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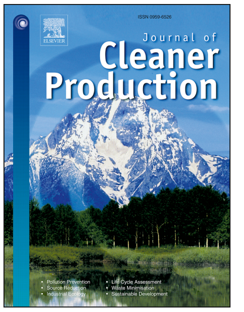

An empirical analysis of financial markets and instruments influencing the low-carbon electricity production transition

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ABSTRACT

This study focuses on Brazil, Russia, India, China and South Africa (BRICS countries), which contribute over 40% of global CO_2 emissions. Using panel co-integration tests, fully modified OLS and seemingly unrelated regressions, the study contributes to the literature by revealing that public debt securities foster the transition from fossil fuel electricity towards low-carbon electricity, whereas private credit is mostly profitless for electricity production transition. The explanation is that environmental pressure urges public capital to play a vital role in electricity transition, while bank loans are reluctant to leave the electricity from fossil fuel for considerable returns. The installed capacity of electricity stations drives the association between financial capital and electricity production. Financial markets in China and South Africa play a more significant role in electricity transition than the other countries. Low-carbon electricity transition requires transformation of financial markets in all these countries.

KEYWORDS

Low-carbon electricity transition; Financial markets; Panel co-integration tests; Fully modified OLS; Seemingly unrelated regressions

1. Introduction

Since 2007, over half of global greenhouse-gas emissions have stemmed from fossil fuel consumption (BP, 2018; Wang et al., 2019). Anthropogenic climate changes are projected, such as global warming and air pollution (IPCC, 2018; Dellink et al., 2019; Wang and Su, 2019). To achieve the 2°C targets set in the Paris Agreement, fossil fuel needs to be gradually replaced by low-carbon energy (Lilliestam et al., 2018) and low-carbon electricity generation can promote de-carbonization of energy sectors (Gao et al., 2019). Furthermore, energy supply security has suffered from trade disputes and increasing energy consumption (OPEC, 2017). This alerts countries to reduce reliance on fossil fuels and develop low-carbon electricity.

Electricity generation is dependent on financial markets, due to its capital-intensive characteristics. Developing new electricity infrastructure requires a large investment. From 2010 to 2019, investment has quadrupled the electricity-generating capacity of low-carbon energy, from 414GW to 1650GW. In 2018, investment in low-carbon electricity capacity was $272.9 billion, three times as much as investment in fossil fuel power generation (United Nations, 2019). The 2015 Paris Agreement has put finance at the heart of electricity transition (Kim and Park, 2016). It interests us to explore what role of financial markets play in electricity transition, and furthermore, which financial instruments facilitate or create challenges to the transition.

Literature concentrates on either fossil fuel or low-carbon electricity but seldom investigates the transition from fossil fuel electricity to low-carbon electricity. This study complements previous research by scrutinizing the latter question. First, we attempt to account for the mechanism through which financial instrument affects electricity generation. Second, we categorize financial and energy variables and study the differential impacts of various financial instruments on electricity transition. Third, it assembles a country-year panel data set of five countries from 1996 to 2015 and undertakes empirical analysis.

One of our contributions is the focus on the Brazil, Russia, India, China and South Africa (BRICS countries). The sample is important for three reasons. First, these countries are leaders of low-carbon electricity transition (United Nations, 2018). Despite investment in low-carbon electricity, these countries are heavily reliant on fossil fuel and contribute over 40% of global CO_2 emissions (Azevedo et al., 2018). They are vulnerable to energy shortages and pollution arising from fossil fuels (Vivoda, 2010). Second, these countries have developed energy sectors relying on domestic financial systems and energy enterprises. This stands in contrast to middle-eastern OPEC countries, which give production concessions to oil majors and outsource financing (Adelman, 1995). Third, the countries have their individual characteristics in low-carbon transformation. A comparative study of these five countries can explore these national differences (Wang and Zhang, 2020).

Due to energy security concerns, many countries tend to increase domestic low-carbon electricity to decrease fossil fuel dependence (OPEC, 2017). However, low-carbon electricity has long been impeded by a lack of access to finance (Shi, et al., 2018). Our second contribution is to investigate the impact of financial markets on low-carbon electricity, on account that financial markets act on electricity generation (Elliott, 2017). The present study makes the first attempt to reveal the nexus between financial markets and electricity transition, which has rarely been investigated. It further finds the installed capacity of electricity stations serves as a mechanism through which financial capital affects electricity production. Among the BRICS countries, only the financial markets in China and South Africa play a positive role in domestic transition from fossil fuel electricity towards low-carbon electricity.

This study makes the third contribution by identifying the nexus between financial instruments and electricity transition by using panel co-integration tests, fully modified OLS (FMOLS) and seemingly unrelated regressions (SUR). Our results imply that, for these five countries, issuing public debt securities fosters electricity transition, whereas issuing private debt hampers the transition. In other words, public capital has played a strong role in transition towards low-carbon electricity, however private capital still favors traditional fossil fuels.

The remainder of the article proceeds as follows. Section 2 reviews the literature pertaining to the relationship between financial development and energy production. Section 3 describes variables, data and model specification. Section 4 presents estimation strategies and empirical results. Section 5 concludes the study and discusses the policy implications.

2. Literature review

The effects of financial markets on electricity transition is a topical issue that has yet to be investigated. Traditionally, electricity industry finance stems mainly from bank credit and government support. In 1930s, project finance emerged for the oil industry. This financing method distributing risks promoted the expansion of the electricity industry (Thumann and Woodroof, 2009). With financial markets development, public listings, issuing of bonds and venture capital have come to the fore as sources of capital for electricity enterprises (Pan and Yang, 2019).

Despite the rapid growth of low-carbon energy, its share in total energy production remains relatively small (Klemeš et al., 2013; Su and Thomson, 2016; US Energy Information Administration, 2018). The transition towards low-carbon electricity requires substantial financial resources (Campiglio, 2016). Governments have used various financial channels and instruments to accelerate the development of low-carbon electricity generation. The literature is not silent on the role of financial markets in electricity generation.

Supply-side studies analyze the production function and technology changes. Ohler and Fetters (2014) and Best (2017) examine the relation between renewable electricity generation and financial and economic development. They discover that countries with larger stocks of financial capital are inclined to produce capital-intensive energy. Ji and Zhang (2019) view financial markets as a critical factor restricting China's energy industry. They estimate the contribution of financial capital to renewable energy growth to be 42%. Financial markets is the most important factor in renewable energy development, followed by foreign investment.

Further studies examine the relation between financial markets and the deployment of renewable energy technologies. Sisodia et al. (2016) find bank investment in non-OECD countries significantly supports the improvement of renewable energy technologies. Kim and Park (2016) investigate 15 developing countries and 15 developed countries. In 15 developed countries with well-developed financial markets, their renewable sectors that count more on debt and equity financing are growing faster than those in 15 developing countries. Ji et al. (2020) discover that investment banks are of importance to narrow the financing gaps of low-carbon energy projects. Deleidi et al. (2020) evaluates the effects of technological changes on renewable energy investment, concluding that technological progress does attract more investment.

Despite the growing literature, evidence of the role played by financial markets in low-carbon electricity transition is inconclusive. This is compounded by the fact that most research proceeds on either fossil fuel electricity generation or low-carbon electricity generation, rarely making comparison to study low-carbon electricity transition. It is of great policy significance to understand how financial markets contribute to the transition. Existing studies do not give appropriate identification on the mechanisms through which financial markets influence the structure of electricity generation. The present study aims to address this gap.

3. Data and model

3.1. Variable description

This study utilizes panel data of Brazil, Russia, India, China and South Africa from 1996 to 2015. The main variables are electricity generation, financial capital, GDP and installed electricity capacity. Control variables include gross fixed capital formation, trade, fossil fuel energy reserves and uranium reserves. All variables are based on the literature stated in the following paragraphs. The study defines electricity generation per capita as the dependent variable and classifies it into two categories: fossil fuel electricity and low-carbon electricity (electricity from nuclear, solar, tide, wind, geothermal, biofuels and waste). It excludes hydroelectricity from low-carbon electricity, first considering that reservoir water releases a large amount of carbon dioxide, methane and other greenhouse gases (Song et al., 2018). Second, water-abundant countries have exploited hydro energy because its electricity generation cost is lower than that of fossil fuel. This is not true for water-shortage countries (Bahmani et al., 2020). In addition to hydroelectricity, biofuel and organic waste also release greenhouse gases. The carbon dioxide released by burning biofuel and organic waste is roughly equivalent to the carbon dioxide absorbed by photosynthesis during their growth. The net carbon dioxide emissions of burning biofuel and organic waste are approximately equal to 0. Thus, different from hydroelectricity, biofuels and waste are low-carbon to mitigate the greenhouse effect (Aracil et al., 2017).

