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Petroleum subsidies, clean energy transition, and decarbonisation in oil-producing developing countries: what is the role of regulatory quality?

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Abstract: Energy transition and decarbonisation are critical gateways to cutting carbon emissions, improving energy security, and achieving the United Nations Sustainable Development Goals. Researchers have paid enormous attention to understanding key drivers of clean energy transition and decarbonisation. However, they have overlooked the role of fossil fuel subsidies and regulatory quality in developing countries where fuel subsidies are prominent and institutional quality is weak. This study employs a Prais-Winsten regression to examine the impact of petroleum subsidies and regulatory quality on clean energy transition and decarbonisation in 25 developing countries between 2010 and 2020. The result revealed that petroleum subsidies hinder the shift to clean energies and encourage high carbon intensity. However, when these subsidies are accompanied by a strong regulatory quality, they promoted energy transition and decarbonisation. The study recommends practical pathways to reform fuel subsidies, swap subsidy saving into clean energies, and strengthen regulatory quality.

Keywords: clean energy; energy transition; carbon emission; decarbonisation; petroleum subsidies; regulatory quality; developing countries; Prais-Winsten regression; SDGs; renewable energy.

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1 Introduction

Climate change is threatening the human race and biodiversity. The frequency, intensity, and severity of extreme weather events have become unprecedented in recent times. According to the WMO (2020), weather, climate, and water-related disasters are currently five times more likely and seven times more destructive compared to five decades back. These disasters are largely due to human activities associated with carbon emissions that heat planetary bodies, causing global warming (Rivera-Collazo, 2022; Malla et al., 2022). Developing countries have contributed less than 4% to global carbon emissions, they however carry a disproportionate burden of the severe consequences of adverse climate events (Truccone-Borgogno, 2022; Wilkens and Datchoua-Tirvaudey, 2022).

The energy sector contributes more than one-third of global greenhouse gas emission and holds one of the strongest potentials to cut carbon emissions (Arzova and Sahin, 2023; Wang and Min, 2020). Based on estimates from the IEA (2022) more than 37% of global emissions come from the energy sector where fossil fuels account for over 80% of the current energy supply. Shifting global energy systems away from carbon-intensive fuels to clean renewables is critical for tackling the climate crisis and availing a sustainable, affordable, and modern energy for all in line with the United Nations Sustainable Development Goal 7 (Nguyen and Dingle, 2022; Leal Filho et al., 2022; UN, 2022). Over the past decade, significant progress in the development and deployment of clean renewables has been recorded. A recent report by the IRENA (2022) noted that renewable energy capacity increased by 130%, with renewable electricity generation reaching 8,000 terawatt-hours of electricity between 2010 and 2021. The cost of these energies has also been on a free fall since 2010, with the global weighted average levelised cost of solar-based electricity falling by 85% as of 2020 (IRENA, 2022; Neuhoff et al., 2022).

But despite the progress recorded, the pace and scope of the current energy transition fall woefully short of what is required to keep global warming below 2°C by 2030 and to reach a net zero emission by 2050 (World Bank, 2022; Matthews and Wynes, 2022; Obobisa, 2022). To limit global warming to 1.5°C, the share of renewables in total final energy consumption would need to rise from 19% as of 2019 to 79% by 2050 (IEA, 2022; IRENA, 2022). Anything short of an ambitious target could diminish and possibly eliminate the chance of staying within the 1.5°C or even 2°C paths (IPCC, 2022). Yet, several techno-economic and socio-institutional barriers currently undermine the rapid deployment of renewables globally, and more acutely in developing economies (Mungai et al., 2022; Olabi and Abdelkareem, 2022).

Economic development, propelled by cheap fossil fuels, is a policy priority of developing countries. For example, fossil fuel subsidies are prominently used as policy tools to boost industrial production and lower the cost of living in these countries (Said

et al., 2022; van Asselt and Newell, 2022). Furthermore, because social welfare systems are often weakly developed in these countries, fuel subsidies have become endemic means of redistributing wealth and closing socioeconomic inequality (Mahdavi et al., 2022). In precisely oil-producing countries, these subsidies are even considered entitlements of the citizens and part of a binding social contract with the government (McCulloch et al., 2021a, 2021b). Coupled with the risk of stranded assets and uncertainties around the economic impact of a clean transition, these realities suggest that the shift to sustainable energy systems may take more time to materialise in developing economies (Ramachandran, 2021; Ozili, 2022). However, climate inaction is not an option (Bosello and Parrado, 2021).

Rather, the realities of developing oil-rich countries underscore the need for a carefully designed transition plan based on context-relevant evidence (Mulugetta et al., 2022). In response to this, several empirical studies have examined the determinants of renewable energy development and carbon emissions, focusing on a broad range of factors including technological, economic, and institutional determinants (e.g., Bekun and Alola, 2022; Jeetoo, 2022; Harrathi and Almohaimeed, 2022). However, these studies have not paid sufficient attention to the nexus between fossil fuel subsidies, institutional qualities, clean energy transition, and decarbonisation in developing oil-producing countries. This is important because insight from such analysis would be key to leveraging scalable policies to mitigate climate change and foster sustainable development in developing economies.

This study contributes to the extant literature in three ways. Firstly, it considers the impact of fossil fuel subsidies on clean energy transition and growth decarbonisation in developing countries. Secondly, while the extant evidence points to the significance of regulatory quality in promoting renewable energy development, studies on the nexus between regulatory quality, fossil fuel subsidies, clean energy transition, and decarbonisation are grossly missing. This study provides evidence of the interactive impact of fuel subsidies and regulatory quality on renewable energy transition and decarbonisation. Lastly, findings from spatial econometrics and conclusions from multiple review studies have shown the determinants of renewable energy development to differ across countries, regions, and between developed and developing economies (e.g., Bourcet, 2020; Lv et al., 2022; Njoh, 2021). By focusing on a subset of developing countries (i.e., oil-rich), this study presents fresh evidence on the determinants of clean energy transition and decarbonisation in developing countries.

