**Examining the Impact of Mineral Export Controls on Sustainable Energy Transition in the Global South**

**Abstract:** Export control policies for mineral resources may constrain the development of countries in the Global South. This study used data from 31 countries from 2009 to 2021 and employed a double fixed effects (FE) model to explore the impact of mineral resource export control policies implemented by countries in the Global South on sustainable energy transition. Our results show that prohibiting the export of base metals and ores significantly inhibits energy transitions. Moreover, energy transition performance improves when only licensing requirements are implemented without the enforcement of export bans and taxes. This study also highlights the importance of improved governance in mitigating the adverse effects of export prohibitions. Improvements in governance, such as corruption control, regulatory quality, rule of law, and voice/accountability, provide institutional guarantees for sustainable energy transition. This study also provides insights into measures that can help the countries in the Global South to balance resource conservation and clean energy development.

**Keywords:** Mineral resources; Base metals; Export controls; Renewable energy consumption; Energy transition

# Introduction

Mineral export control measures substantially impact the pace and path of global energy transition. The global use of various fossil energy sources has exacerbated climate change and environmental pollution problems (Feng et al., 2024; Kim and Cho, 2023; Li et al., 2017; Song et al., 2022; Zhao et al., 2024). Renewable energy transformation is gradually moving on the right track with the recent maturity of renewable technologies such as wind and solar energy. For this transformation process, minerals such as lithium, cobalt, and rare earth elements are indispensable materials for efficient batteries, electric vehicles, and other clean energy technologies (Arrobas et al., 2017; World Bank, 2023). The availability of these minerals directly affects the cost, development speed, and eventual market promotion of renewable energy technologies. More than three billion tons of metallic minerals are expected to be required for renewable energy production to combat the effects of climate change by 2050 (Arrobas et al., 2017; World Bank, 2023).

However, the distribution of these essential mineral resources is geographically uneven, with the Global South (including, but not limited to, sub-Saharan Africa, Latin America, and the Caribbean) holding a significant proportion of resource reserves (**Fig. 1**). This uneven distribution has led resource-rich countries to occupy key positions in global supply chains. To protect their economic interests and resource security, these countries often resort to imposing export control measures such as high tariffs (Bouët and Debucquet, 2012), export quotas (Charlier and Guillou, 2014), or even bans on the export of certain vital minerals altogether (Pandyaswargo et al., 2021). The list of raw material export restrictions provided by the OECD includes 60 countries, with 50 countries of those having at least one ore or metal subject to varying degrees of export control (as of 2020). Although these policies can increase a country’s trade income and protect domestic industries in the short term (Fliess et al., 2017; Saygili et al., 2018), from a global perspective, they may impact the cost and development speed of renewable energy technologies, increase the uncertainty and complexity of global energy transitions (Ahmed et al., 2023; Wang et al., 2024a).



**Fig. 1.** Export product share of ores and metals by world region, 2009‒2020.

First, mineral export control measures hinder the global flow of mineral resources and increase global market prices (Chen et al., 2021), thereby increasing the production cost of renewable energy technology, which may hinder the development of renewable energy. Second, export controls have sharply increased the instability of the supply of these raw materials, making companies and investors more worried about future market uncertainty (Machacek and Fold, 2014; Mancheri, 2015), making them cautious about investing in renewable energy projects. Finally, these policies also cause international conflicts (Charlier and Guillou, 2014; Mineiro, 2011), inhibit international cooperation and technological exchanges, and limit the innovation and popularization of renewable energy technologies.

For resource-rich mineral-producing countries, implementing export controls may result in a resource curse (Han and Heng, 2024; Nkoa et al., 2023; Song and Hou, 2024), leading to slow economic growth (Chen et sl., 2023; Zhang et al., 2024), political instability, and social injustice, thereby limiting the policy formulation and implementation required for countries to engage in long-term sustainable development and neglecting investments in renewable energy infrastructure. In addition, relying on the mineral revenue raised by export taxes leads to economic simplification (Abdelwahed, 2020), increases a country’s sensitivity and vulnerability to global market changes, and reduces investments in sustainable development in the government and private sectors.

Therefore, this study aims to provide an in-depth exploration of the impact of export control measures in the mineral sector of the Global South on energy transition and compare the intensity of the impacts of different control measures. Specifically, the study focuses on the most stringent export control measures, the export ban, and the impact of other measures, such as licensing requirements and export taxes, on energy transition. In addition, global governance indicators were introduced into the research framework to explore whether governance improvements can moderate the implementation effect of export controls on renewable energy transition to promote the balance between resource exports and sustainable development.

The results show that when an export prohibition is imposed on at least one ore or metal, it significantly reduces the proportion of renewable energy consumed and hinders energy transition. Specifically, export prohibitions disrupt the supply chains of critical minerals, such as cobalt, lithium, and rare earth elements, which are essential for the production of batteries, electric vehicles, and other renewable energy technologies. With respect to export restrictions, simply imposing licensing requirements yields noticeably better results for energy transition. Licensing allows for controlled, yet flexible, mineral exports and facilitates smoother transitions to renewable energy. However, there is no evidence indicating that energy transition performs better under various export taxation scenarios (such as, export taxes, fiscal charges, and surcharges) than when an export ban is in place. Finally, the results of the moderating effects show that governance indicators such as corruption control, regulatory quality, rule of law, and voice/accountability significantly mitigate the negative impact of export prohibition on energy transition. Effective governance ensures transparent and efficient implementation of export controls, reduces uncertainty, and fosters an environment conducive to renewable energy investments.

This study makes three key contributions to existing literature. First, it fills a research gap regarding the impact of export control policies on energy transition. Previous research on export control policies has focused on the impact on the export prices (Chen et al., 2021) or production performance (Fliess et al., 2017) on downstream products. However, empirical testing of the actual impacts of these regulatory policies on energy transition is lacking. This study emphasizes the crucial role of key minerals, such as cobalt, lithium, and rare earth elements, in global energy transition. These minerals are essential for developing key renewable energy technologies, including efficient batteries and electric vehicles, which are integral to reducing greenhouse gas emissions and combating climate change (Arrobas et al., 2017; World Bank, 2023). This study emphasizes that export control measures, particularly prohibitions, can severely disrupt the supply of these crucial minerals, thereby impeding technological advancements and slowing the global shift towards renewable energy sources.

Furthermore, previous studies have examined only one export control policy (Charlier and Guillou, 2014; Waschik and Fraser, 2007). In contrast, the current study examines three regulatory policies (export bans, licensing requirements, and export taxes) and compares their differential impacts on energy transition. This enables us to better understand the specific mechanisms by which different regulatory measures affect energy transitions.

