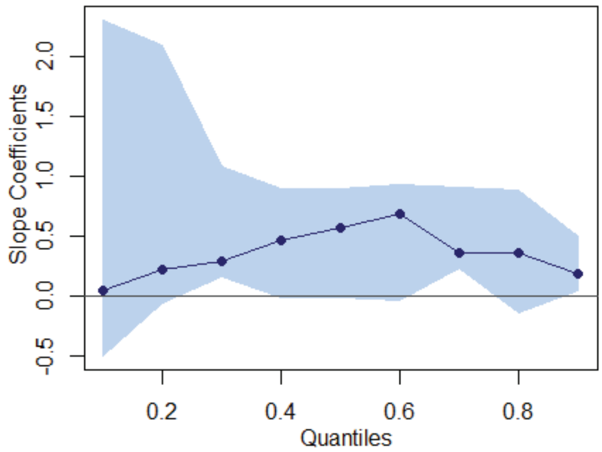
(a) Impact of *EER&D* on *CARE*



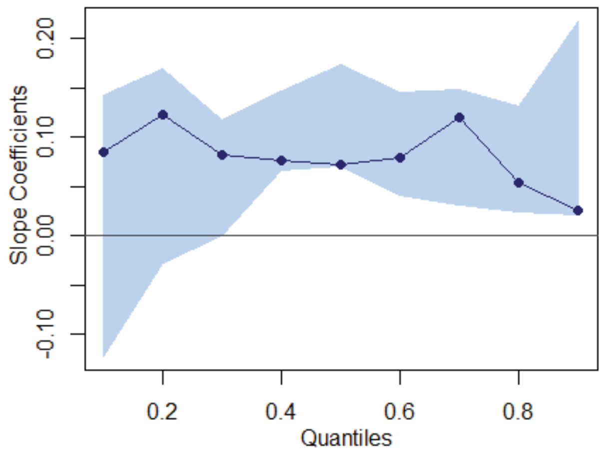
(b) Impact of *RENE* on *CARE*



(c) Impact of *POLR* on *CARE*



(d) Impact of *NATR* on *CARE*



Note: The plots demonstrate the estimated slope coefficients $\partial_1(q)$, $\partial_2(q)$, $\partial_3(q)$, and $\partial_4(q)$ by the QR for the model: ln*CARE* = *f*(ln*EER&D*, ln*RENE*, ln*POLR* and ln*NATR*). QR: quantile regression.

Source: Authors' own calculations

5. Conclusion and Policy Pathways

5.1 Conclusion

Despite France's status as one of the world's most advanced countries, it faces substantial ecological challenges that have affected the well-being of its diverse environmental features. Despite economic prosperity, the country has struggled to safeguard its environment. The present paper addresses this need by examining the effects of energy efficiency R&D, renewable energy use and natural resources among political risks on CO_2 in France. The investigation utilized an annual dataset from 1985 to 2021 to examine this correlation. The kernel-based regularized least squares (KRLS) methodology was employed and a robustness check with quantile regression (QR) was introduced to explore this association. The KRLS analysis revealed a nuanced understanding of the intricate relationship between various factors and their impacts on CO_2 across quantiles. Energy efficiency R&D and renewable energy adoption significantly reduce CO_2, highlighting the benefits of transitioning to sustainable energy alternatives. Responsible utilization of natural resources emerges as a critical factor in CO_2 reduction, emphasizing the importance of sustainable resource management for ecological goals: political risks, including geopolitical uncertainties, influence CO_2, underscoring their tangible effects on environmental sustainability. The robustness check using QR supports these findings, providing confidence in their reliability. In summary, these insights significantly contribute to understanding the interplay of energy-related practices, political dynamics and environmental sustainability in the context of France.

5.2 Policy pathways

Based on the findings, it is recommended that the French government implements targeted policies focusing on increased investment in energy efficiency R&D. Collaborative ventures with the private sector, alongside incentives, can stimulate the creation of CO_2-reducing technologies, reaffirming France's dedication to environmental sustainability. Additionally, there is a crucial need to encourage the advancement and adoption of green technologies by offering financial incentives. Aligning with the study's suggestions, this can be accomplished via tax credits, subsidies and grants. These incentives act as catalysts, motivating businesses and industries to transition towards sustainable and environmentally friendly practices. Moreover, the French government and policymakers must allocate resources to develop and deploy renewable energy sources. This entails funding for research and development, incentivizing investments in sustainable energy and encouraging the integration of renewable energy across various sectors.

Moreover, the French government and policymakers should drive this transition by enacting policies incorporating subsidies, tax incentives and regulatory frameworks. These measures will further cement France's leadership in adopting sustainable energy practices. Moreover, the French government must ensure responsible resource extraction methods to mitigate environmental degradation and carbon emissions. Achieving this goal entails implementing stringent environmental laws, establishing robust monitoring systems and effective enforcement mechanisms. In addressing critical political risks that affect stability and environmental sustainability, the government can develop transparent policy frameworks, ensure regulatory coherence and engage in international collaborations. Encouraging a diversified energy mix, including a balanced combination of renewable sources, is essential. Policies promoting energy storage solutions can address intermittency challenges associated with specific renewable sources. Strengthening international collaboration on energy issues, sharing best practices and engaging in joint research and development projects is crucial. Participation in global initiatives and agreements to address climate change, emphasizing a commitment to sustainable energy practices, is essential. A robust monitoring and evaluation framework is necessary to track progress towards energy efficiency, renewable energy and environmental sustainability goals. Regular assessments of policy effectiveness and data-driven adjustments ensure continual improvement.

5.3 Study limitation and future research

Despite employing KRLS and quantile regression as robustness checks, our study faces certain limitations that warrant attention from future researchers. Firstly, the dataset's timeframe spans only from 1985 to 2021, urging scholars to extend it further to enable a more comprehensive analysis. Secondly, our focus is solely on France, indicating a need for future investigations to encompass a wider array of both developed and developing nations for a more globally inclusive perspective. Thirdly, several factors influencing CO_2 emissions, such as economic policy uncertainty, financial development, renewable energy, and climate policy uncertainty, were not accounted for in this study, thereby presenting avenues for further exploration. Lastly, our study employs CO_2 as a proxy for ecological deterioration, predominantly emphasizing the demand side of the environment, while neglecting the supply side. Future studies could explore the load capacity factor, which incorporates both supply and demand aspects of the environment, serving as a proxy for ecological quality in their analyses

Acknowledgement

Funding: There was no funding, either externally or internally, towards this study.
Conflicts of interest: The authors hereby declare that this article was not submitted or published elsewhere.

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