Section 2 of the paper provides a review of the relevant theoretical literature. Section 3 reviews the empirical literature. Section 4 discusses the methodology and data issues while Section 5 present and analyse the result. Section 6 concludes the study and put forward policy recommendations.

2 Theoretical review

Energy subsidies, particularly those that improve the consumption of modern hydrocarbon fuels are important for scaling up modern energy access in developing countries. Data from the IEA (2023a) shows that billions of people in the developing world still rely on carbon intensive fuels such as biomass and firewood to meet basic energy needs including lighting, heating, and cooling. Several studies in the fuel-choice literature have however shown that the use of traditional cooking fuels is responsible for

a host of early and later-life health challenges ranging from ailments such as neonatal anomalies, morbidity, and infant mortality to cardiovascular diseases, blindness, and acute respiratory tract infections (Jestin-Guyon et al., 2023; Khavari et al., 2023; Nardocci et al., 2023). The WHO (2023) estimate that every year, exposure to indoor air pollution coming from the use of traditional biomass fuels claims 3.2 million lives. Thus, subsidies on modern fuels such as kerosene, gasoline, and liquefied petroleum gas could be beneficial for improving living quality and welfare in developing countries where the uses of these traditional harmful fuels are prevalent.

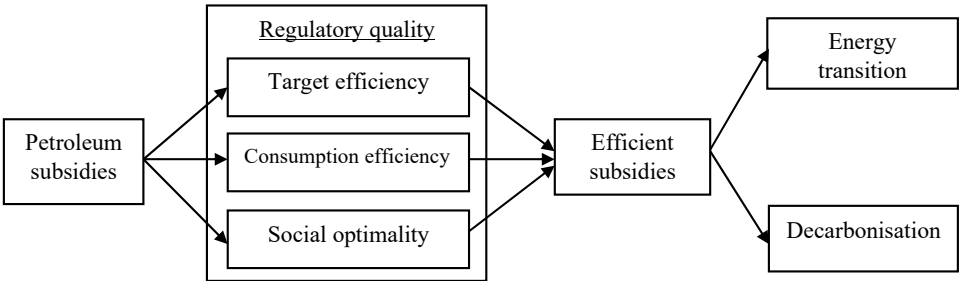
However, the prevalence of fuel subsidies can pose serious socioeconomic and environmental challenges. In developing countries where regulatory quality is often weak, government subsidies on energy consumption are mostly badly targeted (Baršauskaitė, 2022). A significant share of these subsidies goes to the wealthy much more than they reach the poor who are supposed to be the intended beneficiaries (Moayed et al., 2021). For this reason, some studies have found strong suggestive evidence between blanket energy subsidies and income inequality (Solarin, 2022). On the economic front, increases in international oil prices have pushed most government to increase spending on subsidising domestic energy consumption to keep pump prices down (IMF, 2019). This strain on government fiscal space has in turn contributed to rising debt levels and denied vital expenditure on flagship projects that are of immense national impact (IEA, 2023b). The environmental impact of subsidies to particularly fossil fuels have also been unsettling. The latest report from the IPCC (2023) attributes the rapid increases in carbon emissions causing global warming to the unabated subsidies going to energy sources such as coal, oil, and natural gas. This behaviour has precipitated more frequent and severe climate catastrophe in recent times (WMO, 2023).

This double-edge sword nature of fuel subsidies in developing countries implies that they feature both costs and benefits. In line with this realisation, a joint report by the IEA, OPEC, OECD, and World Bank in 2010 proposed a framework to guide policymakers towards eliminating all the inefficiencies in subsidy expenditure coming from poor targeting, wasteful consumption, and sub-optimal policy tool (see IEA et al., 2010). The report underscores the critical role of a strong regulatory framework that can help the government to enforce and monitor the allocation of energy subsidies to poor households and prevent leakages to unintended persons through targeted interventions. For example, they will need to define who are vulnerable persons, how can they be targeted, how much subsidies should be provided, and for how long (OECD and IEA, 2021). Undoubtedly, this would require strong coordination between various levels, departments, and agencies of government that are guided and regulated by a central planning unit (IMF, 2022).

Similarly, with a strong regulatory quality, government can moderate the amount paid out in energy subsidies to reduce superfluous consumption of energy services among beneficiaries by defining and identifying minimum levels of energy consumptions that are considered critical for a decent survival and national development (IEA et al., 2010). In places where cross-border smuggling of subsidised fuels is prevalent, improved regulation by the government can also help to enhance monitoring and dissuade arbitraging through persuasions or penalties. Furthermore, stronger regulation can also increase the efficiency and efficacy of alternative social protection policies that serve similar purpose to those intended with making energy cheaper and affordable to vulnerable persons. Thus, there will not be a need to use fuel subsidies to assist the poor since other policy tools than achieve similar objective much more efficiently.

With better targeted subsidies aided by a stronger regulatory quality, countries can ensure that socially desirable prices of energy products prevail. In turn, the prevailing subsidies that helps to attain this price level (*efficient subsidies*) are beneficial to the environment because they help to minimise the wasteful consumption of carbon-intensive fuels and thus promote the decarbonisation of countries' economic growth (Bassi et al., 2023). Also, because fossil fuel prices get closer to their efficient market levels when government subsidies become more efficient, it creates a favourable level playing field for investment and adoption of alternative renewable energies that are vital to foster the transition away from carbon-intensive fuels towards clean and sustainable energy solutions (Timperley, 2021). In addition, funds saved from abolishing blanket fuel subsidies and preventing cross-border leakages can be used to foster business environment of modern clean energies through means such as providing green subsidies, concessional loans, and expanding expenditure in R&D (Bridle et al., 2019; Christensen et al., 2022). This nexus between petroleum subsidies, energy transition and decarbonisation, and the mediating role of regulatory quality is presented in Figure 1.