Finally, this study introduces governance indicators (corruption control, regulatory quality, rule of law, voice and accountability, government efficiency, political stability, and the absence of violence/terrorism) as moderating variables to explore the role of governance in mitigating the negative impact of export prohibitions on energy transition. Although some studies have explored the impact of governance on the environment (Ahmad et al., 2021; Vatamanu and Zugravu, 2023), the moderating role of export controls on energy transitions has not yet been thoroughly studied. Our results show that governance can alleviate the negative impact of export prohibitions on energy transitions to a certain extent, providing a new perspective and method for achieving a balance between resource exports and sustainable development.

This study aims to reveal the impact mechanism of export controls on energy transition and provide policy recommendations for global energy transition and the sustainable utilization of mineral resources by utilizing panel data from 31 countries in the Global South and adopting a fixed-effects regression model. This study provides policymakers with strategic recommendations, based on empirical research, to address the challenges of global energy security and climate change.

The remainder of this paper is organized as follows: Section 2 presents the literature review and theoretical hypotheses. Section 3 introduces the research design, (including the theoretical mechanisms), model settings, and data. Section 4 presents the empirical and robustness test results. Section 5 discusses and analyzes the results, and Section 6 concludes the paper and discusses policy recommendations and limitations.

# Literature review and theoretical hypotheses

Our literature review shows that existing literature mainly focuses on the relationship between export controls and economic factors such as price fluctuations (Chen et al., 2021), production performance (Fliess et al., 2017), and innovation performance (Anwar et al., 2024). Studies conducted specifically on the impact of export control measures on the transition to renewable energy are limited. Therefore, the current study contributes to the literature on trade policy and sustainable development by examining the impact of mineral export controls on energy transition.

The impacts of trade policies (such as export controls and tariffs) on sustainable development have been confirmed from multiple perspectives (Dai and Du, 2023; Klotz and Sharma, 2023; Liu et al., 2024b; Liu et al., 2020; Shapiro, 2021; Yan, 2024; Yu et al., 2024; Zhang and Zhao, 2024). As a trade policy, export control measures are often formulated for positive purposes such as reducing price fluctuations (Bouët and Debucquet, 2012), increasing government revenue (Waschik and Fraser, 2007), and protecting the environment and natural resources (Korinek and Kim, 2010; Fliess et al., 2017). However, studies show that export control policies have had a number of negative impacts on the economy, society, and environment (Anwar et al., 2024; Charlier and Guillou, 2014; Liu et al., 2020; Korinek and Kim, 2010; Rude and An, 2015). Nevertheless, few studies have examined the impact of export controls from the perspective of energy transition.

## *2.1. Challenges to energy transition from mineral trade controls*

Theoretically, mineral export control measures affect the energy transition in several ways. Optimistically, export controls may increase the supply of these resources in the domestic markets of mineral-producing countries (Fliess et al., 2017), protect downstream industries (Korinek and Kim, 2010), stimulate demand for renewable energy technologies, and thus, promote energy transition. However, these policies also pose additional risks and challenges:

First, strict trade controls hinder the global flow of mineral resources and restrict renewable energy development. Mineral resources, especially raw materials such as cobalt, which are indispensable in almost all clean energy technologies (World Bank, 2023), play a vital role in global energy transition (Arrobas et al., 2017; World Bank, 2023). However, owing to widespread export controls on mineral resources in the Global South, many metals and ores are prohibited from export (Fliess et al., 2017), resulting in severe restrictions on resource supply and rising global market prices (Chen et al., 2021), increasing the production costs of renewable energy technologies, thereby potentially hindering the development of renewable energy. Second, export controls reduce the supply stability of the market, increase the uncertainty of project development, and expose companies and investors to more risks and concerns (Machacek and Fold, 2014; Mancheri, 2015), resulting in delays or cancellations of renewable energy projects. Finally, these policies, especially those involving export prohibitions, can cause international conflicts (Charlier and Guillou, 2014; Mineiro, 2011), inhibit international cooperation and technological exchanges, and limit the innovation and popularization of renewable energy technologies. Therefore, this study proposes hypothesis 1.1:

**H1.1:** Export prohibition on minerals hinders energy transition.

Export prohibitions are the most stringent export control measures. They prohibit the outflow of resources and deprive people of their export rights to a great extent. In comparison, other measures, such as export licensing and export taxes, appear relatively flexible. With no export prohibition, some licensing systems only increase the time required for trade, and their impact on the economy is relatively small. Through licensing, governments can implement different control strategies and adjust export volumes as required (EU Commission, 2020; WTO, 2020), ensuring market stability while promoting the development of green energy. However, the situation can become more complicated with the various types of export taxes. Although taxes allow for the export of resources, they increase the price of exported goods, leading to an increase in resource costs (Chen et al., 2021; Fliess et al., 2017), and forcing some companies to find alternative markets or adjust their production processes to adapt to the tax burden. They also reduce a company’s export performance (van der Marel, 2017) and energy efficiency (Cui et al., 2023), both of which are detrimental to renewable energy development. Therefore, this study proposes hypotheses 1.2 and 1.3.

**H1.2:** License requirements are less of an impediment to energy transition than export prohibitions.

**H1.3:** No significant difference between export taxes and prohibition hinders energy transition.

## *Trade controls and sustainable energy transition: the moderating role of governance indicators*

Improved governance is typically accompanied by a transparent regulatory system (Massuga et al., 2023), efficient resource allocation (dos Santos and Rover, 2019), and robust supervision mechanisms (Hou et al., 2021). These improvements can help increase information transparency (Lim, 2022), stimulate corporate innovation (Zhou et al., 2024), and reduce trade costs (Hou et al., 2021), thereby creating a more favorable environment for sustainable energy transitions. Even if export prohibition harms energy transition, under a superior governance environment, companies and people can easily obtain clear energy policy information (Lim, 2022), flexibly adjust energy usage, and reduce the costs of renewable energy and investment uncertainty. Jiang et al. (2022) showed that a favorable institutional environment helps to mitigate the adverse effects of trade barriers. The advantage of an institutional environment is that it reduces trade costs (Hou et al., 2021), and companies are more willing to conduct research, develop, and produce renewable energy. Simultaneously, strengthening supervision mechanisms ensures policy implementation and prevents possible abuse (Afolabi, 2023). Thus, this study proposes hypothesis 2.1:

**H2.1:** Improved governance mitigates the negative impact of mineral export prohibitions on energy transitions.

## *2.3. Research gaps*

Few studies have analyzed the impact of export controls from the perspective of renewable energy transition, and empirical testing is lacking. Previous studies have focused on price fluctuations (Charlier and Guillou, 2014; Chen et al., 2021; Rude and An, 2015; Sun et al., 2022) and production performance (Anwar et al., 2024; Fliess et al., 2017) to observe the consequences of export control policies. Studies have also usually examined only one export control policy (Charlier and Guillou, 2014; Waschik and Fraser, 2007) and rarely compared different export policies. Finally, the moderating role of national governance indicators in the relationship between export controls and energy transition has not yet been thoroughly studied.