The independent variables are financial capital and real GDP. Financial variables include private credit by banks and other financial institutions, private debt securities, public debt securities and stock market capitalization (Sun and Wang, 2014). Since lack of access to finance is a prevailing challenge for low-carbon electricity development (Sovacool et al., 2016), the support of financial markets in sustainable electricity transition is instrumental (Alam et al., 2017). For most countries, the banking sector is the major financing source for electricity investments, and capital markets provide a secondary source of funding. Expansion of financial markets enhances competition and lowers the cost of capital (Acharya et al., 2017). Electricity producers gain access to financial support more easily and cheaply. Especially for capital-intensive electricity production, a shortage of funds will push up financing costs and render some electricity projects unviable (IEA, 2014). Countries ascend an energy ladder as their per capita incomes improve. Economic development can led to a shift from fossil fuel to nuclear and other low-carbon energies (Burke, 2013; Wang et al., 2018).

Installed capacity is the quantity of generator sets multiplied by the average power generation per hour per generator. It is a key indicator reflecting the scale of power station (quantity) and power production capacity (quality). Electricity producers get access to financing and influence the electricity production through expanding the installed capacity of power stations (Zhang et al., 2019). Thus, installed capacity could be a mechanism through which financial markets influence electricity production.

We define A_{jit} as the quality of machine of type i used in electricity sector j$\in \{l, f\}$ (l:

low-carbon electricity; f: fossil fuel electricity) at time t, which implies productivity of each sector. A_{ft} corresponds to fossil fuel electricity technologies, while A_{lt} represents low-carbon electricity technologies. x_{jit} is the quantity of machinery. A_{jit} and x_{jit} are functions of invested financial capital K:

$$A_{jit} = B_1 K^{\theta} \ and \ x_{jit} = B_2 K^{1-\theta} \quad (1)$$

where B_1, B_2 denote the efficiency of funding for improving the quality and quantity of machines for energy production. θ is the share of financial capital for improving the quality of machines, and 1-θ is the share of financial capital for enlarging the scale of machinery. Investors determine how to allocate endowment K between low-carbon electricity and fossil fuel electricity.

As for control variables, trade (the aggregate of goods and service trade) promotes the transfer of skilled labor, capital, technology and materials, and thereby enhances low-carbon electricity technological development (Deleidi et al., 2020). Gross fixed capital formation refers to the level of physical infrastructure and assets. The more developed the physical infrastructural assets are, the better and faster the electricity develops (Hu et al., 2014). Energy resource endowment is the most basic factor affecting electricity production (Sheng et al., 2014). The theoretical framework is shown in Figure 1.

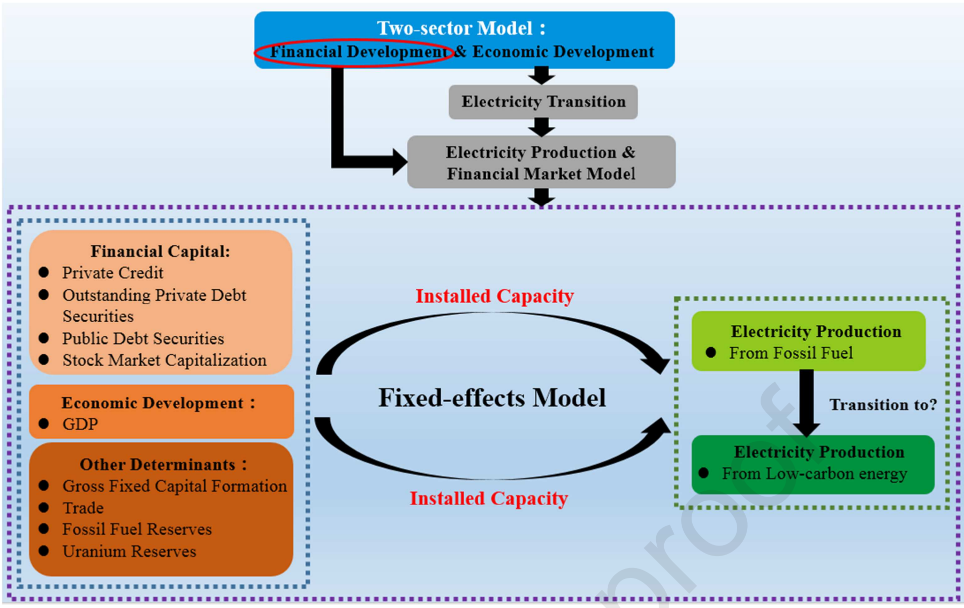


Figure 1. Theoretical framework.

3.2. Empirical model

Electricity producers increase electricity supply through expanding the installed capacity of power stations, which requires access to financing. We investigate the role of financial markets on electricity production transition. Following Kao et al. (1999), the fixed effects model is:

$$energy_{sit} = \beta_1 + \beta_2 private\ credit_{it} + \beta_3 private\ debt\ securities_{it} + \beta_4 public\ debt\ securities_{it} + \beta_5 stock\ market\ capitalization_{it} + \beta_6 gdp_{it} + \beta_7 installed\ capacity_{it} + \beta_8 X_{sit} + u_{i,t} + \varphi_{it} \quad (2)$$

The subscripts *s*, *i*, and *t* denote electricity type (fossil fuel or low-carbon electricity), country and time period, respectively. The explanatory variables include private credit, outstanding private debt securities, public debt securities, stock market capitalization, GDP and installed capacity. X_{sit} is a vector of control variables: capital stock, trade, oil reserves, coal reserves, natural gas reserves, and uranium proven reserves. $u_{i,t}$ indicates country fixed effects and time fixed effects for non-observational purposes. φ_{it} is the error term with $E(\varphi_{it}) = 0$, representing factors not included in the model but affecting electricity production.

3.3. Data and descriptive statistics

Figure 2 depicts the electricity production mix (the proportion of total electricity) of the five countries in 2015. As the figure depicts, fossil fuel electricity generation still dominates the electricity structure of the countries. However, this does not infer they have not made a substantial effort towards electricity transition over the past decades.