Figure 1 Theoretical model



3 Empirical literature review

The urgent need to tackle the climate crises and address issues of energy security and sustainable development has sprung huge interest in the economics of renewable energies (Norouzi, 2022; Olabi and Abdelkareem, 2022). This has commonly involved understanding the drivers of and barriers to clean energy consumption (Juszczyk et al., 2022). Multiple empirical studies have fed this interest with ample and growing evidence (Dogan et al., 2021). Some of the widely studied determinants of renewable energy consumption (REC) include economic, environmental, political, and institutional determinants. A few other studies have gone beyond these standard determinants to include cultural and psychological factors. However, even in spite of the large body of research, no clear consensus has emerged on the impact of some of these factors on REC (Njoh, 2021). A recent review by Bourcet (2020) identified factors such as differences in methodology, sample countries, framework, and choice of outcome variables as the major cause of mixed findings in the literature.

Early studies on the determinants of REC focus on economic and environmental factors namely GDP, trade, oil price, foreign direct investment, CO₂ emissions, and climate policies. Precisely, these studies have found GDP to significantly promote REC in especially developed countries such as the G7, OECD, and EU (see El-Karimi and

El-Houjjaji, 2022; Alam and Murad, 2020; Simionescu et al., 2023; respectively). The intuition is that higher economic growth and development increases not only affordability for clean, costly energies, but also encourages the use of more efficient energy systems (Raza et al., 2020). However, this is not the case for most developing economies where substantial evidence points to the negative impact of growth on REC (see Bekun and Alola, 2022; Kumaran et al., 2020; Jeetoo, 2022). In light of this, Ergun et al. (2019) argued that RE portfolio in developing countries largely consists of traditional biomass. So as income increases, there is a shift away from biomass to modern fossil fuels. Uzar (2020a) also noted that because energy stock in developing countries is prominently fossil fuel, additional growth potential would often leverage such inexpensive fuels to drive the needed growth. Similarly, the impact of oil prices on REC has produced equally mixed findings with some studies showing that higher oil prices encourage REC (e.g., Chen et al., 2021; Sahu et al., 2022) while others found it to deter REC (e.g., Karacan et al., 2021; Mukhtarov et al., 2020).

Factors such as trade and foreign direct investment have mostly been found to negatively impact REC. For example, Somoye et al. (2022) and Kumaran et al. (2020) found this result to hold in Nigeria and in four southeast Asian countries (Indonesia, Malaysia, Philippines, and Thailand) respectively. Insights from the pollution heavens hypothesis help to reinforce these findings (Balsalobre-Lorente et al., 2022; Bashir, 2022; Chaudhry et al., 2022). Conversely, factors such as financial development, CO₂ emissions, and signatory to global climate treaties have been found to promote REC (see Lahiani et al., 2021; Li and Shao, 2021; Mukhtarov et al., 2022; Shahbaz et al., 2021). Take financial development, for example, the huge capital outlay of clean renewables requires robust financial markets to accelerate investment in and uptakes of these technologies (Khan et al., 2021). Similarly, higher CO₂ emissions help to awaken environmental consciousness and motivate the shift to cleaner sustainable fuels (Lv et al., 2022). And national commitments to global climate treaties help to beef up visible action against climate change (Bashir et al., 2022; Shahzad et al., 2021).

Later works on the determinants of REC focused on the impact of institutional and political factors. This strand of the literature is motivated by the idea that renewable energies are relatively costly and if left to the market, would be outcompeted by cheap fossil fuels (Omri et al., 2022). Furthermore, the uncertainties around the socioeconomic impact of energy transition including lower growth, job loss, and income inequality (see Aldieri et al., 2022; Gatto, 2022; Mulugetta et al., 2022) underline the need for a robust and resilient institution but also a strong and stable political atmosphere to bolster a rewarding transition to sustainable energy systems (Lazaro et al., 2022; Leonhardt et al., 2022). Thus, researchers have examined the impact of institutional factors such as rule of law, control of corruption, regulatory quality, property right, and social freedoms in promoting REC. Most empirical studies have found that improvements in these factors promote REC (e.g., Chen et al., 2021; Jeetoo, 2022; Li and Shao, 2021; Uzar, 2020b). Similarly, political factors such as democracy, democratic systems, party proliferation, and political ideology have all played a key role in explaining REC. For example, some studies have shown that more democratic countries promote the use of RE compared to autocratic ones (e.g., Saadaoui and Chtourou, 2022; Sequeira and Santos, 2018). Also, parliamentary systems of government, and left and centred ruling parties, have been found to encourage the use of RE, while party polarisation discourages it (Apergis and Pinar, 2021).

One area that has received little scholarly attention is the cultural and psychological determinants of REC. For one, it is challenging to measure and cross-compare these factors and for another, deciphering their mechanism of impact can be Herculean. Yet, the work of Njoh (2021) finds that the use of firewood for cooking was particularly hard to change among rural Ethiopians. Similarly, Shortall and Kharrazi (2017) found certain social values to hinder the development of geothermal energy in Iceland and Japan. Higuera-Castillo et al. (2019) also showed that countries with higher levels of collectivism were more pro-environment and had greater intentions to adopt renewable energies compared to those with high levels of individualism. Oryani et al. (2021) and Rosso-Cerón and Kafarov (2015) also found a similar result.

The current trend of research in the literature of REC is observably characterised by two distinct features namely the inclusion of non-conventional determinants and analysis of nonlinear relationships. On the one hand, some researchers have explored factors such as the spatial effect of REC, noting that countries nowadays do not exist as isolated entities (Bilyaze, 2022). Rather, they learn and mimic each other (Chiu et al., 2022; Palit, 2022). Thus, REC in a parent country can potentially spill over to neighbouring and trade partnering countries. Empirical evidence in support of this argument can be found in the works of Jeetoo (2022) and Lv et al. (2022). Other researchers have found factors such as fiscal decentralisation and geopolitical risk to significantly impact on REC (see Shahbaz et al., 2022; Flouros et al., 2022; respectively). On the other hand, the literature has also explored the nonlinear relationship between REC and its determinants. For example, Chen et al. (2021) found GDP and trade to result in lower REC in less democratic countries compared to more democratic ones. Similarly, Raza et al. (2020) found that financial development significantly contributed to REC in a high and low growth regime. And Qian et al. (2021) showed that accounting for environmental regulation weakened the effect of resource curse in selected coal mining cities in China. However, the literature has not studied the impact of fossil fuel subsidies on REC nor have researchers examined how regulatory quality can influence this impact.