Considering these limitations, we conducted an in-depth analysis of the impact of mineral resource control policies implemented by countries in the Global South on renewable energy transition. We examined the impact of three mineral export control measures (export prohibition, licensing requirements, and export taxes) on energy transition to compensate for the lack of research in related fields. In addition, we verified the regulatory role of governance improvements in the relationship between metal export controls and energy transition.

# 3. Research design

## *3.1. Theoretical framework*

International trade theory provides a theoretical basis for analyzing the impact of mineral resource control on economic output and comparative advantage. According to the theory of comparative advantage, a country should focus on producing products that have a comparative advantage and obtain other products through trade (Acharya and Perez-Pena, 2020). However, export controls on mineral resources may undermine this theoretical premise and harm the global trade efficiency of countries (Dincer and Tekin-Koru, 2020). Previous studies (Fliess et al., 2017) have addressed the impact of mineral export controls on industrial performance and comparative advantages. However, their specific impact on energy transitions requires further in-depth research.

Energy transition theory focuses on factors that promote the evolution of a society’s energy structure in a more sustainable direction. Previous research (Arrobas et al., 2017) has emphasized the critical role of mineral resources in the renewable energy transition, especially the indispensability of irreplaceable metals (such as cobalt and zinc) in clean energy technologies, such as wind energy, solar energy, and hydropower (World Bank, 2023). However, in the context of trade barriers and mineral export controls faced by countries in the Global South, solving these problems to promote energy transition remains an under-researched issue.

Governance theory provides a framework for analyzing state behavior in mineral export controls. Governance levels play a vital role in promoting energy transition process (Massuga et al., 2023; Vatamanu and Zugravu, 2023). Adeyemi (2023) found that regulatory quality can mitigate the negative impact of natural resource extraction on sustainability goals. In addition, effective governance can provide a good foundation for balancing trade measures and energy transitions by strengthening supervision mechanisms (Afolabi, 2023), optimizing resource allocation (dos Santos and Rover, 2019), and improving information transparency (Lim, 2022).

In summary, we used international trade, energy transition, and governance theories, to jointly construct a theoretical framework for exploring the impact of mineral resource control policies on renewable energy transition in southern countries.

## *3.2. Modeling*

We used a fixed-effects model to analyze the impact of national mineral resource export control measures in the Global South on energy transition. Heterogeneity cannot be ignored, given the differences in economic levels, internal environments, and policy implementation across countries, and time-varying factors need to be considered. Therefore, we included both individual and time fixed effects in our model (Wang et al., 2024b). The first step was to test the overall performance of the sustainable energy transition in the case of controls on various types of metals or ores that contain export prohibitions. The first model was established as follows,

|  |  |
| --- | --- |
| $$Energy\\_Trans\_{it}=α\_{0}+α\_{1}Export\\_Proh\_{it}+\sum\_{j=1}^{5}p\_{j}Control\_{it}^{j}+δ\_{i}+π\_{t}+ε\_{it}$$ | ,(1) |

where $Energy\\_Trans\_{it}$ is the explanatory variable representing the first $t$ year of the $i$ country’s energy transition, measured using the share of renewable energy consumption in total energy consumption. $Export\\_Proh\_{it}$ is a proxy for export prohibition: if $i$ country in $t$ year includes export prohibition in its mineral resource control measures, then $Export\_{Proh}=1;$ if export prohibition is not included, then $Export\\_Proh=0$ . We focused on export controls for base metals (Cu, Ni, Al, Pb, Zn, Sn, and other base metals) and ores (ore, slag, and ash), which were also included in the analysis. Five control variables were included in $Control\_{it}^{j}$ , namely economic growth, industrial production, natural resource dependence, foreign direct investment, and population density, and a detailed description of these variables is provided in **Table 2**. $δ\_{i}$ and $π\_{t}$ are country and time-fixed effects, respectively, and $ε\_{it}$ represent the error terms.

We introduced a series of control variables into the model. First, economic growth is closely related to the balance between energy supply and demand (Wang et al., 2021), and its connection to renewable energy transition has been widely confirmed (Karim et al., 2022). While the level of industrial production reflects the degree of industrialization in a country, highly industrialized countries usually have a higher demand for traditional energy, thereby inhibiting the growth of renewable energy consumption (Su et al., 2022). Similarly, Afolabi (2023) found that natural resource rents negatively affect the environment, especially in resource-rich countries. Foreign direct investment can introduce internationally advanced technology and management experience and accelerate the adoption and promotion of new technologies, which are crucial for the development of renewable energy technologies (Dossou et al., 2023). Finally, population growth also affects energy consumption (Muzayanah et al., 2022). We anticipate that by carefully selecting these control variables, we can improve the explanatory power of the study and credibility of the empirical results.

Second, we distinguished between the differences in the impact of the three regulatory measures (export prohibition, export licenses, and export taxes) on energy transition, and the second model was therefore constructed,

|  |  |
| --- | --- |
| $Energy\\_Trans\_{it}=β\_{0}+\sum\_{m=1}^{3}β\_{m}Export\\_Con\_{it}^{m}+\sum\_{j=1}^{5}q\_{j}Control\_{it}^{j}+δ\_{i}+π\_{t}+ε\_{it}$, | (2) |

where $Export\\_Con\_{it}$ is used to distinguish between different control measures. $Export\\_Con\_{it}=1$ represents export controls on ores or metals that do not include export prohibition and taxes but do include licensing requirements; $Export\\_Con\_{it}=2$ represents no export prohibition and licensing requirements but includes taxes; $Export\\_Con\_{it}=3$, represents the absence of export prohibition but includes taxes and licensing requirements; and $Export\\_Con\_{it}=4$ represents the inclusion of export prohibition. To perform the test, we used $Export\\_Con\_{it}=4$ as the reference group and generated dummy variables for the other categories, $Export\\_Con\_{it}^{1}$ , $Export\\_Con\_{it}^{2}$, and $Export\\_Con\_{it}^{3}$ are dummy variables generated when $Export\\_Con\_{it}=1, 2, and 3 $

