"Does fiscal decentralization foster renewable electricity generation? A panel data study of OECD countries"

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DOES FISCAL DECENTRALIZATION FOSTER RENEWABLE ELECTRICITY GENERATION? A PANEL DATA STUDY OF OECD COUNTRIES

Abstract

As the global community intensifies efforts to transition toward sustainable energy systems, the role of institutional and fiscal arrangements in fostering renewable energy has gained increasing attention. This study aims to assess whether fiscal decentralization contributes to the expansion of renewable electricity generation in OECD countries by analyzing panel data and identifying the direction and significance of this relationship. Utilizing a panel dataset of 34 countries spanning 2000–2023, the analysis employs a fixed-effects regression model with Driscoll-Kraay standard errors. It includes a one-year lag of fiscal variables to ensure robustness. The findings reveal a statistically significant but modest negative relationship between the share of subnational revenues in GDP and the share of renewables in electricity generation, suggesting that greater fiscal decentralization may not automatically incentivize renewable energy adoption. More specifically, the fixed-effects model corrected for heteroskedasticity and autocorrelation indicates that the coefficient for lagged subnational revenue (as a percentage of GDP) is negative and marginally significant ($p \approx 0.057$), hinting at a potential delayed inhibitory effect. Additionally, country-level fixed effects demonstrate substantial heterogeneity, with nations like Iceland, Norway, and Canada showing systematically higher renewable electricity shares, regardless of fiscal structure. These results underscore the importance of complementary institutional frameworks and national coordination mechanisms to ensure that decentralization effectively supports climate policy goals.

Keywords	fiscal decentralization, renewable energy, electricity generation, panel data, OECD countries, climate policy
JEL Classification	H72, Q42, Q48, C23

INTRODUCTION

The global transition toward sustainable energy systems has intensified interest in institutional and fiscal mechanisms that could accelerate the deployment of renewable energy. The International Energy Agency (IEA, 2021) emphasizes that decentralized governance and local financing frameworks, such as subnational incentives, green bonds, and regionally adapted investment strategies, can enhance policy effectiveness and public acceptance of clean energy. Similarly, the OECD (2022) reports that in 2019, subnational governments in OECD and EU countries accounted for approximately 63% of public spending on climate-relevant activities (1.1% of GDP) and 69% of public investment in climate-related infrastructure (0.4% of GDP), underscoring their pivotal role in financing the energy transition.

Subnational governments also represent a significant share of public fiscal activity – approximately 40% of total expenditure and 55% of investment in OECD countries (OECD, n.d.a). This substantial fiscal

capacity makes fiscal decentralization, devolving revenue and expenditure authority to subnational entities, a potentially powerful tool to support localized green investments and energy initiatives. Understanding whether decentralized fiscal structures help or hinder renewable electricity generation has become increasingly relevant, given the diversity of environmental, economic, and institutional contexts.

OECD countries offer a fertile testing ground for this inquiry due to their heterogeneity in fiscal autonomy and environmental ambition. According to OECD statistics (OECD, n.d.c), countries like Sweden and Denmark grant significant tax autonomy to local authorities, whereas others, such as Ireland and Greece, maintain more centralized systems. This variation, combined with differing progress toward renewable energy targets (OECD, n.d.b), allows for a comparative assessment of how fiscal governance interacts with climate policy outcomes. While countries like Germany and Portugal have advanced renewable electricity generation with strong subnational involvement, others have struggled despite centralized efforts.

Despite its policy relevance, empirical evidence on the relationship between fiscal decentralization and renewable electricity generation remains limited and inconclusive. This study addresses that gap by analyzing whether fiscal decentralization supports the expansion of renewable electricity generation in OECD countries.

1. LITERATURE REVIEW

The relationship between fiscal decentralization and the expansion of renewable electricity generation is increasingly viewed as multidimensional, shaped by institutional, financial, technological, and socio-environmental determinants. This section synthesizes existing research across four thematic areas that are critical to understanding this nexus:

1) institutional and governance configurations;
2) fiscal and financial instruments;
3) technological and market readiness; and
4) socio-environmental context.

1.1. Institutional and governance configurations

Institutional structures and the degree of decentralization significantly influence how effectively governments can implement renewable energy policy. Decentralized systems tend to allow greater flexibility and responsiveness to local conditions, potentially improving the alignment of energy strategies with regional needs and capacities. This view is supported by studies emphasizing the enabling role of fiscal decentralization in fostering subnational innovation and tailored policymaking in the energy sector (Vasa et al., 2024; Melnyk et al., 2020; Sala et al., 2023). Variations in implementation effectiveness across EU countries further confirm

that regional capacity is a decisive factor in determining the outcomes of decentralized energy policies (Dinca et al., 2023; Dragoi et al., 2023; Sotnyk et al., 2021). Scholars argue that decentralized systems facilitate climate governance experimentation and adaptability, particularly in diverse administrative settings (Kuzior et al., 2023; Juracka et al., 2024). The capacity of decentralization to overcome regulatory bottlenecks and accelerate the energy transition is highlighted in governance-focused studies (Myroshnychenko et al., 2024; Sotnyk et al., 2023; Mustafa, 2024). Moreover, the importance of leadership, organizational culture, and knowledge management in cultivating sustainability practices across governance levels is emphasized in broader institutional frameworks (Alemu, 2025a, 2025b).