Studies on the determinants of carbon emissions have interestingly paralleled those of the REC with the literature equally exploring the impact of a broad range of multidimensional factor. For example, several studies have used multiple versions of the IPAT frameworks to understand the drivers of emission across economies and concluded that factors such as population growth, economic growth, energy consumption, and energy intensity are major factors that increase emissions level while technological growth tames it (e.g., Raza and Hasan, 2022; Thio et al., 2022; Yang et al., 2022; Zuo et al., 2020). Other groups of studies focus on institutional and political determinants of emissions and have reported conclusions in favour of the constraining role of strong institutional and regulatory quality on carbon emission (e.g., Khan et al., 2022; Yuan et al., 2022; Zhang et al., 2022). Evidence on the impact of political factors suggest that more democratic and civil states tend to encourage lesser emissions compared to alternative political arrangements (e.g., Benlemlih et al., 2022; Muttakin et al., 2022; Wang et al., 2022). However, the impact of petroleum subsidies on emissions and the moderating role of regulatory quality have not been previously explored in the literature. This is an important shortfall considering the wide prevalence of these subsidies in many countries that are simultaneously committed to reducing carbon footprints and achieving net zero emissions by 2050. This study therefore provides insights into the impact of petroleum subsidies on the transition to clean energies and the decoupling of economic activities from high carbon intensity.

4 Methodology

4.1 Empirical model

Two sets of analyses were conducted in this study. The first examines the nexus between fuel subsidies, regulatory quality, and energy transition. The second explores the relationship between fuel subsidies, regulatory quality, and energy intensity. Following the panel data framework set out in Park (2011), we start with the rather basic assumption of no systematic differences in the panel, and therefore the error term ε is assumed to be identically and independently distributed (i.i.d) (Baltagi, 2021). Thus, we pool and estimate the data using a simple OLS (Hsiao, 2022). However, countries in the panel are likely heterogeneous, sharing dissimilar country-fixed effects (Wooldridge, 2020). Consequently, the error term ε_{it} is made up of

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \dots + \beta_k x_{kit} + \varepsilon_{it} \quad (1)$$

$$\varepsilon_{it} = \lambda_i + \mu_{it}, \mu_{it} \sim N(0, \sigma_u^2) \quad (2)$$

where μ_{it} is assumed to be i.i.d with zero error mean and variance σ_u^2 while the individual-specific effect λ_i represents unobserved, time-invariant heterogeneity (Baltagi, 2021). If we assume that λ_i is drawn independently from some random sample, then we have a random effect model (Sul, 2019) and the randomness is subsumed into the error term as

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \dots + \beta_k x_{kit} + (\lambda_i + \mu_{it}) \quad (3)$$

with the corresponding variances being σ_λ^2 and σ_u^2 . However, the problem is that these variances are potentially correlated due to the common component λ_i across observation, making OLS an inefficient estimator (Das, 2019). To address this problem of autocorrelation, the random effect model is estimated using a generalised least square estimator of the form

$$y_{it} = \theta \bar{y}_t = \delta + \beta(x_{it} - \theta \bar{x}_t) \quad (4)$$

$$\theta = 1 - \sqrt{\frac{\sigma_u^2}{T\sigma_\lambda^2 + \sigma_u^2}} \quad (5)$$

which is a weighted average of the within and between variations in the data (Greene, 2008). If all country-specific effects are homogenous, σ_λ^2 and therefore $\theta = 0$, in which case the random effect model becomes a pooled OLS model (Greene, 2008). To test the hypothesis that $\sigma_\lambda^2 > 0$, we use the Breusch-Pagan Lagrangian multiplier (LM) test given as

$$LM = \frac{NT}{2(T-1)} \left[\frac{\sum_{i=1}^N \left(\sum_{t=1}^T \hat{\varepsilon}_{it} \right)^2}{\sum_{i=1}^N \sum_{t=1}^T \hat{\varepsilon}_{it}^2} - 1 \right] \quad (6)$$

where N is the number of cross-sections and T is the time frame. LM is distributed as chi-squared with one degree of freedom under the null hypothesis (Breusch and Pagan, 1980). Alternatively, the individual-specific effect λ_i may be assumed to be non-random in which case $Cor(\lambda_i, x_{it}) \neq 0$ and therefore λ_i is treated as a constant

$$y_{it} = (\beta_0 + \lambda_i) + \beta_1 x_{1it} + \beta_2 x_{2it} + \dots + \beta_k x_{kit} + \mu_{it} \quad (7)$$

and estimated either by using a within-mean transformation or a least square dummy variable fixed effect to eliminate the covariance between the λ_i and x_{it} (Gujarati and Porter, 2009). Whether or not the random effect model is preferable over the fixed effect model is determined through the Hausman specification test as

$$Haus = (\widehat{\beta}_{fe} - \widehat{\beta}_{re})' [V_{fe} - V_{re}]^{-1} (\widehat{\beta}_{fe} - \widehat{\beta}_{re}) \quad (8)$$

where $V_{fe} - V_{re}$ is the variance-covariance matrix of the fixed and random estimators respectively (Hausman, 1978). The Hausman test is asymptotically chi-squared distributed with k degrees of freedom under the null hypothesis of regressor-effect independence (RE is appropriate). Based on the preceding models, we estimate two augmented panel models as

$$Etr_{it} = \beta_0 + \beta_1 Sub_{it} + \beta_2 GDP_{it} + \beta_3 RegQ_{it} + \beta_4 Trd_{it} + \beta_5 Sub_{it} * RegQ_{it} + \varepsilon_{it} \quad (9)$$

$$COi_{it} = \beta_0 + \beta_1 Sub_{it} + \beta_2 GDP_{it} + \beta_3 RegQ_{it} + \beta_4 Trd_{it} + \beta_5 Sub_{it} * RegQ_{it} + \varepsilon_{it} \quad (10)$$

where Etr_{it} and COi_{it} are the dependent variables and represent energy transition and carbon intensity respectively. Sub is petroleum subsidies, GDP is gross domestic products per capita and $RegQ$ is regulatory quality. Trd is total trade as a percentage of GDP and $Sub * RegQ$ is the interaction of government subsidies and government regulatory quality. ε is the error term and the subscripts i and t are the cross-sectional and time series indicators.

