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How Does Trade Openness Impact Energy Transition Under Different Fiscal Policy and Technological Capability?

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This study examines how trade and fiscal policies affect renewable electricity generation in 30 major economies. The analysis demonstrates that while import intensity promotes renewable electricity generation, export intensity has an insignificant impact. In terms of fiscal policy, fossil fuel subsidies hinder, whereas tax revenues support, the development of renewable electricity generation. Furthermore, both economic and technological capabilities play a positive role in supporting renewable electricity generation. The study also cautions that trade conflicts may impede the pace of the global energy transition.

I. Introduction

This study investigates how trade and fiscal policies influence renewable electricity generation across 30 leading economies. We posit that imports, rather than exports, serve as the primary driver of renewable electricity expansion, as renewable deployment depends on access to rare minerals, advanced technologies, and intermediate inputs sourced from global markets. This argument builds on the theory of trade-facilitated technology transfer (Grossman & Helpman, 1991), which identifies imports as key channels for knowledge diffusion and innovation spillovers.

The positive impact of imports on renewable electricity generation is further strengthened when countries possess sound fiscal capacity and robust technological capabilities. Conversely, fossil fuel subsidies tend to impede, while higher tax revenues promote, renewable energy development. This integrated perspective highlights the structural and interactive mechanisms through which trade, fiscal, and technological factors collectively advance the energy transition, while also explaining how trade disruptions or deglobalisation may expose economies to significant vulnerabilities. Supporting this view, Zhang et al. (2021) and Shi & Yu (2024) found nonlinear relationships between trade flows and renewable electricity generation across 35 OECD countries, indicating that trade conflicts and deglobalisation could slow the progress of global renewable transitions.

The quality and composition of trade further shape these outcomes. Zhang et al. (2025) finds that international trade

enhances renewable energy efficiency, particularly in economies with strong human capital, while Khan et al. (2020) identifies nonlinear patterns, such as inverted U- or N-shaped relationships, between trade and renewable energy. Economic factors like rising oil prices and income growth generally support renewable electricity generation; however, manufacturing-intensive economies remain reliant on fossil fuels (Magazzino & Giolli, 2024; Qing et al., 2024). Among emerging economies, trade openness promotes renewable adoption in BRICS nations but does not fully mitigate emission pressures (Li et al., 2024). In MINT countries, macroeconomic conditions exert mixed influences on renewable generation (Suleman et al., 2025).

Despite these contributions, existing research remains limited in several respects. First, most studies treat trade openness as a single measure, neglecting the distinct roles of imports and exports. Second, few have investigated the joint influence of trade and fiscal policies on renewable electricity generation. Third, the contribution of technological capability, proxied by renewable energy patents, has received insufficient attention. Addressing these gaps, this study examines how macroeconomic factors, including import and export intensity, fiscal policies (fossil fuel subsidies, tax revenue, and production and sales taxes), technological capability, economic capacity (per capita GNI), and natural resource rents, shape renewable electricity generation across 30 major economies. The findings show that import intensity significantly enhances renewable genera-

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tion, even after accounting for fiscal, technological, and resource-related variables.

II. Data and Methodology

A. Data

Our analysis employs the following indicators: the share of renewable electricity generation in total electricity generation for country i at time t ($SRETEG_{it}$), total imports as percentage of GDP ($Import\%GDP_{it}$), total exports as percentage of GDP ($Export\%GDP_{it}$), total fuel imports as percentage of GDP ($FuelIMPORT\%TOTALIMPORT_{it}$), total fossil fuel subsidy as percentage of GDP ($TFFS\%GDP_{it}$), tax revenue as percentage of GDP ($TR\%GDP_{it}$), tax on sales and production as a percentage of GDP ($TSP\%GDP_{it}$), rent from natural resources as a percentage of GDP ($RNR\%GDP_{it}$), the natural logarithm of GNI per capita at current international dollars ($\ln_GNIPC_{it}$), and the natural logarithm of patents in renewable energy ($\ln_PTREN_{it}$). Data for $SRETEG$ and $TFFS\%GDP$ are obtained from the IMF Climate Change Dashboard; $TR\%GDP$ and $TSP\%GDP$ from the IMF World Revenue Longitudinal Database; $Import\%GDP$, $Export\%GDP$, $FuelIMPORT\%TOTALIMPORT$, and GNI per capita from the World Bank; and $PTREN$ from IRENA's Patents Evolution Database.