1.2. Fiscal and financial instruments

The availability and design of fiscal and financial instruments are crucial for incentivizing renewable energy investments under decentralization. Evidence suggests that decentralization can enhance the efficiency and responsiveness of such instruments, including feed-in tariffs, green bonds, and local tax incentives, especially when fiscal authority is devolved to subnational levels (Balcerzak et al., 2023, 2024; Moroz & Lyeonov, 2024; Krause et al., 2024). ESG-based financial planning frameworks have become essential tools for facilitating green investments in decentralized settings

(Draksaite et al., 2018; Zheng et al., 2023). Scholars note that fiscal decentralization improves the ability of local governments to adapt financing to specific regional needs, thus supporting investment diversification and risk mitigation (Zatonatska et al., 2025). Moreover, the entrepreneurial ecosystem for renewables is often more vibrant in decentralized fiscal environments, where targeted budgetary mechanisms support small-scale energy producers and start-ups (Dobrovolska et al., 2024). These patterns align with findings on investor perceptions, highlighting the relevance of governance level in shaping financial confidence in green sectors (Obagbuwa & Munzhelele, 2024) and are supported by research on priorities of impact investing in environmental protection projects (Rieznyk et al., 2023; Makarenko et al., 2024b).

1.3. Technological and market readiness

The extent to which decentralized governments can promote renewable electricity is also mediated by technological readiness and market conditions. Decentralization often enables more rapid uptake of emerging energy technologies, such as smart grids, distributed storage systems, and energy communities, due to its proximity to users and ability to tailor deployment (Bilan et al., 2022, 2023; Badreddine & Cherif, 2024; Chygryn et al., 2023). Local initiatives tend to be more agile in adopting innovations and engaging the public, which is critical for the success of decentralized energy projects (Delcea et al., 2024; Redko et al., 2023; Tymoshenko et al., 2023). Structural changes in the energy sector, such as the move toward prosumerism and the decentralization of grid management, also require responsive policy instruments at the local level (Chygryn & Shevchenko, 2023). Regional strategies integrating energy, waste, and public health, such as energy-from-waste technologies, are increasingly being developed as part of local responses to climate and energy challenges (Matvieieva et al., 2023).

1.4. Socio-environmental context

Socio-environmental factors significantly influence the success of decentralized energy governance. Public health concerns, environmental awareness, and citizen participation are crucial

in shaping the public's acceptance of and engagement with renewable energy projects (Dankevych et al., 2023; Hrytsenko et al., 2024; Vasylyeva & Pryymenko, 2014). In the Ukrainian context, expectations for green energy are closely linked to citizen demand, signaling the importance of public opinion in shaping energy priorities (Kuzior et al., 2021). Crises such as war or macroeconomic instability often disrupt centralized energy systems but can simultaneously empower regional actors to implement innovative, adaptive strategies (Koilo, 2024; Taher, 2024). The call for resilient, multi-level governance capable of withstanding shocks is echoed across multiple studies (Makarenko et al., 2023; Makarenko et al., 2024a; Mahmood & Furqan, 2025). Several researchers focus on fuels and adaptive strategies at the regional level, reinforcing that local contexts are critical to energy diversification (Grebski & Kuzior, 2022; Havrysh et al., 2021). Socioeconomic and fiscal stability also intersect with decentralization outcomes through the design of subsidy schemes, tariff structures, and social spending (Riabokon & Kyryliuk, 2025; Piekut & Rybaltowicz, 2024; Samusevych et al., 2024). Decentralized engagement is further amplified by citizen awareness campaigns and participatory models that increase support for local energy initiatives (Piwowarski, 2024; Dudek et al., 2023). Regional resilience perspectives emphasize the role of governance in adapting to energy crises (Wołowiec et al., 2022; Shtunder et al., 2022), while spatial disparities in finance and infrastructure continue to shape renewable energy potential (Štreimikienė, 2024; Streimikiene et al., 2024).

An integrative perspective is needed to understand how fiscal decentralization interacts with broader energy transition processes. Several scholars emphasize the importance of simultaneously evaluating fiscal, environmental, and energy security dimensions to assess better policy outcomes (Mentel et al., 2020; Ksonzhyk et al., 2021). Governance models that link decentralized decision-making with energy and waste management systems are increasingly relevant in this context (Wołowiec et al., 2022; Ziabina et al., 2023). The legitimacy of institutional promotion and the ethical underpinnings of policy reform also play a role in shaping the effectiveness of decentralization for sustainability outcomes (Chee & Karhulahti, 2020).

The literature suggests that fiscal decentralization can enhance the effectiveness of renewable energy policies by strengthening institutional adaptability, facilitating financial innovation, and aligning policy actions with local conditions. However, the impact of decentralization is highly context-dependent and mediated by administrative capacity, technological readiness, fiscal instruments, and socio-environmental dynamics. These insights provide a conceptual foundation for the empirical analysis undertaken in this study, which aims to assess whether fiscal decentralization contributes to the expansion of renewable electricity generation in OECD countries.

This study aims to assess whether fiscal decentralization contributes to the expansion of renewable electricity generation in OECD countries by analyzing panel data and identifying the direction and significance of this relationship.