In the third step, to explore the moderating role of governance between export prohibition and renewable energy transition in depth, we introduced an interaction term between governance and export controls in equation (1), and the third model was established as follows,

|  |  |  |
| --- | --- | --- |
|  | $Energy\\_Trans\_{it}=γ\_{0}+γ\_{1}Export\\_Proh\_{it}+γ\_{M}^{\*}Export\\_Proh\_{it}\*Moder\_{it}+γ\_{M}Moder\_{it}+\sum\_{j=1}^{5}r\_{j}Control\_{it}^{j}+δ\_{i}+π\_{t}+ε\_{it} $, | (3) |

where $Moder\_{it}$ is the moderating variable, and $γ\_{M}^{\*}$ measures the direction and magnitude of the moderating effect. We used six global governance indicators (corruption control, regulatory quality, rule of law, voice/accountability, government effectiveness, political stability, and the absence of violence/terrorism) as proxies for the moderating variables. These indicators represent the management and governance level of the national government: first, a high level of corruption control means that the government can effectively combat corruption and bribery, and can improve the fairness and transparency of resource allocation (Gao and Li, 2024; Wadho, 2013; Wang et al., 2020). Second, high-quality supervision and legal systems are conducive to supervising and managing resource extraction activities (Liu et al., 2024a; Yıldız et al., 2024), ensuring that they comply with regulations and environmental protection standards, while safeguarding resources. The legality and stability of extraction activities thereby mitigate the possible negative impacts of export control policies. Third, good voice and accountability help ensure that government decision-making in resource extraction is more democratic and transparent (Brunnschweiler et al. al., 2021; Chen et al., 2024; Liu et al., 2024a; Porumbescu, 2017). Fourth, efficient governments can better coordinate resource extraction activities and promote sustainable development and energy transformation (Wang et al., 2024a). Finally, political stability and a violence/terrorism-free environment help to create a safe and stable investment and operating environment and promote the smooth progress of resource extraction and energy transition (Han et al., 2024). Introducing these indicators can help us understand the coping capabilities of different countries under export control policies and the environments for resource extraction. It can also help policymakers formulate better resource management policies and energy transition strategies, and promote sustainable national development.

## *3.3. Data*

After processing and screening, we included data from 31 countries in the Global South from 2009 to 2021 (**Table 1**). The data on the core explanatory variable (export control measures on ores or metals) were obtained from the OECD Trade in Raw Materials. Data began being obtained in 2009 and the latest data were obtained in 2021, which represents the timeframe of this study. Data for the dependent variables (renewable energy consumption) the control variables (economic growth, industrial production, natural resource dependence, foreign direct investment, and population density), and the moderating variables (six global governance indicators) were collected from the World Development Indicators Database (WDI). **Table 2** provides a detailed explanation of the variables and the source information.

**Table 1**

List of countries.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Argentina | Gabon | Mexico | Sierra Leone | Kenya |
| Bolivia | Ghana | Mozambique | South Africa | Malaysia |
| Botswana | Guatemala | Myanmar | Viet Nam | Madagascar |
| Brazil | Guinea | Nigeria | Zambia | Democratic Republic of the Congo |
| Burundi | India | Philippines | Zimbabwe | Ethiopia |
| Chile | Indonesia | Rwanda | Senegal | Jamaica |
| Colombia |  |  |  |  |

**Table 2**

Description of variables.

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Variable symbol | Description | Source |
| Dependent variable | Energy\_Trans | Renewable energy consumption (% of total final energy consumption) | WDI |
| Independent variables | Export\_Proh | If export prohibition is included in the export control measures for minerals, then Export\_Proh = 1; otherwise, Export\_Proh = 0. | OECD-Trade in raw materials |
| Export\_Con | The finer classification of export control measures imposed on minerals: 1= No export prohibition and tax, but includes licensing requirement2=No export prohibition and licensing requirement, but includes tax (Export tax; Fiscal tax on exports; Export surtax)3= No export prohibition, but includes taxes and licensing requirement4=includes export prohibition |
| Control variables | GDP\_Growth | GDP growth (annual %) | WDI |
| Industrial  | Industrial value added (% of GDP) |
| Res\_Rent | Total natural resources rents (% of GDP) |
| FDI | Foreign direct investment, net inflows (% of GDP) |
| Pop\_Density | Population density (people per sq. km of land area) |
| Moderator variables | Mode | Corruption | Control of Corruption | WDI |
| Regulatory | Regulatory Quality |
| Law | Rule of Law |
| Voice | Voice and Accountability |
| Stability | Political Stability and Absence of Violence/Terrorism: Estimate |
| Effectiveness | Government Effectiveness |

**4. Empirical results**

*4.1. Impact of mineral export prohibition on energy transition*

We analyzed the impacts of mineral export prohibitions on energy transition and focused on the export control of base metals (including Cu, Ni, Al, Pb, Zn, and Sn) and ores (ore, slag, and ash). Base metals play a crucial role in high-tech industries and clean energy fields such as battery and electric vehicle manufacturing, which are directly involved in energy transition. Although ores are the early products of base metals, they are mainly supplied as raw materials to downstream industries. The empirical results are presented in Table 3, and the results with and without control variables are distinguished. Columns (1)–(2) indicate whether export prohibitions were included in the control measures for base metals, columns (3)–(4) focus on ores, and columns (5)–(6) combine base metals and ores together for observation. We found that the regression coefficient for export prohibition was significantly negative for both base metals and ores. This shows that the prohibition of mineral exports suppresses the proportion of renewable energy consumption to overall energy consumption and hinders the development of energy transition. Therefore, H1.1 was verified.

The following socioeconomic phenomena explain this empirical result: first, a critical point in international trade theory is comparative advantage. However, export prohibitions restrict international trade for southern countries that have relatively rich mineral resources. This weakens a country’s ability to utilize its comparative advantages, thus affecting its economic and resource allocation efficiencies and hindering the development of renewable energy technologies.

Second, although countries in the Global South are rich in mineral resources, they often have limited knowledge of renewable energy technologies (Cust and Zeufack, 2023), and export prohibitions weaken the possibility of international cooperation and technology exchange (Charlier and Guillou, 2014; Mineiro, 2011), thereby hindering cooperation between mineral-producing countries and other countries, limiting the spread and innovation of technology, and affecting the speed of energy transition.