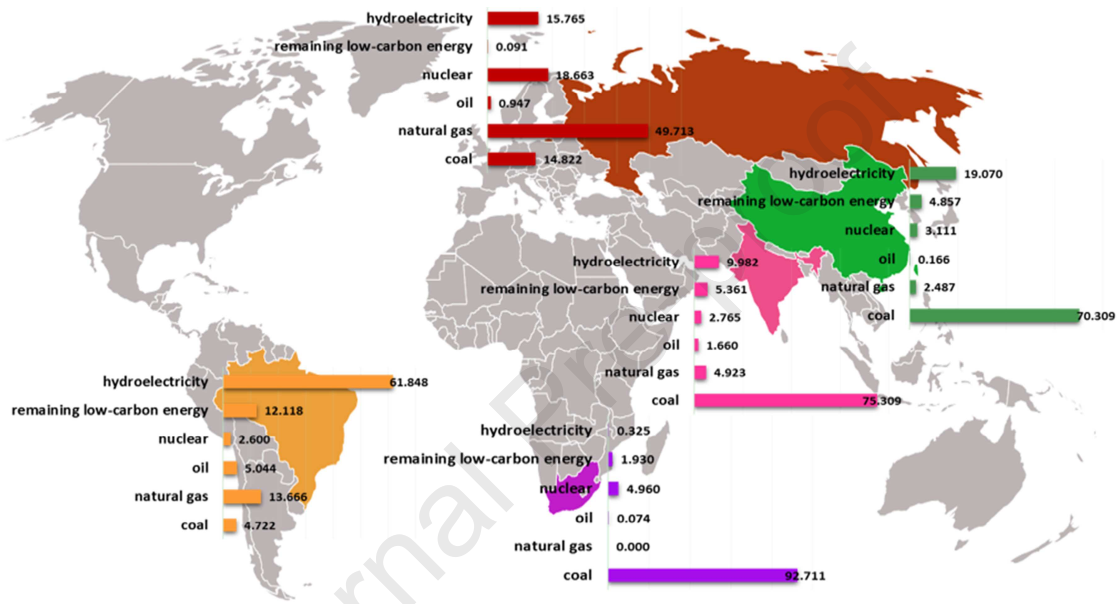
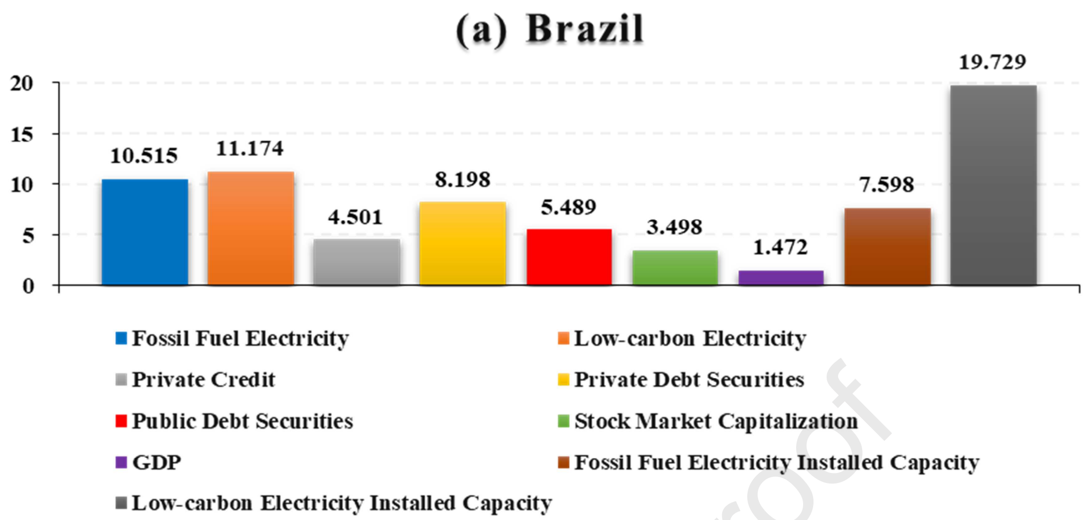
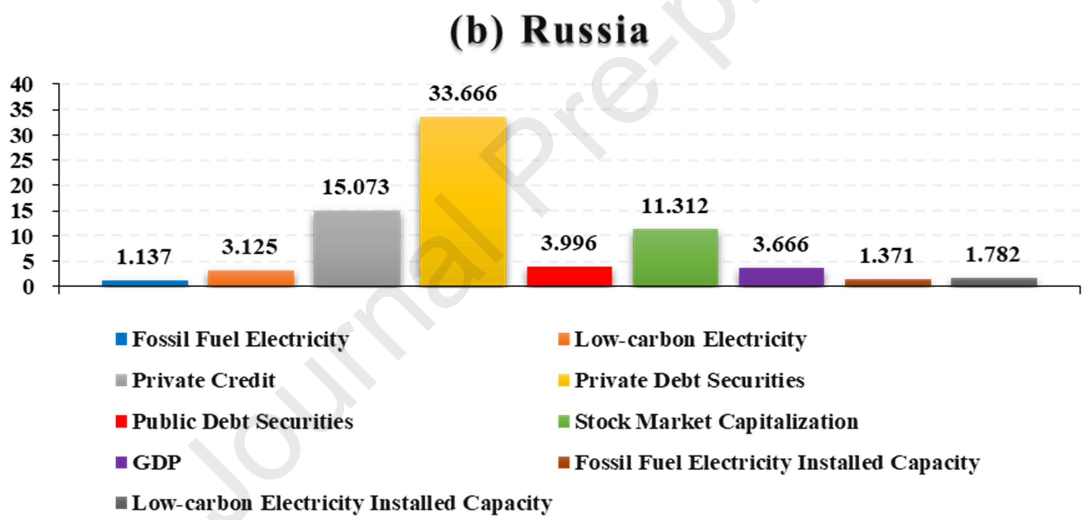


Figure 2. Proportion of total electricity production in the five countries (2015).
Data source: World Bank, World Development Indicators 2018.

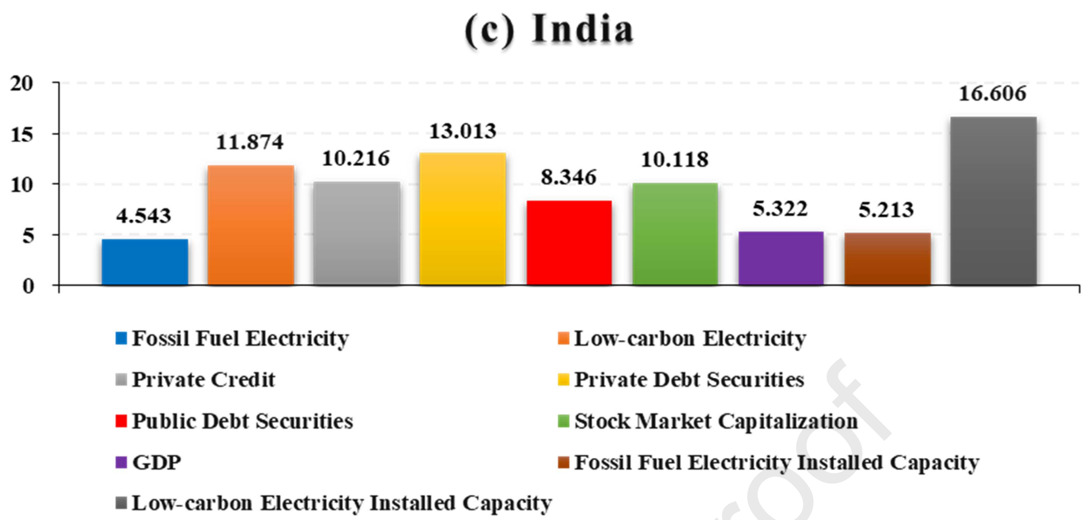
Figure 3 shows the average growth rates per annum of main variables. Heterogeneity exists across countries for these statistics. The annual growth rate of low-carbon electricity generation is higher than that of fossil fuel electricity for each country. Similarly, the annual growth rate of low-carbon electricity installed capacity also exceeds that of fossil fuel electricity installed capacity for each country. Particularly for South Africa, the annual growth rate of fossil fuel electricity production and installed capacity are negative. For all countries, the annual growth rates of the four types of financial capital are positive and high, implying financial markets are in rapid development.

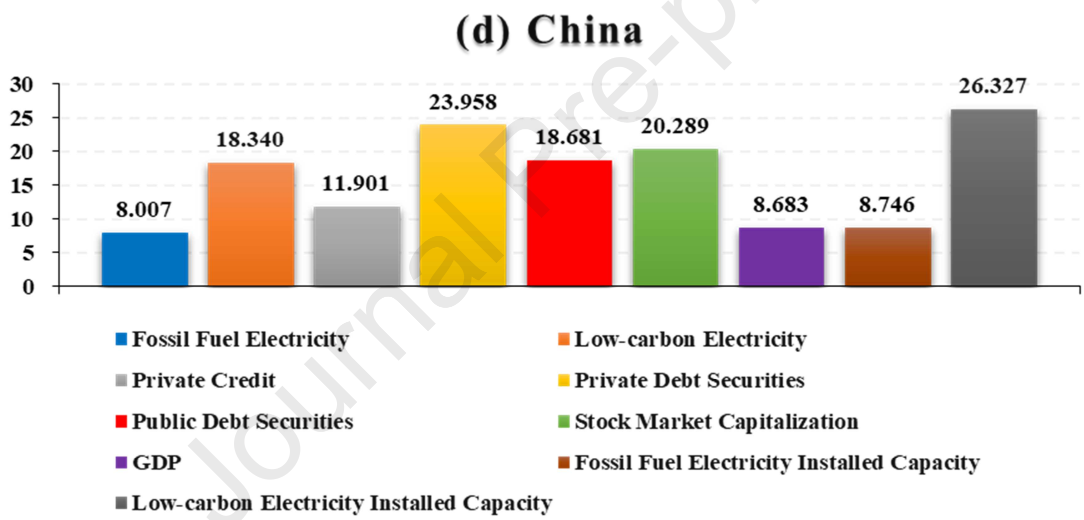

(a) Brazil
20
15
10
5
0
10.515
11.174
4.501
8.198
5.489
3.498
1.472
7.598
19.729
Fossil Fuel Electricity
Low-carbon Electricity
Private Credit
Private Debt Securities
Public Debt Securities
Stock Market Capitalization
GDP
Fossil Fuel Electricity Installed Capacity
Low-carbon Electricity Installed Capacity

207


(b) Russia
40
35
30
25
20
15
10
5
0
1.137
3.125
15.073
33.666
3.996
11.312
3.666
1.371
1.782
Fossil Fuel Electricity
Low-carbon Electricity
Private Credit
Private Debt Securities
Public Debt Securities
Stock Market Capitalization
GDP
Fossil Fuel Electricity Installed Capacity
Low-carbon Electricity Installed Capacity

208


(c) India
20
15
10
5
0
4.543
11.874
10.216
13.013
8.346
10.118
5.322
5.213
16.606
Fossil Fuel Electricity
Low-carbon Electricity
Private Credit
Private Debt Securities
Public Debt Securities
Stock Market Capitalization
GDP
Fossil Fuel Electricity Installed Capacity
Low-carbon Electricity Installed Capacity