B. Methodology

The study applies the Driscoll–Kraay standard error (DKSE) model to ensure robust inference. We first determine the appropriate panel specification by comparing fixed effects (FE) and random effects (RE) models. The Hausman test ($Prob > \chi^2 = 0.0123$) favours the FE specification, indicating that unobserved country-specific effects are correlated with the explanatory variables. Diagnostic tests reveal the presence of heteroskedasticity, autocorrelation, and cross-sectional dependence. To correct for these issues, the regression is estimated using Driscoll–Kraay standard errors, which are robust to all three forms of misspecification. The regression equation is specified as follows:

$$\begin{aligned} SRETEG_{it} = & \beta_0 + \beta_1 Import\%GDP_{it} + \beta_2 Export\%GDP_{it} \\ & + \beta_3 FuelIMPORT\%TOTALIMPORT_{it} \\ & + \beta_4 TFFS\%GDP_{it} + \beta_5 TR\%GDP_{it} \\ & + \beta_6 TSP\%GDP_{it} + \beta_7 RNR\%GDP_{it} \\ & + \beta_8 \ln(GNIPC_{it}) + \beta_9 \ln_PTREN_{it} \\ & + \beta_{10} COVID_{it} + \alpha_i + \varepsilon_{it} \end{aligned} \quad (1)$$

here, the subscripts i and t denote country i at time t , β represents the regression coefficient, α_i is country specific effect, and ε_{it} is the error term.

This specification incorporates the influence of trade relations (imports, exports, and fuel import reliance), fiscal policy (fossil fuel subsidies, tax revenue, and sales and production taxes), economic capacity (GNI per capita), and technological capability (renewable energy patents) in determining renewable electricity generation. Employing the DKSE makes the estimates robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, thereby providing more reliable inference. All explanatory variables

are expressed for country i in year t , and the fixed effects term, μ_i , accounts for unobserved heterogeneity.

Our static empirical model excludes a lagged dependent variable that could reflect persistence in energy investment. While dynamic panels are common in transition studies, our short time span ($T = 8$) risks the Nickell bias. We therefore rely on the Driscoll–Kraay estimator for more robust inference, while noting that future work with longer panels should incorporate dynamic persistence.

III. Results

[Table 1](#) presents an overview of the indicators used in our analysis for 30 major economies in 2022. This highlights wide disparities in renewable electricity generation, trade openness, and fossil fuel dependence. Sweden and Switzerland record the highest renewable electricity generation, while Saudi Arabia and Indonesia show the lowest. Trade openness is greatest in Singapore, Belgium, and Ireland. India and Japan exhibit the highest fuel import dependence, whereas Russia and Saudi Arabia rely least on imports. Resource rents are highest in Saudi Arabia and Russia but minimal in Europe. Advanced economies like Switzerland and the United States have high income and patent intensity, contrasting with lower values in India and Indonesia. Advanced economies report higher renewable patents, reflecting stronger technological capability.

[Table 2](#) presents the results of the Fixed Effects model with Driscoll–Kraay standard error (DKSE) panel regression, and [Table 3](#) presents the diagnostic test results for the FE model. The findings offer a nuanced view of how trade and fiscal policy shape renewable electricity generation after controlling for factors such as economic and technological capacity, dependence on natural resource rents, and the effects of COVID-19. Imports as a share of GDP exert a moderately positive and significant effect, highlighting that countries engaged in global markets benefit from improved access to technologies and intermediate goods. However, the modest economic effect serves as a supportive enabler rather than the main driver of renewable electricity generation. By contrast, the possible reason for insignificant exports may be that trade is dominated by fossil-intensive products, which can divert resources away from renewables, thereby weakening any positive trade-driven impact on renewable electricity generation. Fossil fuel imports do not have a significant impact on renewable electricity generation.