2. METHODOLOGY

This study examines the relationship between fiscal decentralization and the share of electricity generated from renewable sources across 34 OECD member and partner countries over the period 2000–2023. The empirical analysis is based on an unbalanced panel dataset covering 34 OECD and partner countries, including Australia, Austria, Belgium, Canada, Chile, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

The analysis utilizes unbalanced panel data to capture both temporal and cross-country variation. Table 1 summarizes the variables used in the model and their data sources.

The dependent variable (y) is the share of electricity generated by renewables, expressed as a percentage of total electricity production. This indicator, obtained from Ember (n.d.), reflects the extent to which countries have adopted decentralized, low-carbon energy systems. Two key independent variables were selected to capture fiscal decentralization:

- x1 – consolidated state and local government revenue as a percentage of total general government revenue (OECD, n.d.c), representing the degree of subnational fiscal autonomy.

- x2 – consolidated state and local government revenue as a percentage of GDP (OECD, n.d.c), reflecting the economic significance of decentralized fiscal resources.

The descriptive statistics for the dataset, covering 804 observations across OECD countries, are presented in Table 2. The dependent variable y, representing the share of electricity generated by renewables, has a mean of 36.45% with a relatively large standard deviation of 29.71, indicating substantial variation across countries and years. The distribution is moderately right-skewed (skew = 0.74) with slightly platykurtic characteristics (kurtosis = –0.61), suggesting a mild deviation from normality and some outliers at the upper end.

The independent variable x1, measuring consolidated state and local government revenue as a percentage of total government revenue, shows a mean of 17.98% and a standard deviation of 14.10. The skewness of 1.09 indicates moderate right skew, while the kurtosis of 0.17 suggests a distribution closer to normal compared to y. However, the skewness still justifies transformation before regression analysis. The second independent variable, x2, which represents the same revenue as a percentage of GDP, maintains a mean of 7.47%, is less dispersed (SD = 5.76), and moderately skewed (skew = 0.83, kurtosis = –0.42).

Table 1. Variables and their sources

Variable	Definition	Source
y	Share of electricity generated by renewables	Ember (n.d.)
x1	Consolidated state and local government revenue as a percentage of total general government revenue	OECD (n.d.c)
x2	Consolidated state and local government revenue as a percentage of GDP	OECD (n.d.c)

Table 2. Descriptive statistics for variables

Source: R Studio.

Variable	y	x1	x2
n	804	804	804
mean	36.45	17.98	7.47
sd	29.71	14.10	5.76
median	26.78	13.86	5.14
trimmed	33.20	15.93	6.88
mad	27.79	11.93	4.60
min	0.04	2.47	0.70
max	100.00	56.40	23.20
range	99.96	53.93	22.50
skew	0.74	1.09	0.83
kurtosis	−0.61	0.17	−0.42
se	1.05	0.50	0.20

Initial exploratory analysis revealed skewed distributions in the independent variables. To address this and improve model estimation, the study employed the bestNormalize procedure in R, which tests multiple transformation techniques using cross-validated normality statistics. The orderNorm transformation was identified as the most effective for both x1 and x2, and the normalized variables were used in all subsequent estimations.

The econometric analysis proceeded in several steps. First, fixed effects (FE) and random effects (RE) panel regression models were estimated using the plm package in R. Model selection was guided by the Hausman test, which assesses the consistency of the RE estimator relative to the FE alternative.

To explore the delayed effect of fiscal decentralization on renewable energy deployment, the analysis incorporates a one-year lag of the normalized x2 variable (x2_norm_lag). The panel regression model is estimated using an FE specification to control for unobserved, time-invariant heterogeneity across countries. This approach allows the model to focus on within-country variation over time.

Diagnostic tests revealed the presence of heteroskedasticity, serial correlation, and cross-sectional dependence. Therefore, the final model employs Driscoll-Kraay robust standard errors to produce consistent and reliable coefficient estimates under these conditions.

The selected FE model with a lagged fiscal decentralization term provides a theoretically grounded and empirically robust basis for evaluating the policy implications of decentralization in the renewable energy domain.
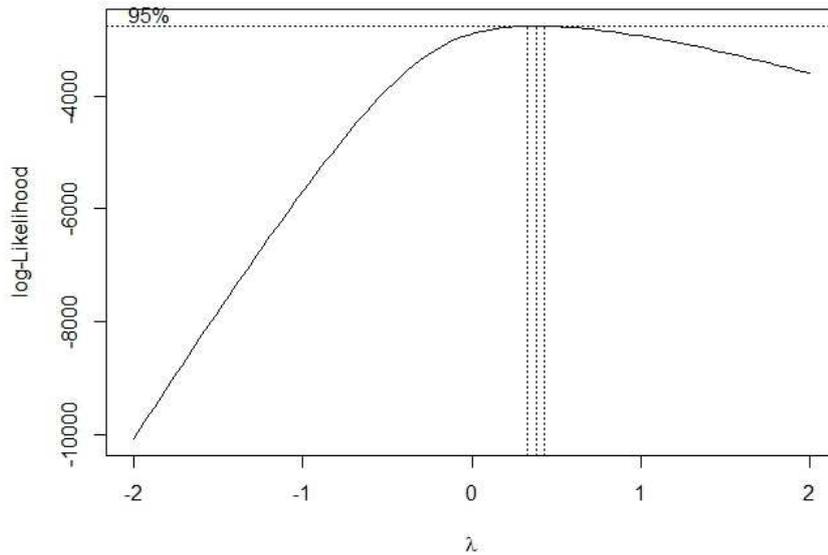
3. RESULTS