(d) China
30
25
20
15
10
5
0
8.007
18.340
11.901
23.958
18.681
20.289
8.683
8.746
26.327
Fossil Fuel Electricity
Low-carbon Electricity
Private Credit
Private Debt Securities
Public Debt Securities
Stock Market Capitalization
GDP
Fossil Fuel Electricity Installed Capacity
Low-carbon Electricity Installed Capacity

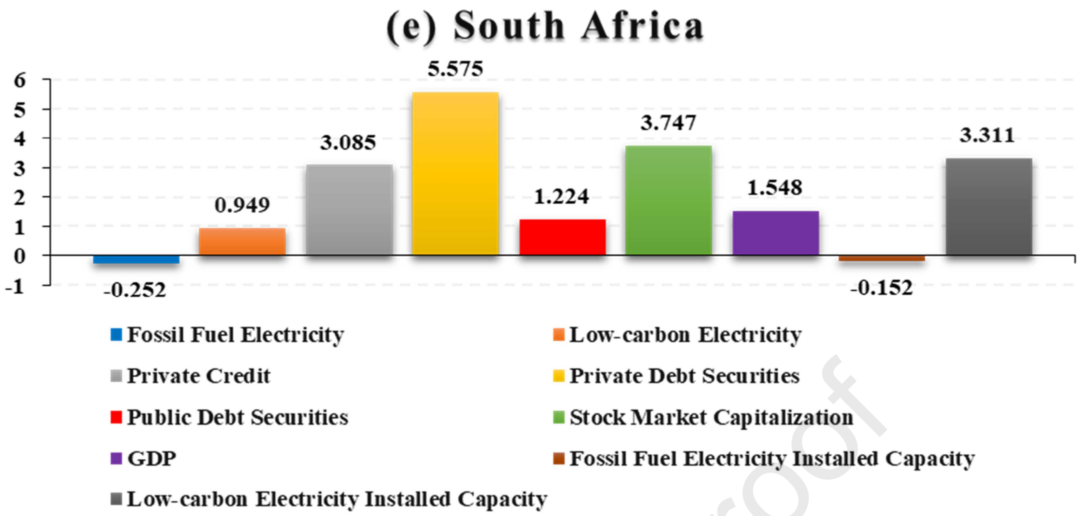


Figure 3. Annual average growth rate of main variables from 1996 to 2015 (%).
Data source: World Bank, World Development Indicators (2018) and GFDD (2018).

Table 1 lists variables in the model. We divide the total value of all the variables by the respective total population to get per capita units. Data on population are from the World Development Indicators (World Bank, 2018). Next, we take the logarithm of all variables for empirical analysis. Logarithmic transformation not only enables the estimated coefficients to be interpreted as elasticities, but also helps control for heteroscedasticity (as logarithmic transformations can resolve or narrow differences between variables associated with their units of measure). Table 2 presents descriptive statistics for all the variables.

Table 1. Variables and data source.

Variables	Definition	Data source
Fossil fuel electricity	Electricity production from oil, gas and coal sources per capita (kWh)	WDI (2018)
Low-carbon electricity	Electricity production from non-hydro renewables and nuclear per capita (kWh)	WDI (2018)
Private credit	Private credit by deposit banks and other financial institutions per capita (constant 2010 USD)	GFDD (2018)
Private debt securities	Outstanding private debt securities per capita (constant 2010 USD)	GFDD (2018)
Public debt securities	Public debt securities per capita (constant 2010 USD)	GFDD (2018)
Stock market capitalization	Stock market capitalization per capita (constant 2010 USD)	GFDD (2018)
GDP	GDP per capita (constant 2010 USD)	WDI (2018)
Installed capacity	Production capacity of power station (Kw)	EIA
Capital stock	Gross fixed capital formation per capita (constant 2010 USD)	WDI (2018)
Trade	Trade per capita (constant 2010 USD)	WDI (2018)

Oil reserves	Oil reserves per capita (kg)	EIA
Coal reserves	Coal reserves per capita (ton)	BP
Natural gas reserves	Natural gas reserves per capita (thousand cubic feet)	EIA
Uranium reserves	Uranium proven reserves per capita (g)	UNSD

Table 2. Descriptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.
Fossil electricity	2305.286	1685.175	5040.681	99.010	1889.647
Low-carbon electricity	322.233	184.108	1321.128	10.211	385.094
Private credit	4032.253	3139.386	11137.480	138.147	3281.753
Private debt securities	1210.836	1045.807	4759.496	3.077	1200.095
Public debt securities	1827.029	817.951	7582.547	5.479	2079.448
Stock market capitalization	4670.735	2832.051	19414.140	123.970	5031.123
GDP	5994.254	6125.590	11915.420	656.697	3652.850
Fossil fuel energy installed capacity	0.481	0.335	1.269	0.031	0.398
Low-carbon energy installed capacity	0.056	0.038	0.187	0.002	0.056
Capital stock	1321.323	1378.783	2842.676	164.014	742.590
Trade	2599.406	2581.533	5920.085	145.571	1689.149
Oil reserves	13240.887	2238.930	76372.628	37.167	22118.398
Coal reserves	429.663	88.085	1154.352	22.731	465.140
Natural gas reserves	2363.753	40.788	11769.460	0.020	4674.712
Uranium reserves	2305.286	1685.175	5040.681	99.010	1889.647

4. Empirical results

Our empirical approach consists of five steps: (1) panel unit root tests for stationarity; (2) panel co-integration tests; (3) FMOLS and DOLS estimates of the long-run coefficients of variables; (4) robustness checks for endogenous issues; (5) estimation of long-run output elasticities for individual countries.

4.1. Panel unit root tests

Testing for stationarity is to ensure the regression analysis does not produce spurious results (Levin et al., 2002). The study uses four traditional unit root tests for examining the integration order of variables. Assuming a common unit root process across countries, we calculate the LLC-t test statistic (Levin et al., 2002). Assuming an individual unit root process across the cross-sections, we then use the following additional tests: W-stat (IPS-W) (Im et al., 2003), ADF Fisher Chi-square (ADF-FCS) (Dickey and Fuller, 1979) and PP-Fisher Chi-square (PP-FCS)

(Phillips and Perron, 1988). For all the tests, the null hypothesis is the presence of a unit root.

The test results in Table 3 show that all variables are stationary in first differences (under the assumption of individual unit root process across the cross-sections). There is a long-run equilibrium relationship among the variables since all of the variables are integrated of the same order. We explore this in the following section.

Table 3. Unit root tests.

Variables	**Level**			
	LLC-T	*IPS-W*	*ADF-FCS*	*PP-FCS*
Fossil fuel electricity	0.977	2.422	4.464	1.878
Low-carbon electricity	1.000	2.545	3.376	5.126
Private credit	-0.219	1.820	2.803	2.264
Private debt securities	-2.233**	0.245	8.628	7.433
Public debt securities	-3.116***	-2.757***	26.991***	41.717***
Stock market capitalization	-0.375	0.473	4.371	10.545
GDP	-0.491	1.280	8.806	1.628
Fossil fuel electricity installed capacity	-0.434	-0.889	20.068	14.139
Low-carbon electricity installed capacity	-7.968***	-5.053***	29.791***	8.348
Capital stock	-1.176	0.218	9.032	2.480
Trade	-3.136***	-1.319*	15.483	28.008***
Oil reserves	-0.664	0.129	7.668	24.662***
Coal reserves	-0.328	0.570	9.040	5.116
Natural gas reserves	0.850	1.821	5.755	6.318
Uranium reserves	0.781	-1.903**	55.808***	73.703***
Variables	**First Difference**			
	LLC-T	*IPS-W*	*ADF-FCS*	*PP-FCS*
Fossil fuel electricity	-7.511***	-6.817***	57.263***	56.698***
Low-carbon electricity	-5.735***	-5.029***	41.983***	41.478***
Private credit	-3.429***	-3.044***	27.1127***	16.810*
Private debt securities	-4.541***	-5.638***	48.266***	59.398***
Public debt securities	-9.688***	-8.353***	69.514***	86.479***
Stock market capitalization	-5.372***	-4.148***	38.655***	50.469***
GDP	-3.368***	-2.649***	23.784***	23.527***
Fossil fuel electricity installed capacity	-3.889***	-3.822***	31.889***	39.695***
Low-carbon electricity installed capacity	-5.623***	-5.843***	45.934***	69.091***
Capital stock	-4.139***	-3.373***	28.157***	27.356***
Trade	-6.157***	-5.252***	43.690***	47.395*
Oil reserves	-7.879***	-7.360***	61.383***	106.004***
Coal reserves	-2.205***	-3.232***	30.344***	28.086***
Natural gas reserves	-8.410***	-7.191***	60.131***	70.829***
Uranium reserves	0.570	-2.635***	44.024***	35.634***

Notes: *, **, *** indicate the rejection of null hypothesis at the 10%, 5%, and 1% significance level, respectively.