Fiscal determinants such as fossil fuel subsidies discourage renewable electricity generation, confirming their distortionary effect on clean energy investments and underscoring the need for subsidy reform. Other fiscal factors, such as tax revenue, positively influence renewable electricity generation, whereas sales and production taxes reduce renewable electricity generation.

Natural resource rents are insignificant, suggesting that resource dependence alone is not harmful. In contrast, the economic capacity of a country, measured through per capita GNI, and indigenous technological capability, measured by renewable patents, support renewable electricity generation. This implies that wealthier countries have

Table 1. Overview of data for 30 major economies in year 2022

Country Name	SRETEG	Import% GDP	Export% GDP	FuelIMPOR T%TOTAL IMPORT	TFFS%GDP	TR%GDP	TSP%GDP	RNR%GDP	ln_GNIPC	ln_PTREN
Argentina	0.31	15.30	16.25	15.69	8.85	21.59	11.42	2.65	10.28	5.46
Australia	0.31	20.29	25.53	15.29	2.87	27.52	7.22	13.36	11.05	8.32
Austria	0.79	62.42	61.96	12.61	1.46	28.22	11.88	0.12	11.17	3.89
Belgium	0.50	96.70	95.24	25.48	2.25	29.71	11.68	0.04	11.15	3.69
Brazil	0.91	19.19	19.63	17.78	3.20	24.67	13.19	7.94	9.87	6.81
Canada	0.80	33.37	33.94	7.89	1.98	28.40	7.07	4.95	11.02	8.34
China	0.32	17.14	20.30	20.63	12.46	13.86	5.44	1.71	10.01	13.89
France	0.66	39.29	36.50	18.80	2.08	30.91	12.50	0.03	10.98	5.27
Germany	0.47	43.28	45.78	12.67	2.99	24.42	10.13	0.08	11.14	8.29
India	0.20	26.82	23.25	37.84	10.61	17.33	9.57	3.16	9.11	1.10
Indonesia	0.15	20.96	24.50	18.91	15.45	10.39	4.66	5.16	9.54	1.10
Ireland	0.39	95.45	136.68	9.28	0.59	17.22	5.88	0.10	11.47	1.10
Israel	0.09	29.26	31.39	13.62	1.28	27.08	11.91	0.44	10.85	7.14
Italy	0.35	36.92	35.10	21.40	2.80	29.01	11.85	0.11	10.94	4.08
Japan	0.24	25.27	21.55	28.34	5.84	21.98	7.60	0.05	10.82	10.34
Mexico	0.23	45.88	42.95	10.12	7.61	14.49	5.19	3.64	10.05	6.76
Netherlands	0.42	87.66	96.44	19.14	1.25	25.68	11.16	0.34	11.21	5.59
Poland	0.21	60.67	62.35	9.72	7.88	21.39	12.44	1.03	10.72	5.62
Russia	0.22	15.06	27.72	0.78	21.59	25.62	7.38	18.51	10.60	1.61
Saudi Arabia	0.01	20.84	35.99	7.52	27.01	7.90	6.14	25.57	11.03	4.47
Singapore	0.03	146.24	186.11	22.13	4.91	11.93	3.40	0.00	11.65	3.26
South Korea	0.10	48.26	48.27	29.90	8.05	18.32	4.90	0.05	10.87	10.12
Spain	0.54	38.87	39.76	19.22	1.71	24.59	11.04	0.12	10.80	6.09
Sweden	0.99	51.97	53.88	14.04	0.24	39.69	12.21	1.21	11.15	5.41
Switzerland	0.99	62.36	76.14	6.48	0.52	21.28	5.60	0.01	11.40	3.40
Thailand	0.20	67.49	65.37	20.12	15.38	15.78	8.77	1.82	9.98	3.33
Türkiye	0.40	42.59	38.58	8.72	11.32	16.37	8.21	0.83	10.54	2.71
United Arab Emirates	0.06	85.13	103.81	4.89	4.77	17.47	2.20	17.63	11.21	4.47
United Kingdom	0.50	35.31	33.57	16.90	2.31	28.98	11.88	0.59	10.95	7.11
United States	0.26	15.29	11.60	9.57	3.24	21.56	4.14	1.28	11.27	10.61