Given the observed skewness in all three variables, particularly x1 and x2, transformation is warranted to reduce asymmetry and fulfill regression assumptions. The skew coefficients for x1 (1.09) and x2 (0.83) exceed the commonly used threshold of ±0.5. This indicates the need to apply power transformations such as logarithmic, square root, or more advanced methods like Box-Cox or orderNorm. These transformations help normalize the distributions, improve linearity, and enhance the interpretability and validity of regression results.

Figure 1 presents the results of the Box-Cox transformation test applied to the dependent variable – share of electricity generated by renewables – to identify the most suitable power transformation to improve normality and stabilize the variance.

The plot displays the log-likelihood values associated with different Box-Cox parameter values (λ) values. The peak of the curve corresponds to the maximum log-likelihood and represents the optimal transformation. In this case, the estimated λ is approximately 0.384, between 0 and 0.5. This suggests that the distribution of the dependent variable is right-skewed and would benefit from a power transformation between the natural logarithm (λ = 0) and square root (λ = 0.5). The narrow 95% confidence interval around the estimated λ indicates a high level of precision in this estimation. Based on these results, a Box-Cox transformation with λ = 0.384 or a simpler square root transformation may be considered appropriate for further regression analysis, improving compliance with the assumptions of linear panel models.

Figure 2 presents Q-Q plots for the original variable (*y*, share of electricity generated by renewables) and its Box-Cox transformed version (*y_bc*). In the Q-Q plot of the original variable, the data points deviate significantly from the theoretical regression line, particularly in the lower and

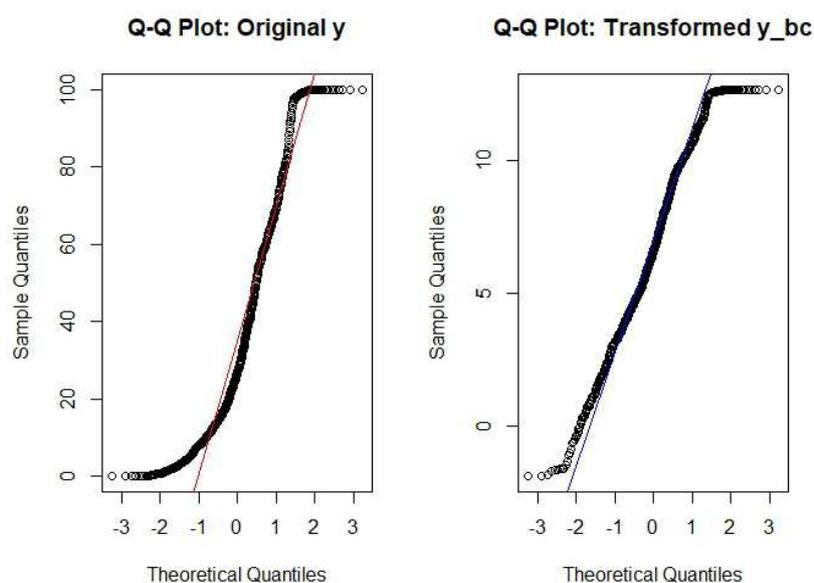**Figure 1.** Box-Cox transformation test applied to variable y

upper quantiles. This S-shaped pattern indicates a clear right-skewness in the distribution, violating the assumption of normality required for linear modeling. In contrast, the Q-Q plot for the transformed variable (y_bc) shows a visibly improved alignment with the standard reference line. Although some deviations remain in the tails, the central portion of the distribution conforms more closely to normality. This confirms that the Box-Cox transformation ($\lambda = 0.384$) successfully reduced skewness and enhanced the suitability of the variable for regression analysis by improving the distributional properties. Therefore, the trans-

formation is justified and should be applied in subsequent econometric modeling.

The results of the normalization tests for the independent variables x1 and x2 confirm the necessity of transformation to improve normality and satisfy model assumptions. For both variables, orderNorm (ordered quantile normalization) was selected as the best-performing transformation based on cross-validated Pearson P/df statistics.

For x1 (consolidated state and local government revenue as % of total government revenue), or-

Figure 2. Q-Q plots for the original variable y and its Box-Cox transformed version

derNorm achieved a Pearson P/df value of 1.167, a substantial improvement over the untransformed version (5.30). Similarly, for x2 (consolidated revenue as % of GDP), orderNorm produced a value of 1.167, compared to 5.87 for the raw data. Other common transformations, like log, Box-Cox, and square root, were less effective in reducing distributional skewness and kurtosis.

The orderNorm transformation maps empirical quantiles to a normal distribution, preserving the order of data while ensuring distributional normality. Given the results, the transformed versions of x1 and x2 should be used in all subsequent regression models to provide more reliable coefficient estimates, valid standard errors, and statistical inference.