4.2. Panel Co-integration Tests

Panel co-integration tests examine for long-run equilibrium relationships among the variables. As all the variables are stationary in first differences, we proceed to use the Kao residual panel co-integration tests to substantiate the existence of a co-integrating relationship. The Kao co-integration test specifies cross-section specific intercepts on the first-stage regression (Kao, 1999). Under the null hypothesis of no co-integration, the test statistic is calculated as:

$$\text{ADF} = t_{\hat{\rho}+\sqrt{6N}\hat{\sigma_v}/(2\widehat{\sigma_{0v}})} \Bigg/ \sqrt{\frac{\hat{\sigma}_{0v}^2}{2\hat{\sigma}_v^2} + 3\hat{\sigma}_v^2/(10\hat{\sigma}_{0v}^2)} \tag{3}$$

The ADF test statistic converges to N (0, 1) asymptotically. The estimated variance is $\hat{\sigma}_v^2 = \hat{\sigma}_u^2 - \hat{\sigma}_{u\epsilon}^2\hat{\sigma}_\epsilon^{-2}$ with an estimated long-run variance $\hat{\sigma}_{0v}^2 = \hat{\sigma}_{0u}^2 - \hat{\sigma}_{0u\epsilon}^2$.

From Table 4, the null hypothesis of no co-integration is rejected at the 1% level of significance. Therefore there exists a long-run co-integrating relationship between electricity production and the explanatory variables.

Table 4. Kao co-integration test.

H_0: No co-integration	t-statistic	p-value
Model (fossil fuel electricity)		
ADF	-2.918^{***}	0.002
Residual variance	0.010	
HAC variance	0.007	
Model (low-carbon electricity)		
ADF	-6.976^{***}	0.000
Residual variance	0.010	
HAC variance	0.007	

Notes: *** denotes 1% significance level of the statistic.

4.3. Panel data analysis of long-run output elasticities

The study estimates long-run output elasticities under dynamic OLS (DOLS) and fully modified OLS (FMOLS) models. The two methods deal with serial correlation, endogeneity and heterogeneity. Phillips and Hansen (1990) propose an estimator that eliminates the problems caused by the long-term correlation between co-integrated equations and random regression innovations, using semiparametric corrections. The FMOLS estimator is asymptotically unbiased and has effective mixed normal asymptotic property, which allows the use of the standard Wald test of asymptotic Chi-square statistical inference. Stock and Watson (1993) propose a simple method of constructing an asymptotically efficient estimator to eliminate the feedback of the co-integration system, namely DOLS. Kao and Chiang (2001) propose a generalization of the method, including increasing the co-integration regression with lags and leads of ΔX_t. Thus, the resulting covariance equation error term is orthogonal to the history of stochastic regression innovation.

The panel FMOLS estimator for the coefficient β:

$$\hat{\beta}^{*}_{NT} - \beta = \left(\sum_{i=1}^{N} \hat{L}_{22i}^{-2} \sum_{t=1}^{T} (x_{it} - \bar{x}_i)^2\right)^{-1} \sum_{i=1}^{N} \hat{L}_{11i}^{-1} \hat{L}_{22i}^{-1} \left(\sum_{t=1}^{T} (x_{it} - \bar{x}_i)\mu^{*}_{it} - T\hat{\gamma}_i\right. \quad (4)$$

where:

$$\mu^{*}_{it} = \mu_{it} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \Delta x_{it} \hat{\gamma}_i \equiv \hat{\Gamma}_{21i} + \overset{\frown 0}{\Omega}_{21i} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} (\hat{\Gamma}_{22i} + \overset{\frown 0}{\Omega}_{22i}) \quad (5)$$

The estimator $\hat{\beta}^{*}_{NT}$ converges to the true value at rate $T\sqrt{N}$, and is distributed as:

$$T\sqrt{N}(\hat{\beta}^{*}_{NT} - \beta) \rightarrow N(0, v), where\ v = \begin{matrix} 2\ iff\ \bar{x}=\bar{y}=0 \\ 6\ else \end{matrix} \quad (6)$$

as $T \rightarrow \infty$ and $N \rightarrow \infty$.

When the estimator is modified appropriately, the corresponding asymptotic distribution will not be influenced by the interference parameters pertinent to the particular serial correlation mode of any member of the data. The DOLS estimator is:

$$\begin{bmatrix} \hat{\beta}_{DP} \\ \hat{\gamma}_{DP} \end{bmatrix} = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \bar{W}_{it} \bar{W}'_{it}\right)^{-1} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \bar{W}_{it} \bar{y}'_{it}\right) \quad (7)$$

where $\bar{W}'_{it} = (\bar{X}'_{it}, \bar{Z}'_{it})'$, $\bar{Z}'_{it}$ is the regressor formed by interacting the $\Delta\bar{X}'_{it+j}$ terms with cross-section dummy variables. $\bar{y}'_{it}$ and $\bar{X}'_{it}$ are data purged of the individual deterministic trends. Kao and Chiang (2001) prove that the asymptotic distribution of the estimator is consistent with that of FMOLS. The FMOLS and DOLS estimation results are presented in Table 5. Estimated coefficients describe the elasticity of the dependent variable with respect to the explanatory variables. The relatively high value of R-squared does not matter for panel cointegration estimations (Lin and Chen, 2019).

Table 5. Panel data analysis of long-run output elasticities.

(a) Model with fossil fuel electricity.

	FMOLS		DOLS	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Private credit	0.160***	0.027	0.086	0.146
Private debt securities	-0.031**	0.013	0.012	0.071
Public debt securities	-0.073***	0.006	-0.061*	0.033
Stock market capitalization	-0.086***	0.011	-0.066	0.060
GDP	-0.474***	0.091	-0.514	0.530
Installed capacity	0.984***	0.029	0.995***	0.165
Control variables	Yes		Yes	
R-squared	0.991		0.991	
Adjusted R-squared	0.989		0.989	
S.E. of regression	0.128		0.130	
Long-run variance	0.001		0.025	

(b) Model with low-carbon electricity.

	FMOLS		DOLS	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Private credit	-0.050*	0.028	0.016	0.111
Private debt securities	-0.059***	0.014	-0.065	0.054
Public debt securities	0.019***	0.006	0.009	0.025
Stock market capitalization	-0.174***	0.011	-0.142***	0.045
GDP	1.922***	0.079	1.906***	0.349
Installed capacity	0.406***	0.013	0.419***	0.055
Control variables	Yes		Yes	
R-squared	0.994		0.994	
Adjusted R-squared	0.993		0.993	
S.E. of regression	0.114		0.114	
Long-run variance	0.001		0.014	

Notes: DOLS and FMOLS are dynamic and fully modified ordinary least square methods, respectively.
*, **, *** denote the significance level at 10%, 5%, and 1%, respectively.

In fossil fuel electricity regression, the coefficients of private credit, outstanding private debt securities, public debt securities, stock market capitalization, GDP and installed capacity are 0.160, -0.031, -0.073, -0.086, -0.474 and 0.984 at 1% significance respectively. In low-carbon electricity regression, the coefficient of private credit is -0.050 at 10% level of significance. The coefficients of outstanding private debt securities, public debt securities, stock market capitalization, GDP and installed capacity are -0.059, 0.019, -0.174, 1.922 and 0.406 at 1% level of significance.

Based on the empirical results above, public debt is found to promote the development of low-carbon electricity. Since public debt also engenders negative effects on fossil fuel electricity, public debt securities contribute to the transition from fossil fuel electricity towards low-carbon electricity. As private credit positively drives fossil fuel electricity and negatively drives low-carbon electricity, private credit hampers electricity transition. Moreover, the expansion of installed capacity plays a significant role in promoting the production of both electricity types. This implies that the installed capacity of electricity stations serves as a mechanism through which financial capital affects electricity production.

The estimated results also suggest that higher levels of economic development and greater supplies of financial capital (except for private credit) reduce fossil fuel electricity. In other words, the financial markets generally do not favor traditional high-polluting, non-regenerative fossil fuel electricity, and various types of financial instruments are withdrawing from fossil fuel electricity investments. In the financial markets, private credit, private debt and stock market capitalization have a significant and negative influence on the production of low-carbon electricity.