From equations (9) and (10), we derive the marginal effect of petroleum subsidies on energy transition and carbon intensity respectively as

$$\frac{\partial Etr_{it}}{\partial Sub_{it}} = \beta_1 + \beta_5 RegQ_{it} \quad (11)$$

$$\frac{\partial COi_{it}}{\partial Sub_{it}} = \beta_1 + \beta_5 RegQ_{it} \quad (12)$$

where ∂ is the partial derivative measuring the influence of regulatory quality on the nexus between fuel subsidies, energy transition, and carbon intensity (Giesselmann and Schmidt-Catran, 2022; Solarin, 2022).

4.2 Variable description and country selection

Our first primary variable of interest is the share of renewable energy in final energy consumption, which is a proxy for energy transition (see Dogan et al., 2021; Saadaoui and Chtourou, 2022). The higher the share, the closer economies move towards clean energies (Leonhardt et al., 2022). In the second model, kilogram of carbon emission per dollar unit of GDP is used to measure countries' level of carbon intensity. This data

reflects the amount of carbon dioxide produced from solid, liquid and gas fuels including gas flaring per unit of useful economic output produced. The lower the carbon intensity of countries, the higher their decarbonisation and vice versa (Hamid et al., 2022).

Table 1 Variable description and sources

<i>Variables (symbols)</i>	<i>Measurements</i>	<i>Symbols</i>	<i>Data source</i>
<i>Dependent variable</i>			
Energy transition	% of renewables in final energy consumption	<i>Etr</i>	World Bank (2023a)
Carbon intensity	CO ₂ emissions (kg per 2017 PPP \$ of GDP)	<i>COi</i>	World Bank (2023a)
<i>Independent variables</i>			
Energy subsidies	Million, constant 2017 USD	<i>Sub</i>	OECD and IISD (2023)
Regulatory quality	Regulatory quality	<i>RegQ</i>	World Bank (2023b)
<i>Control variables</i>			
Economic growth	GDP per capita, PPP (constant 2017 international \$)	<i>GDP</i>	World Bank (2023a)
Trade	Trade (% GDP)	<i>Trd</i>	World Bank (2023a)

Both the first and second variables were sourced from the World Bank's (2023a) World Development Indicators database. Next, is the data on petroleum consumption subsidies expressed in constant 2017 international USD and sourced from the global fossil fuel subsidy tracker (OECD and IISD, 2023). This data measures the difference between the end-user price of petroleum products and the full cost of their supply, often referred to as the 'price gap' (Gasim and Matar, 2023). This gap typically results from government market regulation and price supports mechanisms (Moerenhout, 2022).

Regulatory quality is included as an explanatory variable in the model and used to measure the ability of the government to formulate and implement sound policies and regulations that promote private sector development (Kaufmann et al., 2011). The data is an index constructed from a set of survey variables, part of which measures the strength of government policies in terms of the extent of protectionary and targeted interventions, the efficiency of market competition, and the strength of regulatory enforcement (Kraay, 2023). The data is sourced from the World Bank's (2023b) World Governance Indicators database and scaled from -2.5 to $+2.5$ with higher values indicating stronger regulatory quality (Apergis and Pinar, 2021). However, we made a slight adjustment to this data by adding 2.5 points across the data points to allow for a more convenient interpretation of our results. Thus, the data have been rescaled to range between 0 and 5. In the diagnostic analysis, we confirmed that this adjustment does not alter the result nor conclusion of the study in any way.

In line with the works of Li and Shao (2021) and Jamshid et al. (2022), two control variables were included in the analysis. First, is the economic growth of countries measured by their GDP per capita at constant 2017 USD. This variable reflects the sum of gross value added by all resident producers in the economy plus any product taxes but less subsidies. Second, is total trade volume expressed as the sum of import and export of goods and services as a percentage of GDP. Both variables were sourced from the World Bank (2023a) database. We provide a summary of all the variables utilised in this study in Table 1.

Table 2 Selected sample countries

<i>S. no.</i>	<i>Countries</i>
1	Algeria
2	Angola
3	Bangladesh
4	Bolivia
5	Ecuador
6	Egypt
7	El Salvador
8	Equatorial Guinea
9	Gabon
10	Ghana
11	Guatemala
12	Iran
13	Iraq
14	Kazakhstan
15	Kyrgyzstan
16	Libya
17	Malaysia
18	Nigeria
19	Pakistan
20	Sri Lanka
21	Sudan
22	Thailand
23	Turkmenistan
24	Uzbekistan
25	Vietnam

All data collected span the period 2010 to 2020 for 25 oil-producing developing economies. The choice of the time period and sample size was informed by the availability of sufficient panel data. Specifically, panel data on petroleum subsidies for developing countries only began to exist from 2010 when the IMF, IEA, and OECD started publishing annual energy subsidy data for these countries. Moreover, not all developing countries provide subsidies on petroleum products. These subsidies are notably widely spread across major oil-producing countries partly because there are sometimes often considered as a way of redistributing gains from the countries' oil resources to the people (see McCulloch et al., 2021a). Thus, we focus on those countries and time period for which comprehensive panel data is available. Table 2 presents the 25 selected countries classified as developing countries based on the World Bank (2020) country grouping and considered oil-producing countries according to the US EIA (2022).

5 Result analysis and discussion

The summary statistics in Table 3 show that the annual average petroleum subsidies are sizable but widely varied across countries. Within the sample period, some countries had years in which subsidies were inexistent, thus explaining why the minimum value of subsidies is zero. The average emission intensity appears to be marginal across the sample countries. However, energy transition is still in its infancy as slightly more than a quarter of countries' energy portfolios consist of clean renewable fuels. Regulatory quality is also generally weak among the sample countries and trade constitutes a significant share of most countries GDP. The Fisher-type augmented Dickey-Fuller stationarity test (Dickey and Fuller, 1976) suggests that all the variables are level stationary. Lastly, the table also highlight the fact that data for some of our variables are missing for specific time periods. Specifically, our two primary outcome variables (REC and CO₂ intensity) have only 250 observations. Thus, we expect some data attrition in our regression results.