To improve the distributional properties of the independent variables and ensure the validity of panel regression assumptions, both x1 (consolidated state and local government revenue as a percentage of total general government revenue) and x2 (as a percentage of GDP) were transformed using the orderNorm method. This transformation, recommended by the bestNormalize() procedure, maps the empirical quantiles of a variable to a standard normal distribution while preserving their rank order, effectively correcting for skewness and heavy tails.

Figure 3 and Figure 4 provide Q-Q plot comparisons for x1 and x2, respectively. In both figures, the left panels display the Q-Q plots of the original variables, which exhibit significant deviation from the reference line, particularly in the tails, indicating strong right-skewness and non-normality. In contrast, the right panels show the Q-Q plots for the orderNorm-transformed versions. The transformed variables align almost perfectly with the theoretical regular distribution line, confirming a substantial improvement in normality. This justifies using the transformed variables in subsequent fixed effects panel regression analysis, ensuring more robust coefficient estimation and valid inference.

The results of the FE model (Table 3) using the transformed dependent variable (y_bc) and order-normalized predictors indicate that only x2_norm, representing subnational fiscal share as a percentage of GDP, is statistically significant ($p = 0.043$). Its coefficient of -0.76 suggests a modest negative relationship between fiscal decentralization (in GDP terms) and the share of electricity generated by renewables after accounting for time-invariant differences across countries. Meanwhile, x1_norm (fiscal share in general government revenue) is not significant ($p = 0.234$), indicating that this measure of decentralization may not have a meaningful impact on renewable energy development in
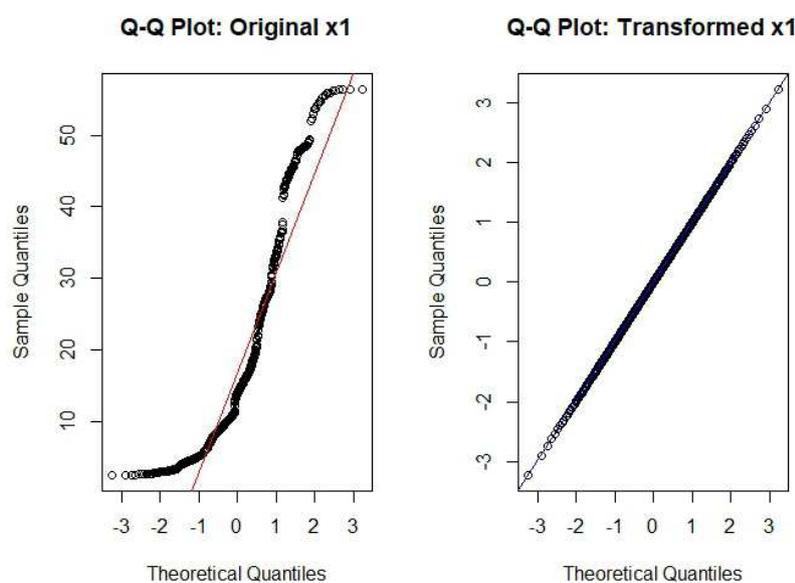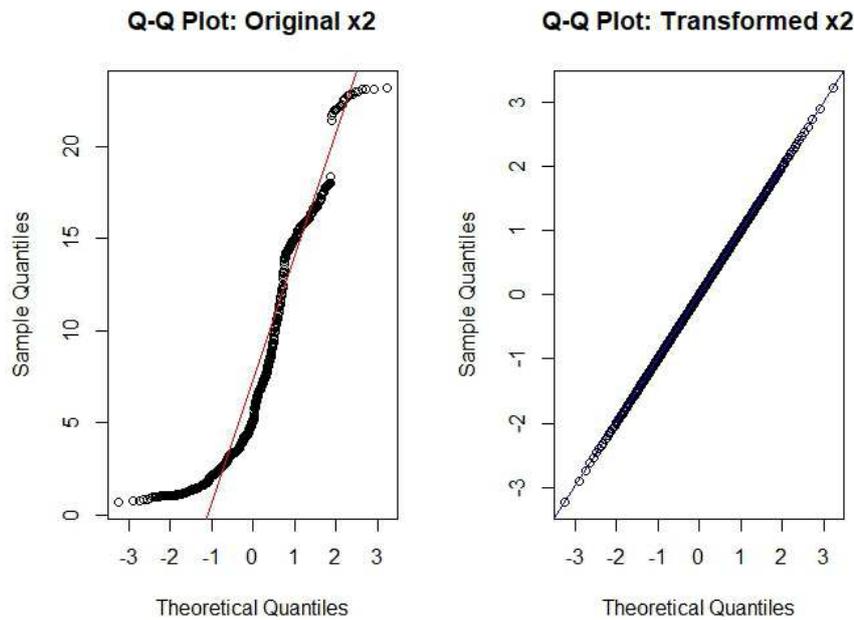
Source: R Studio.

Figure 3. Q-Q plots for the variable x1

Figure 4. Q-Q plots for the variable x2

this panel. The model explains only a small portion of the variation in the dependent variable ($R^2 = 0.0217$), suggesting that other country-specific or time-varying factors not included in the model play a larger role.