As to why public debt securities promote electricity transition and private credit hampers electricity transition, the possible explanations are as follows:

(1) Private credit from banks and other financial institutions is reluctant to finance the immature low-carbon electricity for its uncertain economic returns, still stuck to fossil fuel electricity where economic returns are fair. Since some low-carbon electricity technologies between 1996 and 2015 are not mature, relevant projects were full of uncertainties, with high costs and risks. In contrast, fossil fuel electricity investment is cheap, with mature technologies. Private credit prefers fossil fuel electricity because it provides certainty in the return on investment. According to Lobbying Effect, the more a country's financial system rely on traditional energy, the less likely it reallocates financial resources to low-carbon electricity (Boscán, 2020; Swain and Karimu, 2020). The superimposition of this effect also makes private credit is reluctant to leave fossil fuel electricity and has little motivation to invest in low-carbon electricity. Hence, the financial markets of the five countries are cautious in low-carbon electricity investments.

(2) Climate change and emission reduction requirements force developing countries to use administrative power, like public capital investment, to promote electricity transition. Governments provide public capital, to balance the relatively low economic returns of low-carbon electricity projects. Public debt securities cover long-term bonds and notes, treasury bills, commercial paper and other short-term notes. To date, the five countries' governments are funding large-scale low-carbon electricity projects undertaken by large-sized enterprises. Funding for small and medium-sized energy enterprises are scarce (Wang et al., 2016; Bensch, 2019). The imperfect financial markets of the five countries are ill-equipped to provide adequate financing for low-carbon electricity and electricity transition.

4.4. Robustness checks

To minimize the problem of multicollinearity, we re-estimate equation (2) using separate addition of the financial variables (Table 6). The coefficients of private debt in the fossil fuel electricity regression - and private credit in low-carbon electricity regression - are not significant, whereas their signs are consistent with those in Table 5. Moreover, the remaining estimation results of the four financial variables are also in line with Table 5. The FMOLS regressions prove to be robust.

Technically, the DOLS estimates differ largely from FMOLS in terms of numerical value, sign, and significance. In general, non-parametric estimates tend to be more robust because one does not need to take specific parameter forms. Since non-parametric estimation relies on fewer assumptions, more data than the parametric estimation are usually required. When the time series dimension is not less than the cross-sectional dimension, the FMOLS estimates perform well. Therefore, FMOLS is the most appropriate for our sample study.

Table 6. Robustness check by using the financial variables separately.

	Fossil fuel electricity			**Low-carbon electricity**		
Private credit	0.172^{***} (0.041)			-0.020 (0.038)		
Private debt securities		-0.019 (0.020)			-0.081^{***} (0.024)	
Public debt			-0.074^{***}			0.026^{***}

securities			(0.010)				(0.009)	
Stock market capitalization				-0.094*** (0.014)				-0.183*** (0.016)
GDP	-0.993*** (0.167)	-0.583*** (0.170)	-0.425*** (0.141)	-0.504*** (0.103)	1.641*** (0.120)	1.887*** (0.155)	1.546*** (0.107)	1.803*** (0.103)
Installed capacity	1.049*** (0.053)	0.876*** (0.051)	0.930*** (0.040)	0.862*** (0.030)	0.486*** (0.020)	0.434*** (0.025)	0.494*** (0.014)	0.461*** (0.014)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.989	0.989	0.990	0.989	0.993	0.993	0.993	0.994
Adjusted R-squared	0.987	0.987	0.988	0.987	0.991	0.992	0.992	0.993

Notes: *, **, *** denote the significance level at the 10%, 5%, and 1%, respectively. Standard errors are in parentheses below the coefficients.

Reverse causality might give rise to endogeneity, where electricity production can influence financial and economic development (Kim and Hewings, 2013). In order to mitigate the issue of reverse causality, this study firstly adopts a lead-lag approach (Fich and Shivdasani, 2006). In Table 7(a), we lag all independent variables by one year and reach the same conclusion. Public debt securities contribute significantly to electricity transition, while private credit hampers electricity transition. Next, we apply a composite financial variable by adding credit and debt variables on the basis that one specific type of electricity may engender causal effects on a particular financial instrument (Van Vliet, 2016). Therefore, reverse causality in a specific electricity-finance relation may be mitigated by a composite financial variable. Our results prove that this composite financial variable produces significant impacts on both fossil fuel and low-carbon electricity at 1% level of significance (refer Table 7(b)).

Table 7. Robustness check for reverse causalities.

(a) FMOLS regressions with lagged explanatory variables.

	Fossil fuel electricity		**Low-carbon electricity**	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Private credit (-1)	0.234***	0.022	-0.050**	0.020
Private debt securities (-1)	-0.005	0.012	-0.065***	0.011
Public debt securities (-1)	-0.048***	0.005	0.028***	0.005
Stock market capitalization (-1)	-0.118***	0.011	-0.132***	0.010
GDP (-1)	-0.728***	0.073	1.529***	0.064
Installed capacity (-1)	0.986***	0.023	0.441***	0.010
Control variables	Yes		Yes	
R-squared	0.990		0.994	
Adjusted R-squared	0.987		0.993	
S.E. of regression	0.133		0.110	
Long-run variance	0.001		0.000	

(b) FMOLS regressions with a composite financial variable.

	Fossil fuel electricity		Low-carbon electricity	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Credit and debt securities	-0.227***	0.026	-0.161***	0.031
Stock market capitalization	-0.110***	0.013	-0.195***	0.013
GDP	-0.044	0.109	2.115***	0.104
Installed capacity	0.756***	0.030	0.419***	0.014
Control variables	Yes		Yes	
R-squared	0.990		0.994	
Adjusted R-squared	0.988		0.993	
S.E. of regression	0.131		0.113	
Long-run variance	0.001		0.001	

Notes: *, **, *** denote the significance level at 10%, 5% and 1%, respectively.

To prove that our baseline estimation is robust, we use the alternative explanatory variables and re-estimate our results. Table 8 (a) uses the shares of electricity production from fossil fuel or low-carbon energy as a substitute for per capita electricity output of energy. Data on shares of electricity production are also obtained from the World Development Indicators (World Bank, 2018). The indicator "share" differs from "output" in that "share" has more emphasis on the electricity structure, while "output" emphasizes the scale of electricity production. Dissimilar with the baseline findings, private credit simultaneously improves the shares of fossil fuel and low-carbon electricity. Private debt securities have a significant and positive effect on low-carbon electricity. However, the results for the other independent variables are consistent with our baseline findings in Table 5. Public debt securities still promote the electricity transition. After the dependent variables are replaced with shares of electricity production, the standard errors of regressions and long-run variance significantly increase. The model estimation in Table 8 (a) is biased, and the accuracy is lower than that of the baseline estimation in Table 5. We conclude our baseline estimation is more robust.

Table 8. Robustness check by using alternatives of the core variables.

(a) An alternative: share of electricity production, results under FMOLS.

	Fossil fuel electricity		Low-carbon electricity	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Private credit	7.618***	0.445	2.491***	0.182
Private debt securities	0.118	0.217	0.396***	0.088
Public debt securities	-1.307***	0.097	0.071*	0.038
Stock market capitalization	-0.599***	0.181	-0.962***	0.072
GDP	-25.754***	1.469	1.608***	0.514
Installed capacity	11.447***	0.462	1.793***	0.085
Control variables	Yes		Yes	
R-squared	0.996		0.981	

Adjusted R-squared	0.995	0.977
S.E. of regression	1.980	0.738
Long-run variance	0.187	0.029

(b) An alternative: share of financial capital, results under FMOLS.

	Fossil fuel electricity		**Low-carbon electricity**	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Private credit	-0.000	0.001	-0.003***	0.001
Private debt securities	0.009***	0.001	0.009***	0.001
Public debt securities	-0.010***	0.001	0.0002	0.001
Stock market capitalization	-0.001***	0.000	-0.004***	0.000
GDP	-0.080*	0.042	0.879***	0.032
Installed capacity	0.813***	0.041	0.409***	0.011
Control variables	Yes		Yes	
R-squared	0.992		0.995	
Adjusted R-squared	0.991		0.994	
S.E. of regression	0.116		0.108	
Long-run variance	0.001		0.001	

Notes: *, *** denote the significance level at 10% and 1%, respectively.

In Table 8 (b), private credit, private debt securities, public debt securities and stock market capitalization as shares of GDP are alternatives to the per capita financial capital. We also replace the relevant control variables with their shares of GDP. The signs of estimated coefficients of private credit, private debt securities and public debt securities vary slightly with those in Table 5. Due to the use of "share" as an independent variable, the absolute values of the estimated coefficients are particularly small. For instance, a 1% increase in share of private credit leads to a 0.003% decline in low-carbon electricity production. Although the estimated coefficients are significant, their absolute values are so small that the influence is extremely weak. For instance, share of financial capital has marginal effects on electricity production. Therefore, the interpretation ability of the models is sufficiently weakened, even if the models' R-squares and adjusted R-squares are higher than Table 5, or the standard errors of regressions and long-run variance are lower. Our baseline estimation is thus confirmed to be robust.

Table 9. Robustness check on omitted variable bias (reconsidering hydroelectricity).