Finally, export prohibitions have led to increased market instability. In producing countries, export prohibition prioritizes the supply of these mineral resources for domestic production and reduces prices (Fliess et al., 2017), whereas in importing countries, export prohibition leads to supply restrictions and increases in resource prices (Chen et al., 2021). This uncertainty results in investors and innovators exercising relatively caution when making risky renewable energy investments (Machacek and Fold, 2014; Mancheri, 2015). In addition, while mineral export prohibitions can lower the prices of these products in the markets of producing countries, they can also subsidize production in the processing sector. However, this also means that obtaining profits from the export of these materials is virtually impossible, which harms the interests of mineral producers and reduces the overall production return, thereby weakening the producers’ motivation for metal mining (Fliess et al., 2017).

Overall, the empirical results suggest that prohibiting mineral resource exports weakens the speed and effectiveness of energy transition, which further affects the economy. For example, energy transition usually creates new job opportunities (Swain et al., 2022), but export prohibition reduces the development of related industries and limits the increase in job opportunities, thereby affecting the overall growth and development of the economy. Moreover, energy transition is becoming a global economic development trend, and delays in energy transition caused by export prohibitions may result in mineral-producing countries missing opportunities to participate in this global trend, thereby affecting their status and competitiveness in the global economy.

For the control variables, the results show that economic growth, industrial production, and population density negatively and significantly affect the REC proportion of renewable energy consumption; therefore, these factors also harm energy transition. In many low-income countries in the Global South, the initial stages of development often witness a surge in economic growth and industrial production accompanied by a heightened demand for energy (Zhang et al., 2021). However, reliance on conventional energy sources tends to prevail in meeting this demand, thereby constraining the uptake of renewable energy (Su et al., 2022). A higher population density increases the intense competition for resources and energy consumption (Muzayanah et al., 2022), making a government more inclined to meet short-term energy supply needs while ignoring long-term renewable energy planning. In addition, the foreign direct investment (FDI) coefficient is positive and significant. As investments increase, more funds are used for technological research, development, and production, thereby promoting energy transformation (Dossou et al., 2023). Furthermore, we found no substantial evidence that natural resource rents affect renewable energy consumption.

**Table 3**

Impact of mineral export prohibition on energy transition.

|  |  |
| --- | --- |
| Dependent variable | Energy\_Trans |
| Export\_Proh for different mineral classifications | Base metals | Ores | Base metals and ores |
| Export\_Proh | -0.059\*\*(0.028) | -0.053\*\*(0.026) | -0.083\*\*\*(0.031) | -0.050\*(0.029) | -0.051\*\*(0.025) | -0.070\*\*\*(0.024) |
| GDP\_Growth |  | -0.018\*\*(0.008) |  | -0.021\*\*(0.009) |  | -0.016\*(0.009) |
| Industrial  |  | -0.090\*\*\*(0.018) |  | -0.088\*\*(0.040) |  | -0.081\*\*(0.039) |
| Res\_Rent |  | 0.001(0.015) |  | -0.020(0.016) |  | -0.005(0.016) |
| FDI |  | 0.019\*(0.010) |  | 0.022\*(0.011) |  | 0.019\*(0.010) |
| Pop\_Density |  | -0.360\*\*\*(0.070) |  | -0.307\*\*\*(0.070) |  | -0.334\*\*\*(0.070) |
| Constant | 0.050\*\*\*(0.011) | 0.009(0.012) | 0.006(0.012) | 0.289\*\*(0.128) | 0.013(0.012) | -1.319\*\*\*(0.137) |
| No. of observations | 341 | 341 | 347 | 347 | 368 | 368 |
| No. of countries | 29 | 29 | 29 | 29 | 31 | 31 |
| Country-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes:* 1) \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% levels, respectively; 2) standard errors are given in parentheses; 3) base metals include Cu, Ni, Al, Pb, Zn, and Sn; Ores refers to ores, slag, and ash.

*4.2* *. Differences in the impacts of mineral export prohibition, licensing requirements, and export taxes on energy transition*

In addition to export prohibitions, various forms of control exist, including licensing requirements (non-automatic exports) and export taxes. We therefore explored the differences in their impacts on energy transition, and the results are summarized in **Table 4**. In the empirical process, the group with export prohibition was used as the reference group, and the group without export prohibition was further divided into three categories: (i) licensing requirements only (i.e., Export\_Con1); (ii) export taxes only (i.e., Export\_Con2); and (iii) both licensing requirements and export taxes (i.e., Export\_Con3).

The regression coefficients of Export\_Con1 on energy transition were significantly positive, which implied that compared to the case with export prohibition, the energy transition performance was significantly better when only licensing requirements were employed in relation to either metals or ores. This verified hypothesis 1.2. Second, the coefficients for Export\_Con2 and Export\_Con3 were insignificant. Therefore, there was no evidence that export taxes hinder energy transition more or less than export prohibition, which supports our H1.3.

First, licensing requirements can preserve the mobility of resources to a certain extent, making resource allocation more flexible (Liefert et al., 2012) and promoting energy transition. Governments can regulate mineral resource exports by formulating reasonable licensing standards that provide clear guidance and regulations for the industry, reduce uncertainty, and help companies to make long-term plans and investments. By contrast, export prohibitions and tax policies are more susceptible to political and market fluctuations, bringing more uncertainty and risk to the industry.

Second, although export taxes and export prohibition differ in form and implementation, they affect the market supply and demand relationship, thereby leading to resource price fluctuations (Bouët and Debucquet, 2012; Chen et al., 2021), increasing enterprise production costs, and thus hindering energy transition. Licensing requirements are more transparent and predictable than export prohibitions and taxes. Governments can manage licensing requirements through open and transparent processes to ensure sustainable development and the rational use of resources.

In summary, governments should focus on developing transparent and operable licensing systems to reduce any negative impacts on renewable energy consumption. By rationally setting licensing standards and management procedures, it is possible to balance the relationship between resource utilization and environmental protection, and to promote the smooth progress of energy transformation.