In the RE model (Table 3), the results are broadly similar, though slightly weaker in statistical strength. x2_norm remains marginally significant ($p = 0.083$), while x1_norm again shows no meaningful relationship. The intercept is highly significant, reflecting an overall positive mean level of renewable energy adoption across the sample. However, the Hausman test (Table 3) yields a significant result ($\chi^2 = 11.37$, $p = 0.0034$), leading to the rejection of the null hypothesis that the RE estimator is consistent. This supports the choice of the FE model as the appropriate specification, implying that unobserved country-level characteristics (e.g., governance, geography, energy policy traditions) are correlated with the explanatory variables and must be controlled for. Accordingly, interpretation and policy implications should be based on the fixed effects results, using robust standard errors to ensure inference validity.

The diagnostic tests performed on the fixed effects panel model reveal multiple violations of classical regression assumptions. The studentized Breusch-Pagan test (BP = 31.35, $p < 0.001$) indicates the presence of heteroskedasticity, where the variance of the residuals is not constant across observations. This is further reinforced by the Lagrange Multiplier (LM) test for panel effects ($\chi^2 = 5023.4$, $p < 0.001$), which confirms that the panel structure significantly affects the data, justifying the use of panel estimators over pooled OLS. In addition, the Wooldridge test for serial correlation (F = 12,081, $p < 0.001$) and the Breusch-Godfrey/Wooldridge χ^2 test ($\chi^2 = 576.07$, $p < 0.001$) both provide strong evidence of autocorrelation within individual panels, suggesting that residuals are temporally correlated within countries.

Moreover, the test for cross-sectional dependence (LM $\chi^2 = 7732$, $p < 0.001$) reveals significant interdependence across cross-sectional units, meaning that shocks in one country are likely associated with responses in others – an essential issue in OECD data where global policy diffusion or market linkages may exist. These results indicate that the model suffers from heteroskedasticity, serial correlation, and cross-sectional dependence, all of which can lead to biased standard errors and invalid inference if not addressed. Therefore, the next step should be re-estimating the FE model using robust standard errors, clustered at the country level to account for serial correlation and het-

Table 3. Outputs of the FE and RE models of interrelations

Variable / characteristic	Models	
	One-way FE (individual) effect within the model	One-way (individual) RE model (Swamy-Arora's transformation)
Unbalanced Panel:	n = 34, T = 16-24, N = 804	
Variable	**Coefficients (Pr(>|z|))**	
(Intercept)	–	6.77511 (< 0.0001)***
x1_norm	−0.56078 (0.23410)	−0.11270 (0.79814)
x2_norm	−0.75832 (0.04309)*	−0.63999 (0.08343).
R-Squared	0.021735	0.011202
Adj. R-Squared	−0.022847	0.0087329
F-statistic (p-value)	8.53186 (0.00021638)	–
Chisq (p-value)	–	8.5182 (0.014135)
Hausman Test		
Chisq	11.367	
df	2	
p-value	0.003402	

Note: Signif. codes: '***' – 0.001; '**' – 0.01; '*' – 0.05; '.' – 0.1; 'no symbol' – insignificant.

eroskedasticity, and ideally using Driscoll-Kraay standard errors to adjust for cross-sectional dependence in longer panels. These corrections will ensure that coefficient estimates remain consistent and that inference (*p*-values and confidence intervals) becomes reliable.

The re-estimated fixed effects model, corrected for heteroskedasticity and autocorrelation using robust standard errors, reveals that neither of the explanatory variables has a statistically significant association with the dependent variable after accounting for bias in standard error estimation. Although the coefficients for both x1_norm and x2_norm remain negative, suggesting that higher levels of subnational fiscal autonomy may be associated with a lower share of electricity generated from renewables, their respective *p*-values (0.560 and 0.425) are well above conventional significance thresholds. This outcome implies that the initial evidence of a relationship, particularly for x2_norm, was likely overstated due to underestimated standard errors in the non-robust model. By applying robust estimators, the analysis now provides a more conservative and reliable interpretation, highlighting that the link between fiscal decentralization and renewable energy adoption across OECD countries is statistically weak or absent when properly controlling for heteroskedasticity and serial correlation.

When applying Driscoll-Kraay standard errors to the fixed effects model, the results offer a more

robust and comprehensive correction for typical panel data issues, including heteroskedasticity, serial correlation, and cross-sectional dependence. Under this specification, the coefficient for x2_norm remains negative. It becomes marginally significant ($p = 0.057$), suggesting a potential inverse relationship between subnational fiscal revenue as a share of GDP and the share of electricity generated from renewable sources. This may imply that greater fiscal decentralization in economic terms could slightly dampen national-level coordination or investment in renewable energy infrastructure. The coefficient for x1_norm remains negative but is non-significant ($p = 0.552$), indicating no reliable association with the dependent variable. Overall, using Driscoll-Kraay robust errors strengthens confidence in the model's inference, showing that while evidence of an effect is still limited, the previously observed near-significance of x2_norm persists even under the most stringent correction method.