	Renewable electricity	
	Coefficient	*Std. Error*
Private credit	-0.170***	0.063
Private debt securities	-0.079**	0.031
Public debt securities	0.028**	0.013
Stock market capitalization	-0.021	0.025
GDP	1.457***	0.179
Installed capacity	0.116***	0.030
Control variables	Yes	
R-squared	0.987	
Adjusted R-squared	0.984	

S.E. of regression	0.204
Long-run variance	0.004

Notes: **, *** denote the significance level at 5% and 1%, respectively.

This study excludes hydroelectricity from low-carbon energy. The hydroelectricity produces more than 50% of energy in Brazil, while it is also important in other countries (BP, 2018). Omitted variable bias might give rise to endogeneity. Thus, we use the sum of hydroelectricity and low-carbon electricity production as renewable electricity production (dependent variable), and repeat the FMOLS estimation procedure. Comparing Table 5(b) with Table 9, by excluding the hydroelectricity the results do not change significantly. Our baseline estimation is also robust.

4.5. SUR estimation of variable coefficient panel data

Owing to high degrees of globalization and inter-state cooperation, shocks that impact one country can impact other countries in a panel data model. Bilgili (2017) refers to this as cross-sectional dependence. Although these countries are five independent economies, cross-sectional dependence can be caused by spatial or spillover effects or by unobservable common factors, such as the financial crisis (Baltagi, 2007). The efficiency of the panel estimator may be difficult to improve compared with a country-level time series estimate if the cross-sectional dependence is large and appropriate estimation techniques are not used. The cross-sectional dependency allows estimation of unobservable common factors like global cycles, which cannot be estimated by a country-level time series. Hence, we construct a variable coefficient panel data model：

$$y_{it} = x'_{it}\beta_i + \varepsilon_{it} \tag{8}$$

where β_i is the coefficient of individual country i. Although each country has separate estimated coefficients (including intercept term and slopes), the disturbance terms of the countries may be related. Thus, seemingly unrelated regressions (SUR) is appropriate for system estimation.

Country-level investigations are vital in understanding the impacts of financial markets on electricity transition across countries. The long-run output elasticities are estimated using SUR and FMOLS methods for comparison and the results are displayed in Table 10(a)-(d). The last line of Table 10(a2) reveals that the Breusch-Pagan test cannot reject the null hypothesis of no contemporaneous correlation. Hence, SUR is less efficient than the single equation estimation FMOLS. We therefore employ FMOLS for fossil fuel regressions. Analogously, the last line of Table 10(b2) reveals that the Breusch-Pagan test rejects the null hypothesis of no contemporaneous correlation. SUR is more efficient than FMOLS and SUR should be employed to estimate the variable coefficient panel data model for low-carbon electricity.

Table 10(c) shows that economic development provides impetus for fossil fuel electricity generation. This seems to conflict with the previous tables. Compared with panel estimation, time-series model does not take the cross-section information into consideration. This leads to an increase of co-linearity between variables and a decrease in the degree of freedom. The effectiveness of the estimator may be weakened. The contrary results also suggest that the effect of economic development on electricity transition is inconclusive. Nevertheless, different types of financial instruments engender different effects on fossil fuel electricity production. Private debt securities (-0.895) and stock market capitalization (-0.752) explain negative effects on Brazil. Private credit (0.076) exerts positive effects on Russia, while private (-0.048) and public debt (-0.034) securities explain negative effects. For India, private debt securities and stock market capitalization engender negative impacts (-0.049 and -0.046). For China, private debt (-0.192) produces negative effects and public debt (0.227) produces positive effects. Finally, private credit (-0.463) and public debt (-0.124) negatively affect fossil fuel electricity in South Africa, while private debt (0.108) positively affects it.

Table 10. Long-run output elasticities.

(a1) Model with fossil fuel electricity using SUR.

	Brazil	**Russia**	**India**	**China**	**South Africa**
Private credit	-0.443	0.061	0.005	0.184**	-0.323***
	(0.422)	(0.042)	(0.116)	(0.085)	(0.096)
Private debt securities	-0.684*	-0.037*	-0.056***	-0.182***	0.074*
	(0.394)	(0.022)	(0.015)	(0.033)	(0.043)
Public debt securities	0.060	-0.034**	0.007	0.208***	-0.097***
	(0.404)	(0.014)	(0.005)	(0.049)	(0.023)
Stock market capitalization	-0.739***	0.010	-0.055***	-0.060***	-0.036
	(0.195)	(0.018)	(0.018)	(0.013)	(0.029)
GDP	9.087**	1.020***	1.581***	0.049	2.093***
	(3.874)	(0.172)	(0.240)	(0.213)	(0.227)
Installed capacity	-0.086	-0.402***	-0.287***	0.928***	0.217***
	(0.433)	(0.145)	(0.108)	(0.134)	(0.056)
Constant	-55.141	39.815**	-2.661	-26.243**	-14.912***
	(69.074)	(18.133)	(4.580)	(12.413)	(3.287)

Control variables	Yes	Yes	Yes	Yes	Yes
R-squared	0.958	0.985	0.999	0.9998	0.979
RMSE	0.110	0.013	0.008	0.008	0.008
Chi2	508.130	1482.960	19890.160	98821.540	909.650

(a2) Correlation matrix of residuals by SUR.

Correlation matrix of residuals:

	Brazil	Russia	India	China	South Africa
BRA	1				
RUS	0.185	1			
IND	-0.277	0.161	1		
CHN	-0.063	-0.384	-0.248	1	
ZAF	0.479	0.439	0.040	0.147	1

Breusch-Pagan test of independence: chi2(10) = 15.903, Pr = 0.102

(b1) Model with low-carbon electricity using SUR.

	Brazil	Russia	India	China	South Africa
Private credit	0.424	0.002	-0.710	1.884***	-0.925**
	(0.269)	(0.056)	(0.673)	(0.375)	(0.381)
Private debt securities	0.132	0.051	-0.031	-0.048	-0.613***
	(0.282)	(0.031)	(0.071)	(0.135)	(0.170)
Public debt securities	-0.119	0.022	0.006	-0.320	-0.085
	(0.252)	(0.020)	(0.017)	(0.256)	(0.087)
Stock market capitalization	-0.217*	-0.059**	-0.194***	-0.193***	0.449***
	(0.119)	(0.029)	(0.069)	(0.069)	(0.155)
GDP	-3.562	-0.636**	2.205***	1.529	-4.821***
	(2.233)	(0.295)	(0.575)	(1.081)	(1.167)
Installed capacity	0.052	0.234	0.369***	0.402***	0.086
	(0.064)	(0.182)	(0.121)	(0.101)	(0.076)
Constant	83.780**	15.085	5.185	-39.783	99.747***
	(41.477)	(23.533)	(21.679)	(62.526)	(16.836)
Control variables	Yes	Yes	Yes	Yes	Yes
R-squared	0.987	0.989	0.996	0.999	0.922
RMSE	0.068	0.020	0.040	0.038	0.031
Chi2	1689.730	2055.250	6106.640	16274.360	254.750

(b2) Correlation matrix of residuals by SUR.

Correlation matrix of residuals:

	Brazil	Russia	India	China	South Africa
BRA	1				
RUS	0.331	1			
IND	0.475	0.632	1		
CHN	0.229	-0.390	-0.321	1	
ZAF	-0.172	-0.280	-0.066	-0.176	1

Breusch-Pagan test of independence: chi2(10) = 23.694, Pr = 0.009

(c) Model with fossil fuel electricity using FMOLS.