**Table 4**

Impact of mineral export prohibition, licensing requirements, and export taxes on energy transition.

|  |  |
| --- | --- |
| Dependent variable | Energy\_Trans |
| Export\_ Con for different mineral classifications | Base metals | Ores | Base metals and ores |
| Export\_Con1 | 0.115\*\*\*(0.033) | 0.103\*\*\*(0.030) | 0.082\*\*(0.039) | 0.144\*\*(0.066) | 0.103\*\*\*(0.033) | 0.315\*\*\*(0.052) |
| Export\_Con2 | -0.009(0.040) | 0.039(0.038) | 0.083(0.053) | 0.094(0.092) | 0.013(0.045) | 0.090(0.072) |
| Export\_Con3 | 0.009(0.035) | -0.016(0.032) | 0.055(0.036) | -0.027(0.061) | -0.001(0.032) | 0.070(0.049) |
| GDP\_Growth |  | -0.012(0.008) |  | 0.005(0.016) |  | -0.019(0.014) |
| Industrial |  | -0.101\*\*\*(0.018) |  | -0.125\*(0.074) |  | -0.134\*\*(0.064) |
| Res\_Rent |  | 0.002(0.015) |  | 0.321\*\*\*(0.034) |  | 0.193\*\*\*(0.033) |
| FDI |  | 0.016(0.010) |  | 0.031(0.021) |  | 0.022(0.017) |
| Pop\_Density |  | -0.375\*\*\*(0.070) |  | 1.718\*\*\*(0.065) |  | 2.230\*\*\*(0.084) |
| Constant | -0.007(0.023) | -0.046\*\*(0.022) | -0.069\*\*\*(0.026) | -5.564\*\*\*(0.332) | -0.015(0.022) | -7.180\*\*\*(0.332) |
| No. of observations | 341 | 341 | 347 | 347 | 368 | 368 |
| No. of countries | 29 | 29 | 29 | 29 | 31 | 31 |
| Country-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes:* 1) \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% levels, respectively; 2) standard errors are given in parentheses; 3) base metals include Cu, Ni, Al, Pb, Zn, Sn; Ores refers to ores, slag, and ash.

*4.3**. Base metal export prohibition and energy transition: the moderating role of governance indicators*

Inspired by relevant studies (Adeyemi, 2023; Afolabi, 2023; Lim, 2022), we introduced six governance indicators and interaction terms for export prohibition to examine the role of national governance in export controls and energy transitions and the regulatory effect in between. The results in **Table 5** show that the four indicators of corruption control, regulatory quality, rule of law, voice/accountability, and the interaction term of export prohibition are all significantly positive, whereas the main effect is significantly negative. This indicates that improvements in governance in these four areas reduce the negative impact of export prohibitions on energy transition.

However, the terms of interaction corresponding to political stability, absence of violence/terrorism, and government efficiency are not significant. Although these two governance indicators did not significantly mitigate the negative impact of export controls, overall, improvements in effective governance can still positively reduce the adverse impact of export prohibition on the energy transition. Several studies have analyzed the impact of governance on the environment (Karim et al., 2022; Massuga et al., 2023; Vatamanu and Zugravu, 2023). Karim et al. (2022) found positive effects of corruption control, regulatory quality, and the rule of law on carbon emission reduction. Voice and accountability also benefit environmental sustainability (Massuga et al., 2023). Although political stability, the absence of violence/terrorism, and government efficiency have not been observed to weaken the negative impact of export controls (Massuga et al., 2023), there is no reason to say that they will strengthen this negative effect. Overall, the benefits of effective governance outweigh the disadvantages. Therefore, this result supports hypothesis 2.1.

Improving corruption control improves the transparency and efficiency of government departments and regulatory agencies (Gao and Li, 2024; Wadho, 2013), thus reducing administrative uncertainty and unfair policy implementation. This can reduce corruption during the implementation of export prohibitions and help to increase the confidence and investment of enterprises and investors in energy transition. In addition, improving regulatory quality can strengthen the effective supervision and implementation of export control policies, which helps prevent abuse and misconduct in policy implementation, and reduces the negative external impacts of policies.

The soundness of the rule of law and the strengthening of voice/accountability can enhance citizens’ and businesses’ participation and expression rights and promote the democratization and transparency of policymaking (Brunnschweiler et al., 2021; Porumbescu, 2017). This helps in improving the policy’s legitimacy and social acceptance (Massuga et al., 2023), reduces resistance and social conflict during policy implementation, and creates a good social environment for the smooth progress of energy transition. Finally, improvements in governance factors such as political stability, freedom from violence/terrorism, and government efficiency do not show significant effects in mitigating the negative effects of export controls, as they affect the overall economic and social stability of the country (Hamdaoui et al., 2022), rather than directly affecting the specific implementation process of the energy transition. Overall, improvements in governance can enhance a country’s ability to respond to trade-restrictive measures such as export prohibitions and reduce the hindrance of these measures to the energy transition process.

**Table 5**

Base metal export prohibition and energy transition: the moderating role of governance indicators.

|  |  |
| --- | --- |
| Dependent variable | Energy\_Trans |
| Classification of moderator variables | Corruption | Regulatory | Law | Voice | Stability | Effectiveness |
| Export\_Proh | -0.045\*(0.025) | -0.134\*\*\*(0.033) | -0.190\*\*\*(0.054) | -0.071\*\*(0.029) | -0.053\*\*(0.027) | -0.060\*\*(0.025) |
| Export\_Proh\* Moderator variable | 0.094\*\*(0.037) | 0.211\*\*\*(0.049) | 0.483\*\*\*(0.083) | 0.112\*\*\*(0.035) | 0.037(0.034) | 0.037(0.032) |
| Moderator variable | -0.159\*\*\*(0.023) | -0.230\*\*\*(0.032) | -0.873\*\*\*(0.047) | -0.113\*\*\*(0.033) | -0.004(0.024) | -0.210\*\*\*(0.029) |
| GDP\_Growth | -0.020\*\*(0.008) | -0.011(0.011) | 0.002(0.018) | -0.016\*\*(0.008) | -0.020\*\*(0.009) | -0.016\*\*(0.008) |
| Industrial | -0.061\*\*\*(0.018) | -0.084\*\*\*(0.025) | 0.064\*(0.039) | -0.07 5\*\*\*(0.018) | -0.082\*\*\*(0.019) | -0.073\*\*\*(0.017) |
| Res\_Rent | -0.013(0.016) | 0.094\*\*\*(0.020) | 0.044(0.033) | -0.002(0.016) | -0.008(0.017) | -0.007(0.016) |
| FDI | 0.023\*\*(0.010) | 0.047\*\*\*(0.013) | 0.065\*\*\*(0.021) | 0.021\*\*(0.010) | 0.013(0.010) | 0.025\*\*(0.010) |
| Pop\_Density | -0.427\*\*\*(0.155) | 2.020\*\*\*(0.093) | 0.373\*\*\*(0.136) | 0.252(0.212) | -0.397\*\*\*(0.150) | -0.450\*\*\*(0.139) |
| Constant | 1.792\*\*\*(0.628) | -6.715\*\*\*(0.274) | -0.538\*\*\*(0.118) | -0.854(0.845) | 1.665\*\*\*(0.610) | 1.870\*\*\*(0.566) |
| No. of observations | 341 | 341 | 341 | 341 | 341 | 341 |
| No. of countries | 29 | 29 | 29 | 29 | 29 | 29 |
| Country-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Time-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes:* 1) \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% levels, respectively; 2) standard errors are given in parentheses; 3) base metals include Cu, Ni, Al, Pb, Zn, Sn; Ores refers to ores, slag, and ash.