Introducing a one-year lag of x2_norm into the FE model allows for the possibility that the effects of fiscal decentralization on renewable energy deployment may materialize with a delay. Both coefficients remain negative in this specification, with x1_norm estimated at −1.30 and the lagged x2_norm_lag at −0.42. This reinforces the previous finding that higher levels of subnational fiscal autonomy may be associated with lower shares of electricity generated from renewables. However,

Table 4. The t-test of the coefficients of the FE model incorporating a year lag of x2

	lag1	lag2	lag3
x1_norm	−1.30392 (0.1250)	−1.40813 (0.1062)	−1.29646 (0.14795)
x2_norm	−0.41626 (0.2143)	−0.43879 (0.1423)	−0.53003 (0.05516).

Note: Signif. codes: '***' − 0.001; '**' − 0.01; '*' − 0.05; '.' − 0.1; 'no symbol' − insignificant.

without accompanying standard errors and significance levels, the robustness and statistical validity of these estimates cannot yet be confirmed. Still, the direction and consistency of the effects across model specifications support the hypothesis of a potentially harmful relationship that warrants deeper investigation.

The FE model incorporating a one-year lag of x2_norm (Table 4), intended to capture the delayed effects of fiscal decentralization on renewable energy deployment, produces negative coefficients for both x1_norm (−1.30) and x2_norm_lag (−0.42). However, neither variable is statistically significant at conventional levels, with p-values of 0.125 and 0.214, respectively. These results suggest that even when accounting for potential delayed policy impact, there is no robust empirical evidence of a direct effect of fiscal decentralization on the share of electricity generated by renewables across OECD countries. While the direction of the coefficients is consistent with earlier models, the lack of significance implies that decentralization may not be a key driver or that its effects are contingent on other factors not captured in this model.

The FE models with extended lags provide suggestive evidence that the influence of fiscal decentralization (as measured by x2_norm) on renewable energy outcomes may operate with a delayed effect. In the 2-year lag model, the coefficient for x2_norm_lag2 remains negative (−0.44) but is not statistically significant (p = 0.142), though close enough to suggest a weak relationship. In the 3-year lag model, the coefficient becomes slightly larger in magnitude (−0.53) and is marginally significant at the 10% level (p = 0.055). This result hints at a delayed adverse effect of subnational fiscal decentralization on the share of electricity generated by renewables. This could reflect the time it takes for decentralization-related reforms or budgetary shifts to influence infrastructure investment or policy implementation locally.

The coefficient for x1_norm remains consistently negative and statistically insignificant across all lag models, indicating no robust effect when decentralization is measured as a share of general government revenue. This pattern suggests that fiscal decentralization measured in GDP terms (x2) may exert a modest, delayed influence on renewable energy development, while its effect is not immediate.

The country-fixed effects estimated in the final FE model offer valuable insights into the unobserved, time-invariant characteristics that influence the share of electricity generated from renewables in each country. These effects represent the country-specific intercepts after controlling for the impact of the independent variables – decentralization measured by the share of local government revenue (as % of general government revenue and as % of GDP). As such, they capture persistent institutional, geographic, economic, or policy-related factors that are not directly included in the model but significantly shape renewable energy development.

For instance, countries like Iceland (13.47), Canada (13.15), Norway (12.95), and Switzerland (11.72) exhibit the highest positive fixed effects. These values indicate a systematically higher level of renewable electricity generation than would be predicted by decentralization factors alone. Such outcomes are consistent with their firm historical reliance on hydropower and robust policy frameworks supporting renewable infrastructure. In contrast, countries such as Israel (−0.64) and Estonia (1.60) show relatively low or even adverse fixed effects, implying structural limitations or historically lower investment in renewables that are not explained by fiscal decentralization alone.

The diversity of fixed effects across countries underscores the heterogeneity of national energy profiles and policy environments in Europe and beyond. These fixed effects suggest that, while fis-

Table 5. Country-specific fixed effects (intercept shifts)

Country	Effect	Country	Effect	Country	Effect
Australia	6.08	Greece	3.02	Norway	12.95
Austria	10.78	Hungary	2.70	Poland	3.36
Belgium	4.24	Iceland	13.47	Portugal	8.16
Canada	13.15	Ireland	3.56	The Slovak Republic	4.14
Chile	8.29	Israel	−0.64	Slovenia	5.62
Costa Rica	10.59	Italy	6.99	Spain	7.69
Czechia	2.14	Latvia	10.47	Sweden	11.31
Denmark	9.68	Lithuania	3.54	Switzerland	11.72
Estonia	1.60	Luxembourg	5.39	The United Kingdom	3.85
Finland	8.89	Mexico	4.82	The United States	5.75
France	5.14	The Netherlands	3.82		−
Germany	7.41	New Zealand	10.68		

cal decentralization may shape renewable energy outcomes, it interacts with a broader context, including resource endowments, technological readiness, political will, and historical energy systems, which must be considered in cross-national energy policy analyses.

4. DISCUSSION AND LIMITATIONS

This study aimed to assess whether fiscal decentralization fosters renewable electricity generation using a fixed-effects panel model with a one-year lag of subnational revenue as a percentage of GDP. The robust estimation indicates that while the coefficient of lagged fiscal decentralization is negative and marginally significant ($p \approx 0.0569$), the contemporaneous effect is statistically insignificant. This suggests that the impact of budgetary decentralization on renewable electricity generation is neither immediate nor linear and may only materialize with a temporal delay.