Table 3 Summary statistics

<i>Variable</i>	<i>Obs.</i>	<i>Mean</i>	<i>Std. d.</i>	<i>Min</i>	<i>Max</i>	<i>Fisher-ADF</i>
Energy transition	250	27.009	26.956	0.05	90.13	111.6272***
Carbon intensity	250	0.286	0.219	0.064	1.350	126.1145***
Energy subsidies	275	27,593	61,642	0	39,105	89.3319***
Regulatory quality	275	1.726	0.673	0.218	3.299	123.7923***
Economic growth	274	11,482	70,180	3,414.132	36,671	104.8959***
Trade	260	66.547	32.250	0.785	157.945	96.18740***

Notes: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 4 Pairwise correlation matrix

	<i>Etr</i>	<i>COi</i>	<i>Sub</i>	<i>RegQ</i>	<i>GDP</i>	<i>Trd</i>
<i>Etr</i>	1.000					
<i>COi</i>	-0.832***	1.000				
<i>Sub</i>	-0.500***	0.537***	1.000			
<i>RegQ</i>	0.464***	-0.380***	-0.149***	1.000		
<i>GDP</i>	-0.448***	0.430***	0.257***	-0.002	1.000	
<i>Trd</i>	-0.204***	0.298***	-0.105*	0.310***	0.431***	1.000

Notes: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

At this stage, we are unable to test for cross-sectional dependence because such a test often requires a strongly balanced panel. However, we employ the Pesaran test of cross-sectional dependence as a post-diagnostic (see De Hoyos and Sarafidis, 2006; Pesaran, 2004) and present the result in Tables 5 and 6. In Table 4, we present the pairwise correlation among the variables.

All the data used for estimation have been transformed to their natural log forms to minimise outliers, decrease variability in the data, and enhance the reliability of estimated parameters. As such, the estimated parameters are interpreted as measuring the degree of responsiveness of our outcome variables to changes in the explanatory variables. The

panel regression result on subsidies and energy transition is summarised in Table 5. The table consists of three sections. The first part contains the estimated coefficient based on four competing models while the second and third parts summarise the model robustness and model selection test respectively. Based on the Breusch-Pagan LM test of randomness, the null hypothesis of no random effects is rejected at a 1% level of significance. Meaning, the GLS random effect model is preferable over the Pooled OLS model (Breusch and Pagan, 1980). Next, based on the Hausman test, the null hypothesis of no systematic difference in the fixed and random effect coefficient is rejected at a 1% level of significance.

Table 5 Panel regression 1

<i>Variables</i>	<i>Pooled OLS</i>	<i>GLS random</i>	<i>OLS fixed</i>	<i>P-W</i>
<i>Sub</i>	-0.218*** [0.056]	-0.011 [0.013]	-0.010 [0.012]	-0.048** [0.023]
<i>RegQ</i>	0.991 [0.491]	0.467** [0.182]	0.421** [0.177]	0.724*** [0.178]
<i>GDP</i>	-0.916*** [0.178]	-0.389*** [0.122]	-0.309** [0.121]	-1.157*** [0.119]
<i>Trd</i>	-0.522*** [0.144]	-0.029 [0.039]	-0.022 [0.038]	-0.197** [0.088]
<i>Sub * RegQ</i>	0.045 [0.054]	-0.015 [0.016]	-0.017 [0.016]	0.049** [0.025]
<i>C</i>	15.511*** [1.419]	6.212*** [1.194]	5.406*** [1.147]	14.763*** [1.029]
<i>Model robustness check</i>				
<i>R</i> ²	0.553	0.391	0.372	0.520
Adj. <i>R</i> ²	0.543	-	-	-
F-stat.	57.61***	21.02*** ($\chi^2_{(5)}$)	2.92**	236*** ($\chi^2_{(5)}$)
Pesaran CD	-	-0.251	-0.644	-
No. obs.	239	239	239	239
<i>Model selection test</i>				
<i>Redundancy test</i>	<i>Hausman test</i>		<i>Breusch and Pagan LM test</i>	
<i>F</i> (23, 210) = 493.66***	χ^2 (5) = 22.48***		χ^2 (01) = 751.30***	
Ho: <i>FE</i> = 0	Ho: <i>b^F</i> – <i>B^R</i> = 0		Ho: <i>Var(u)</i> = 0	

Notes: **p* < 0.10, ***p* < 0.05, and ****p* < 0.01.

Standard errors are in parenthesis.

P-W: Prais-Winsten regression.

Pesaran CD: Pesaran test of cross-sectional dependence.

This implies that the fixed effect model is preferred over the random effect model (Hausman, 1978). To further reinforce the preference for the fixed effect model, a redundancy test is conducted (see Sul, 2019), and the null hypothesis of redundant fixed effects was equally rejected. However, post-diagnostic analysis of the fixed effect model reveals the existence of heteroskedasticity and serial correlation (see fixed 1 in Table 7). To correct these problems, we estimate a Prais-Winsten (P-W) regression based on panel-corrected standard errors (PCSEs) following the work of Daniel (2014). Holding all other variables constant, the result from the P-W regression revealed that petroleum subsidies negatively impact energy transition. This means that higher petroleum subsidies hinder the move away from fossil fuels to clean renewable energies.

This is because fuel subsidies often sap government expenditure on renewable energy and make them uncompetitive in the energy market (Montenegro and Ramirez-Alvarez,

2022). Huge and persistent fuel subsidies also create significant carbon lock-ins that make it difficult for countries to easily shift to modern clean energies (Saha and Carter, 2022).

Conversely, the result shows that higher regulatory quality promotes the transition away from fossil fuels towards clean renewables. Meaning, REC increases when governments formulate and implement sound policies and regulations that permit and promote private-sector development. Discriminatory policies such as targeted subsidies and tax waivers in addition to minimising administrative bottlenecks to setting up and operating investment enterprises are key policy incentives for encouraging investment in and uptake of clean technologies (Omri et al., 2022; Saadaoui and Chtourou, 2022).