*4.4. Robustness testing and endogeneity issues*

4.4.1 Robustness check

This study analyzed the robustness of base metal export controls by individually incorporating control variables and conducting tests for heteroscedasticity, cross-sectional correlation, autocorrelation, and multicollinearity. Although previous sections have discussed ores, base metals remain the primary focus of this paper, as they are directly involved in critical stages of the energy transition.

The results in Table 6, where the control variables are added individually, indicate that the coefficient of the export ban on base metals remained consistently negative and significant, aligning with the main findings. Through Modified Wald, Pesaran’s, and Wooldridge tests significant evidence was found for heteroscedasticity, cross-sectional correlation, and autocorrelation problems, respectively (see **Table 6**); therefore, the Panel-Corrected Standard Error (PCSE) method was used for correction (the last two columns of **Table 6**). Even after accounting for these issues, the impact of prohibiting base-metal exports remained significant. Finally, regarding multicollinearity, the correlation matrix (**Table 7**) shows that the correlations between the explanatory variables were all below 0.5 and thus within the acceptable range. The variance inflation factor (VIF) value was also much smaller than the critical value of 10. In summary, the results of this study were verified as being robust and reliable.

4.4.2 Dealing with endogeneity issues

Endogeneity concerns may also arise due to omitted variables or bidirectional causation. Therefore, the endogeneity problem was addressed by performing a generalized moment estimation regression (GMM) and selecting “the number of government agencies responsible for implementing and managing export control policies” [[1]](#footnote-1) as the Instrumental Variable (IV). The number of government agencies responsible for implementing and managing export control policies reflects their importance and enforcement of these policies in a country or region (Jacobsen, 2019). Simultaneously, different agencies are responsible for the starting points and considerations of policies, which will differ, thus affecting the promulgation and implementation of the corresponding measures. Generally, the number of agencies managing export controls does not directly affect the potential energy transition.

Following a theoretical analysis, the IV requires further testing to confirm its effectiveness. An influential instrumental variable must satisfy the following two basic requirements: 1. Exogeneity: the IV is uncorrelated with the disturbance term; 2. Correlation: instrumental variables are related to endogenous explanatory variables. First, for the test of exogeneity, the P-value corresponding to the Hansen J statistic in **Table 6** was larger than 0.1; therefore, the original hypothesis (H0: all instrumental variables are exogenous) was not rejected, and the basic condition of instrumental variables (exogeneity) was met.

In addition, for the correlation test, the P-value of the statistic corresponding to the under-identification test was 0.002. Thus, the unrecognizable null hypothesis was rejected, and the identifiable intuitive meaning was that the instrumental variable was related to the explanatory variable. Under the condition of satisfying the correlation, it was also necessary to avoid the problem of weak instrumental variables, that is, to determine whether the instrumental variables were only weakly related to the explanatory variables. The F statistic corresponding to the endogeneity test in **Table 6** was significant, and the minimum eigenvalue statistic of the 9.368 value was greater than the corresponding critical value of 8.68; thus, the “null hypothesis of weak instrumental variables” was rejected. To be cautious, the limited information maximum likelihood method (LIML), which is less sensitive to weak instrumental variables, was also used for testing. The regression coefficients corresponding to the LIML method (-0.560) and the coefficient estimated by the GMM method (-0.563) were very close, confirming that there was no weak instrumental variable. The above results prove that this study’s selection of instrumental variables satisfied another basic condition, correlation, and they were not weak instrumental variables.

The regression results obtained after addressing the endogeneity problem are presented in the last two columns of **Table 6**. The coefficient of the base metal export prohibition is still significantly negative, which is consistent with the original result, thus validating the result.

**Table 6**

Robustness and endogeneity test results.

|  |  |
| --- | --- |
| Dependent variable | Energy\_Trans |
| Robustness test method | Adding control variables one by one | Addressing heteroscedasticity and cross-sectional dependence | Addressing autocorrelation | Endogeneity problem |
| GMM | LIML |
| Export\_Proh | -0.060\*\*(0.028) | -0.069\*\*\*(0.026) | -0.070\*\*\*(0.027) | -0.063\*\*(0.027) | -0.053\*\*\*(0.019) | -0.054\*\*\*(0.018) | -0.563\*\*\*(0.148) | -0.560\*\*\*(0.155) |
| GDP\_Growth | -0.025\*\*\*(0.009) | -0.020\*\*(0.009) | -0.021\*\*(0.009) | -0.022\*\*(0.009) | -0.018\*\*(0.008) | -0.004(0.005) | -0.015(0.012) | -0.016(0.012) |
| Industrial |  | -0.096\*\*\*(0.018) | -0.100\*\*\*(0.019) | -0.096\*\*\*(0.018) | -0.090\*\*\*(0.011) | -0.075\*\*\*(0.013) | -0.006(0.025) | -0.006(0.026) |
| Res\_Rent |  |  | 0.017(0.016) | 0.014(0.016) | 0.001(0.017) | 0.000(0.018) | -0.043\*\*(0.021) | -0.043\*\*(0.021) |
| FDI |  |  |  | 0.018\*(0.010) | 0.019\*\*(0.008) | 0.011\*(0.006) | 0.010(0.012) | 0.012(0.012) |
| Pop\_Density |  |  |  |  | -0.360\*\*\*(0.031) | -0.461\*\*\*(0.046) | -0.430\*\*\*(0.120) | -0.437\*\*\*(0.122) |
| Constant | 0.047\*\*\*(0.011) | 0.038\*\*\*(0.011) | 0.034\*\*\*(0.011) | 0.037\*\*\*(0.011) | -1.740\*\*\*(0.041) | -1.796\*\*\*(0.052) | -1.409\*\*\*(0.111) | -1.140\*\*\*(0.113) |
| Modified Wald test (for heteroscedasticity) | 1798.44\*\*\* | — | — | — |
| Pesaran’s test (for cross-sectional dependence) | 1.915\* | — | — | — |
| Wooldridge test (for autocorrelation) | — | 97.254\*\*\* | — | — |
| Exogeneity test: Hansen J statistic | — | — | 0.743(p=0.389) |
| Underidentification test (Kleibergen-Paap rk LM statistic) | — | — | 12.511\*\*(P=0.002) |
| First-stage F value | — | — | 6.696\*\*9.368>Critical value=8.68 |
| Minimum eigenvalue statistic | — | — |
| No. of observations | 341 | 341 | 341 | 341 | 341 | 341 | 337 | 337 |
| No. of countries | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 |
| Country-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time-fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Notes:* 1) \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% levels, respectively; 2) standard errors are given in parentheses; 3) these are the robustness results related to base metal export control measures. The base metals include Cu, Ni, Al, Pb, Zn, and Sn; Ores refers to ores, slag, and ash.