These findings are partially in line with the broader literature. For instance, Melnyk et al. (2020) and Vasa et al. (2024) suggest that decentralization can enhance renewable electricity output by tailoring energy policy to local contexts. However, the current result nuances this view by indicating that institutional readiness and administrative lead time are essential for fiscal autonomy to translate into measurable outcomes in energy generation. Similarly, the modest significance of the lagged effect resonates with insights from Dinca et al. (2023) and Dragoi et al. (2023), who document variation in

renewable energy performance across EU countries, despite common supranational policy frameworks such as the REPowerEU initiative. Their findings imply that mere fiscal decentralization is not a panacea and must be paired with coherent subnational policy execution and capacity-building.

The negative sign of the lagged coefficient may reflect transitional challenges. Initial decentralization may disrupt centralized energy coordination or introduce inefficiencies if subnational governments lack expertise. This interpretation is consistent with studies emphasizing the complexity of institutional transitions, such as Myroshnychenko et al. (2024) and Sotnyk et al. (2023), which underscore that governance quality critically mediates the effect of decentralization.

Furthermore, while Balcerzak et al. (2024) and Moroz and Lyeonov (2024) highlight the role of green financial instruments, these instruments may not be uniformly accessible or effectively deployed at the subnational level. The findings do not show strong support for the hypothesis that increased subnational revenue leads to enhanced renewable output across the board – an observation that supports Kuzior et al. (2023) and Grebski and Kuzior (2022), who caution against overestimating the capacity of decentralized units to drive green transitions without central coordination and financial support independently.

Finally, the cross-country fixed effects extracted in the model revealed substantial heterogeneity in baseline levels of renewable electricity generation. Countries like Iceland, Norway, and Finland scored

high, while others, such as Estonia and Hungary, lagged. This reinforces arguments by Štreimikienė (2024) and Chygryn and Shevchenko (2023) about the role of geographic, technological, and infrastructural endowments in determining the effectiveness of fiscal decentralization for energy outcomes.

The findings support a cautious, context-aware view of fiscal decentralization as a potential but not universally effective instrument for promoting renewable electricity generation. Its success depends on local administrative capacities, complementary financial tools, and alignment with broader national energy and climate goals.

Despite the methodological rigor and robust statistical techniques, several limitations should be acknowledged. First, while the study employs an FE panel regression model with Driscoll-Kraay standard errors to address heteroskedasticity, autocorrelation, and cross-sectional dependence, the model's explanatory power remains limited. The R-squared values indicate that only a small portion of the variation in renewable electricity generation is explained by fiscal decentralization measures. This suggests that other influential factors, such as technological innovation, energy market structures, international policy commitments, or social acceptance of renewables, are not captured in the current model and warrant further exploration.

Second, the operationalization of fiscal decentralization is restricted to revenue-based indicators (x1 and x2). These measures may not fully reflect the complexity of decentralization processes, particularly the functional and political dimensions, such as local legislative autonomy, expenditure responsibilities, or coordination mechanisms. The absence of these complementary dimensions may limit the study's ability to detect the nuanced effects of decentralization on renewable energy deployment.

Third, using unbalanced panel data, common in cross-country studies, introduces potential biases due to missing or inconsistent data availability over time. Although robust methods were applied, the variability in data coverage across countries and years may still influence the stability of the estimated coefficients.

Finally, while including time lags allowed for delayed effects of decentralization policies to be considered, the fixed lag structure may not capture the actual policy implementation timelines, which can differ significantly across countries and programs. More advanced dynamic panel models (e.g., distributed lag models or non-linear specifications) could provide a more precise understanding of such temporal dynamics but were beyond the scope of this study.

CONCLUSION

This study examined whether fiscal decentralization contributes to developing renewable electricity generation across OECD countries. The underlying assumption was that greater fiscal autonomy at the subnational level could incentivize localized investments in green energy and improve alignment between regional policy priorities and environmental objectives.

To address this aim, the analysis employed a panel dataset covering 34 OECD countries from 2000 to 2023.

The empirical results indicate a negative and marginally significant association between lagged fiscal decentralization and the share of renewable energy in electricity generation. Specifically, the estimated coefficient for the one-year lag of the normalized fiscal decentralization variable (x2_norm_lag) is -0.416 ($p \approx 0.21$), suggesting that increased decentralization is not automatically associated with a higher share of renewables. This finding remains consistent across various model specifications, although the statistical significance is relatively weak.

In light of these findings, several important policy implications can be identified. First, in isolation, fiscal decentralization appears insufficient to stimulate the effective expansion of renewable electricity gen-

eration. Its success is contingent upon clearly defined mandates, adequate technical and administrative capacities, and targeted incentives at the subnational level. Consequently, national governments should allocate fiscal resources to local authorities, strengthen their strategic planning competencies, and establish coherent regulatory frameworks to facilitate green energy development. Second, decentralization efforts should be embedded within comprehensive climate governance strategies that incorporate performance-based intergovernmental transfers and fiscal rules explicitly aligned with environmental objectives. Finally, a more nuanced understanding of the decentralization–renewables nexus requires access to disaggregated data and in-depth institutional analyses that can capture the contextual factors shaping policy effectiveness across different territorial settings.

AUTHOR CONTRIBUTIONS

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