Note: This table represents data for 30 largest world economies for the variables used in this study. Because of the unavailability of patents data for country UAE, we have taken the patents data of Saudi Arabia. This substitution represents a data constraint that may reduce precision for the UAE. In addition, the eight years panel, though relevant for policy analysis, is relatively short for examining a gradual energy transition, potentially restricting the generalizability of long-term effects.

Table 2. Fixed effect with Driscoll Kraay standard error (DKSE) panel regression

Dependent Variable: Share of renewable electricity generation in total electricity generation (SRETEG)	
Variables	Coefficients
<i>Trade</i>	
<i>Import%GDP</i>	0.001**
<i>Export%GDP</i>	-0.001
<i>FuellImport%TotalImport</i>	-0.000
<i>Fiscal Policy</i>	
<i>TFFS%GDP</i>	-0.002**
<i>TR%GDP</i>	0.005**
<i>TSP%GDP</i>	-0.010**
<i>Other Variables</i>	
<i>RNR%GDP</i>	0.000
<i>Ln_GNIPC</i>	0.134***
<i>Ln_PTREN</i>	0.010***
<i>COVID_Dummy</i>	0.0336***
Constant	-1.190**
N	240
No. of countries	30
Mean dependent var	0.35
SD dependent var	0.28
R-squared	0.5212

Note: ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. This table presents the estimated coefficients from a fixed effects panel model for the period 2015–2022, utilising DKSE to account for cross-sectional dependence, heteroskedasticity, and autocorrelation. The dependent variable is the share of renewable electricity generation (*SRETEG*).

Table 3. Diagnostic Test results obtained using FE model

Test	Test Statistics	p-value
Heteroskedasticity (Modified Wald Test)	$x^2(30) = 2368.26$	0.0000
Autocorrelation (Wooldridge Test)	$F(1,29) = 9.563$	0.0044
Cross-sectional Dependence (Pesaran CD test)	$CD = 4.205$	0.0000

This table presents the diagnostic test results for the baseline fixed effects model. The significant *p*-values for heteroskedasticity, autocorrelation, and cross-sectional dependence confirm the presence of these issues in the error structure, thereby supporting the use of DKSE to ensure robust inference.

greater economic and technological capacity to invest in renewable infrastructure. Finally, the COVID-19 dummy shows a strong positive effect, likely reflecting a mix of targeted green stimulus initiatives, the closure of fossil fuel-based industries, a shift of investments toward sustainable sectors during the recovery, and operational advantages for renewables amid the demand shock.

IV. Conclusion

This paper seeks to identify the influence of trade and fiscal policy on renewable electricity generation, considering the varying economic and technological capacities of countries. The findings reveal that trade and fiscal factors play a crucial role in determining renewable electricity generation across nations. Imports, as a moderate driver, un-

derscore that international integration provides essential technologies and equipment, thereby accelerating renewable electricity generation in countries with limited production capacity. In contrast, the insignificance of exports suggests that renewable-related gains from trade are asymmetric and depend on the composition of traded goods. Regarding fiscal policy, fossil fuel subsidies and taxes on sales and production hinder renewable electricity generation, whereas a higher tax revenue capacity supports it. Other structural factors, such as higher income and indigenous technological capability in renewables, also promote renewable electricity generation. Collectively, the findings emphasise the need to reduce fossil fuel subsidies, utilise the imports option, and strengthen fiscal capacity to accelerate renewable electricity generation. Due to the limited number of years and the interchangeable use of patent

data in this analysis, the study suggests that future research should address these limitations and conduct regional-level analyses.

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