Table 6 Panel regression 2

<i>Variables</i>	<i>Pooled OLS</i>	<i>GLS random</i>	<i>OLS fixed</i>	<i>P-W</i>
<i>Sub</i>	0.064*** [0.020]	0.001 [0.007]	0.008 [0.006]	0.019** [0.010]
<i>RegQ</i>	-0.431** [0.174]	-0.295*** [0.095]	-0.269*** [0.091]	-0.329*** [0.074]
<i>GDP</i>	0.254*** [0.063]	-0.224*** [0.062]	-0.326*** [0.062]	0.200*** [0.054]
<i>Trd</i>	0.274*** [0.051]	-0.005 [0.020]	-0.014 [0.019]	0.106** [0.034]
<i>Sub * RegQ</i>	-0.001 [0.019]	0.016* [0.009]	0.017** [0.008]	0.002** [0.009]
<i>C</i>	-5.781*** [0.502]	0.305 [0.625]	1.405** [0.592]	-4.137*** [0.505]
<i>Model robustness check</i>				
<i>R</i> ²	0.475	0.017	0.083	0.611
Adj. <i>R</i> ²	0.464	-	-	-
F-stat.	42.23***	28.55*** ($\chi^2_{(5)}$)	8.27***	92*** ($\chi^2_{(5)}$)
Pesaran CD	-	1.313	1.098	-
No. obs.	239	239	239	239
<i>Model selection test</i>				
<i>Redundancy test</i>	<i>Hausman test</i>		<i>Breusch and Pagan LM test</i>	
<i>F</i> (23, 202) = 222.03***	χ^2 (5) = 961.06***		χ^2 (01) = 716.93***	
Ho: <i>FE</i> = 0	Ho: <i>b^F</i> - <i>B^R</i> = 0		Ho: <i>Var(u)</i> = 0	

Notes: **p* < 0.10, ***p* < 0.05, and ****p* < 0.01.

Standard errors are in parenthesis.

P-W: Prais-Winsten regression.

Pesaran CD: Pesaran test of cross-sectional dependence.

However, the interaction result between petroleum subsidies and regulatory quality is positive and statistically significant. This suggests that even in the presence of petroleum subsidies, countries with strong regulatory quality are able to foster their clean energy transition agenda. This implies that government regulations that help to block subsidy leakages, prevent wasteful fuel consumptions, improve market competition, and enhance regulatory enforcement are critical to propelling countries from the dominant use of carbon-intensive fuels to a shift towards cleaner energy solutions. Thus, the existence of petroleum subsidies would not jeopardise the transition to clean renewable energies inasmuch as countries concurrently strengthen a policy that reduces overall system

inefficiencies and promote private-sector investment in critical areas of economic development such as clean energy solutions.

Other determinants such as GDP and trade appear to adversely impact countries energy transition. This is understandably so because all of the sample countries are oil-producing countries and thus, expansion in trade and economic growth will most readily be fostered and sustained by cheap oil resources at their disposal, making the rapid shift to renewables unattractive. This latter result is in line with the evidence provided in the works of Bekun and Alola (2022), Kumaran et al. (2020) and Jeetoo (2022).

Table 6 summarises the result of subsidies and decarbonisation. The table is structured similarly to Table 5 and the model selection procedure follows the same steps highlighted earlier. All the model selection test point to a preference for the fixed effect model. However, post-diagnostics of the fixed effect model reveal the presence of serial correlation and heteroskedasticity (see fixed 2 in Table 7). Thus, we estimate a PW regression that corrects panel standard errors. Assuming all other variables are held constant, the coefficient on subsidies is positive and statistically significant, indicating that large petroleum subsidies increase the carbon intensities of countries. Of course, this is because gasoline is a significant source of carbon emission and government subsidies that encourage its consumption promote even more emission per unit of economic output (Majidpour, 2022; Solarin and Al-Mulali, 2022). However, this is not the case with regulatory quality as the coefficient is negative and statistically significant, implying that strong regulatory quality helps to decarbonise economies. This later finding is in line with existing evidence suggesting that through stringent and effective environmental policy choices, strong institutions and regulations helps to tame unabated emissions and aid clean energy investment, production, and consumption (Chhabra et al., 2023; Farooq et al., 2023; Wenlong et al., 2023).

Table 7 Diagnostic test

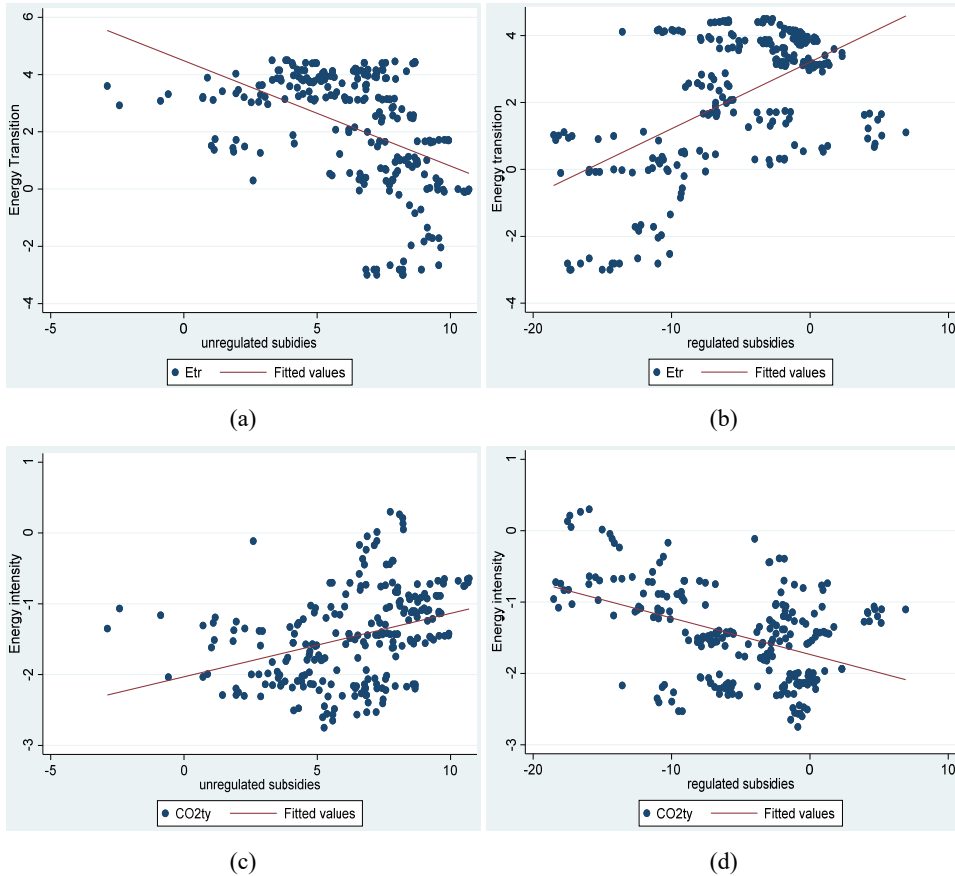
<i>Model</i>	<i>Multi-collinearity</i>	<i>Heteroskedasticity</i>	<i>Serial correlation</i>
Fixed 1	<i>Mean VIF</i> = 7.56	χ^2 (24) = 66,287.73***	$F(1, 23) = 22.738***$
Fixed 2	<i>Mean VIF</i> = 7.56	χ^2 (24) = 1,791.16***	$F(1, 23) = 87.067***$