	Brazil	Russia	India	China	South Africa
Private credit	-0.403	0.076*	0.071	0.105	-0.463***
	(0.330)	(0.035)	(0.098)	(0.103)	(0.104)
Private debt securities	-0.895**	-0.048*	-0.049**	-0.192***	0.108*
	(0.266)	(0.023)	(0.013)	(0.032)	(0.052)
Public debt securities	0.173	-0.034*	0.007	0.227***	-0.124***
	(0.294)	(0.014)	(0.004)	(0.040)	(0.022)

Stock market capitalization	-0.752***	0.026	-0.046**	-0.070	0.011
	(0.135)	(0.014)	(0.017)	(0.013)	(0.033)
GDP	9.822**	0.980***	1.428***	0.053	2.166***
	(2.663)	(0.158)	(0.224)	(0.201)	(0.228)
Installed capacity	-0.184	-0.319**	-0.252**	0.969***	0.206**
	(0.438)	(0.128)	(0.092)	(0.120)	(0.070)
Constant	-37.874	50.008**	-1.495	-22.170	-14.433***
	(53.801)	(13.696)	(4.273)	(12.709)	(3.645)
Control variables	Yes	Yes	Yes	Yes	Yes
R-squared	0.955	0.985	0.999	0.9998	0.986
Adjusted R-squared	0.865	0.956	0.996	0.9994	0.958
S.E. of regression	0.194	0.022	0.014	0.013	0.012
Long-run variance	0.005	0.000	0.000	0.000	0.000

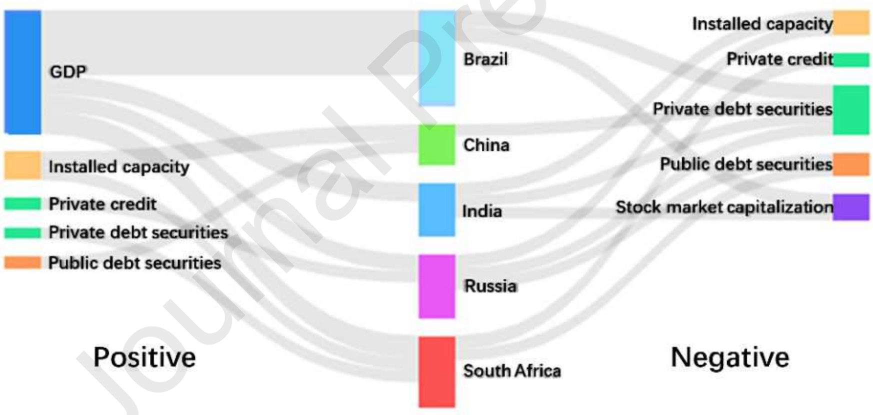
(d) Model with low-carbon electricity using FMOLS.

	Brazil	**Russia**	**India**	**China**	**South Africa**
Private credit	0.769**	-0.066	-0.910	1.754**	-1.172**
	(0.226)	(0.045)	(0.547)	(0.526)	(0.371)
Private debt securities	0.193	0.071*	-0.043	0.002	-0.576**
	(0.285)	(0.031)	(0.064)	(0.117)	(0.193)
Public debt securities	0.035	0.025	0.005	-0.312	0.112
	(0.236)	(0.019)	(0.015)	(0.240)	(0.075)
Stock market capitalization	-0.179	-0.059*	-0.222**	-0.203**	0.486**
	(0.102)	(0.026)	(0.071)	(0.059)	(0.136)
GDP	-3.483	-0.736**	2.409***	1.141	-4.897***
	(1.994)	(0.265)	(0.639)	(1.052)	(1.235)
Installed capacity	0.070	0.403**	0.468***	0.384***	0.024
	(0.073)	(0.155)	(0.105)	(0.091)	(0.076)
Constant	50.682	7.047	2.894	-34.451	104.835***
	(41.969)	(19.743)	(21.085)	(67.634)	(19.364)
Control variables	Yes	Yes	Yes	Yes	Yes
R-squared	0.986	0.989	0.996	0.999	0.923
Adjusted R-squared	0.957	0.966	0.989	0.997	0.770
S.E. of regression	0.118	0.033	0.066	0.062	0.056
Long-run variance	0.002	0.000	0.001	0.001	0.001

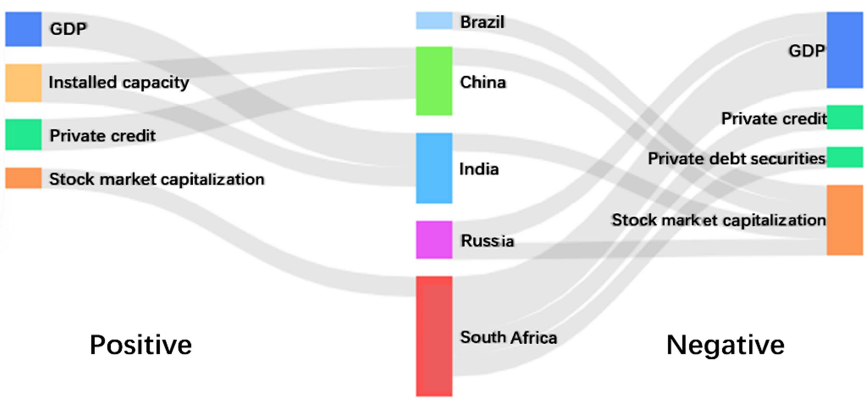
Notes: *, **, *** denote the significance level at the 10%, 5%, and 1%, respectively. Standard errors are in parentheses.

As reported in Table 10(b1), economic development reduces the production of low-carbon electricity in Russia and the South Africa, whereas it increases low-carbon electricity production in India and China. Stock market capitalization exerts positive effects in Brazil (-0.217), Russia (-0.059) and India (-0.194). Private credit (1.884) generates positive effects in China, yet stock market capitalization (-0.193) explains negative effects. However, the gross effect of financial capital is positive on low-carbon electricity in China. Private credit (-0.925) and debt (-0.613) produce negative effects on the South Africa, while the effect of stock market capitalization (0.449) is positive (the gross effect is negative).

Figure 4(a) and (b) are Sankey diagrams for each country, summarizing the economic and financial variables that influence significantly electricity production and transition. The left and right branches refer to explanatory variables, while the middle branches denote explained variables. The width of the extended branches corresponds to the size of coefficients, reflecting the magnitude of the effects of explanatory variables on dependent variables. The branches on the left side refer to positive significant relations, and the right side refers to negative significant relations. Based on the time-series analysis results, the development of different electricity types is influenced by different financial factors. Since time fixed effects are not controlled in time-series analysis, the estimated results of which might be dissimilar with the baseline findings.



(a) Fossil fuel electricity



(b) Low-carbon electricity

Figure 4. Relationships among financial capital, economic development and electricity production.

In summary, the financial markets in Brazil, Russia and India do not make significant contributions to their electricity transition from fossil fuel electricity to low-carbon electricity. In China, private credit supports the development of low-carbon electricity. For South Africa, although private credit and debt significantly reduce the production of low-carbon electricity, electricity transition is still assisted by stock market capitalization. Financial markets in China and South Africa play a more significant role in electricity transition than the other three countries.

5. Conclusions and implications

Achieving electricity transition remains a daunting task. There is a lack of empirical evidence on the relation between financial markets and electricity production. This study sheds light on the effects of financial markets on electricity transition. Using panel co-integration estimation, we construct a panel of Brazil, Russia, India, China and South Africa during the period of 1996-2015. Panel estimation results suggest that public debt securities make a significant contribution to electricity transition from fossil fuel electricity to low-carbon electricity. Meanwhile, private credit hinders electricity transition. Across these countries, there are significant differences in the impact of financial markets on electricity transition. Part of the financial instruments will chase the fossil fuel electricity. Nonetheless, financial markets play a specific catalytic role in electricity transition. For China and South Africa, financial markets play a more significant role in electricity transition than the other three countries. Economic development promotes the production of low-carbon electricity and impedes the fossil fuel electricity generation in these countries. Installed capacity of electricity stations significantly drives the association between financial instruments and electricity production.

The main reasons of public debt securities promoting electricity transition and private credit hampering electricity transition are: (1) Private credit is reluctant to finance the immature low-carbon electricity for its uncertain economic returns, still stuck to fossil fuel electricity where economic returns are fair. The financial markets of these countries are less able to take risks than developed countries and are more cautious in low-carbon electricity investments. (2) Climate change and emission reduction requirements force developing countries to use administrative power, like public capital investment, to promote electricity transition. Governments provide public capital, to balance the relatively low economic returns of low-carbon electricity projects. These countries' governments are concentrating on funding large-scale low-carbon electricity projects undertaken by large enterprises.

For policymakers, this study emphasizes the significance of policies conducive to favorable financing instruments and channels for low-carbon electricity transition. The main policy implications are as follows:

(1) Long-term policy mechanisms should be developed, combining electricity transition with long-term economic development plans. Most of the factors share significant relations in the long run. Therefore, policymakers should recognize the long-term nature of policies that have a major impact on electricity transition.

(2) Innovative financial instruments, such as green debt securities, are useful for electricity transition. Public capital plays a key role in promoting clean energy production, especially in debt securities. Since the government may not have the ability to meet the huge demand for green investment and financing, appropriate financial instruments are needed to encourage private capital to enter green industries.

(3) Promoting the financial sector and increasing access to finance for sustainable electricity investors should be a key priority for policy makers. Countries experiencing financial sector growth could also experience a growth in electricity sector, which are relatively capital-intensive. Financial policies that bear on the size and structure of the financial system have the potential to increase indirectly the use of capital-intensive low-carbon electricity.

(4) Convincing the domestic governments of these countries to opt for low-carbon

technologies is a pivotal task. They should seek to deepen cooperation in financial support, in order to reduce the cost of developing low-carbon energy. The countries should also energize all market players to invest in clean energy through multiple financial instruments.

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☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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