Notes: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Furthermore, the result from the interaction term between petroleum subsidies and carbon intensity is positive and statistically significant. This implies that countries with high petroleum subsidies and strong regulatory quality may still face challenge in reducing their energy intensity level. One explanation for this is that although government regulation may help to foster investment in clean energy solutions, if alternative fossil energy sources remain cheap due to subsidies, firms would prefer to go for cheaper options and thus continue to emit carbon dioxide per unit of output. Besides, if regulations restricting carbon emissions are not enforced across all production units, there is a tendency for carbon leakages where some sectors utilise more petroleum fuels due to lower energy prices precipitated by the fall in demand from sectors that face those regulations. Other determinants such as GDP and trade significantly increase the carbon intensities of countries too. This is because all the countries are oil-producing, and expansion in trade volumes and economic growth is more easily propelled by cheap oil resources that emit a substantial amount of carbon per unit of economic output due to

incomplete combustion (see Kongkuah et al., 2022; Ostic et al., 2022; Rahman and Alam, 2022; for similar finding).

Figure 2 Scatterplot of subsidies, energy transition, and carbon intensity (see online version for colours)



In Figure 2, we present a scatterplot of our petroleum subsidy data with and without interaction with our regulatory quality variable. In Figure 2(a), petroleum subsidies without the interaction with regulatory quality is defined as unregulated subsidies and plotted against our variable of energy transition. It would be observed that the relationship between these two variables is significantly negative, reinforcing our earlier finding that petroleum subsidies adversely affect energy transition in our selected sample countries. However, when petroleum subsidies data is interacted with regulatory quality variable to capture the effect of more regulated subsidies devoid of inefficiencies and leakages, we observe that the impact of the interaction on energy transition of countries becomes positive as shown in Figure 2(b). Again, this result corroborates our early findings summarised in Table 5 which shows that subsidy payments made within a strong regulatory environment are beneficial for energy transition.

We repeat this exercise for our energy intensity variable. In Figure 2(c), as in Figure 2(a), we present a scatterplot of petroleum subsidy data without interacting with

regulatory quality variable and called this, unregulated subsidies. This data is then plotted against the energy intensity levels of countries, and we observe a strong positive relationship between the two variables, similar to the result obtained in Table 6. As shown in Figure 2(d), by accounting for countries' regulatory quality strength, the relationship between regulated subsidies and countries' carbon intensity reverses by a significant margin which is in line with the coefficient of our interaction variable between subsidies and regulatory variable presented in Table 6. Thus, these results provide a graphical representation of our findings from the estimated coefficients presented in Tables 5 and 6.

6 Conclusions

Climate change is an existential problem and perhaps currently the most threatening crisis to the human race. Recent times have witnessed increased frequency and intensity of extreme weather events causing colossal loss of lives and properties. Tackling the climate crises require a drastic and rapid shift in global energy systems that currently emit a significant amount of greenhouse gas causing the climate crises. The transition away from fossil-based fuels to clean renewable energies is already underway. However, it is not happening at a pace fast enough to avoid catastrophic and irreversible consequences of climate change. According to the IIED (2022), this delay is particularly pronounced in developing countries where the climate crisis is expected to hit harder. Yet the use of fossil fuels is heavily subsidised in these countries. This reality underscores the imperative of a carefully designed transition and decarbonisation plan based on context-relevant evidence.

This study examines the impact of petroleum subsidies on energy transition and decarbonisation in 25 developing oil-producing countries between 2010 and 2020. The result from the PW regression revealed that petroleum subsidies hinder the transition to clean renewable energies and increase the carbon intensity of developing oil-producing economies. However, government regulatory quality promotes the transition to clean energies and helps to decouple economic growth from carbon emissions. Furthermore, regulatory quality was found to help reverse the adverse impact of petroleum subsidies on energy transition. However, this is not true for decarbonisation as regulatory quality still led to higher carbon intensity in the presence of petroleum subsidies. Other factors such as trade and growth were found to hinder energy transition and decarbonisation.

This result for developing oil-producing countries implies that despite the engrained priority of promoting economic development using available fossil fuels, there is a need to phase out petroleum subsidies as such subsidies not only prevent the shift to clean energies but also encourage massive carbon emissions. However, the removal of fuel subsidies should be accompanied by comprehensive compensatory pay-outs to vulnerable households and firms that are at risk of being adversely impacted by high energy prices. Additional social programs involving re-skilling and upskilling of labour would also be pertinent in harnessing the socioeconomic benefits of a transition to sustainable energy systems. In addition, these countries also need to strengthen the regulatory quality, particularly in terms of formulating and implementing policies that minimise inefficient energy price interventions and favours market competition and private sector-led investment environment to boost renewable energy solutions.

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