**Table 7**

 Correlation matrix and VIF test.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Correlation | Energy\_Trans | Export\_Proh | GDP\_Growth | Industrial | Res\_Rent | FDI | Pop\_Density |
| Energy\_Trans | 1.00 |  |  |  |  |  |  |
| Export\_Proh | 0.189\*\*\* | 1.00 |  |  |  |  |  |
| GDP\_Growth | 0.247\*\*\* | -0.057 | 1.00 |  |  |  |  |
| Industrial | -0.199\*\*\* | -0.295\*\*\* | 0.036 | 1.00 |  |  |  |
| Res\_Rent | 0.533\*\*\* | -0.096\* | 0.154\*\*\* | 0.313\*\*\* | 1.00 |  |  |
| FDI | 0.181\*\*\* | -0.230\*\*\* | 0.187\*\*\* | -0.114\*\* | 0.133\*\*\* | 1.00 |  |
| Pop\_Density | 0.060 | 0.469\*\*\* | 0.078 | -0.255\*\*\* | -0.145\*\*\* | -0.154\*\*\* | 1.00 |
| VIF |  | 1.42 | 1.10 | 1.33 | 1.22 | 1.20 | 1.41 |

*Notes:* 1) \*\*\*, \*\*, and \* denote significance at the 1%, 5%, and 10% levels, respectively; 2) Mean VIF = 1.28.

**5. Discussion and analysis**

Based on the above results, this section provides an in-depth discussion about the profound impact of mineral export control policies on sustainable energy transition and proposes implications for policy formulation and practice.

*5.1. Impact of Export prohibitions on Renewable Energy Transition*

The results of our study show that export prohibitions on mineral resources implemented by countries in the Global South significantly inhibit renewable energy consumption and hinder energy transition. Although export prohibition may ensure the supply of domestic mineral resources (Fliess et al., 2017; Korinek and Kim, 2010), it has also led to market closures, increased production costs, and investor concerns regarding the long-term development of the renewable energy industry. Producers cannot earn more profits through exports (Cust and Zeufack, 2023), and investors hold a more conservative attitude, which limits production expansion and international competitiveness of enterprises, leading to rigidity and technological progress within the industry (Chen et al., 2023; Ahmed et al., 2023). This slowdown is threatening the long-term development of the renewable energy industry. For example, cobalt is indispensable for the production of electric vehicle batteries (Hunter, 2019). Although the Democratic Republic of the Congo has abundant cobalt resources, frequent export prohibitions may lead to a break in the cobalt supply chain (Korinek, 2018), triggering trade disputes with trading partners (Hunter, 2019). This, in turn, affects the development of the global electric vehicle industry and hinders the popularization of clean energy.

This raises profound questions about the balance between policy development and resource protection. Therefore, when formulating export policies, governments must carefully consider long-term development and seek more flexible policy means to balance the conflict between resource protection and clean energy development.

*5.2. Comparison of Different Export Control Measures*

The study further shows that among the diverse forms of mineral export controls, energetic transition performs better when licensing requirements only are required, compared to when export prohibition and taxes are employed. Government control is limited when licensing requirements exist, and the focus lies on regulating the export behavior of enterprises rather than directly restricting their export volume or increasing costs (Liefert et al., 2012). This relatively mild regulatory approach helps to reduce the negative impacts on enterprises and uncertainty about production activities, thereby increasing production enthusiasm and the willingness of enterprises to export. In contrast, overly strict export prohibitions or high export taxes harm production enthusiasm and the willingness of companies to export, thus hindering the advancement of energy transformation.

These findings provide valuable insights for policymakers, supporting the argument in favor of flexible licensing systems over strict prohibitions or high taxation measures for mineral export control policies. For example, Zambia ended its double taxation policy on mining in 2021 (WHO, 2023). This change prompted a substantial increase in the scope of mining exploration (Reid, 2022) and created a more attractive investment environment (Mitimingi and Hill, 2021) that is conducive to promoting technological innovation and can provide more metal resources for energy transitions in the future. Therefore, policy flexibility and adaptability are crucial to promote the development of the clean energy industry.

*5.3. Role of Governance in Mitigating Negative Impacts*

The study also found that improvements in governance aspects (such as corruption controls, regulatory quality, the rule of law, and voice/accountability) can mitigate the negative impact of export prohibition on energy transition. Combined with the actual situation, a good level of governance usually means more transparent, efficient, and predictable government behavior (dos Santos and Rover, 2019; Hou et al., 2021; Wadho, 2013), reducing uncertainty and administrative obstacles, and enhancing the confidence and investment willingness of enterprises. Such an environment can help enhance industrial innovation capabilities, improve technological research, development, and application, and promote technological progress and innovation in energy transformation. Strengthening voice and accountability can enhance the government’s implementation of energy transition policies and their effectiveness and smooth implementation (Brunnschweiler et al., 2021; Porumbescu, 2017).

This result emphasizes the need to strengthen the governance of resource export controls. By strengthening the corruption control mechanism, governments can control illegal resource flows and more effectively supervise the reasonable allocation of resources (Guo et al., 2021). Improving regulatory quality helps deal with problems such as information asymmetry and poor implementation and ensures that the implementation of export prohibition is fairer and more transparent (Afolabi, 2023). A sound legal system can protect enterprises, encourage them to participate more actively in investment and development, and provide a stable and reliable operating environment for the renewable energy industry (Dossou et al., 2023). The voices of all parties can be better heard when the public and stakeholders participate effectively and where there is an accountability system for decision-makers; this can prevent decision-makers from abusing their power and ensure the fairness and rationality of policies. These improvements in governance provide adequate institutional guarantees to balance resource protection and clean energy development.

Therefore, comprehensively considering the long-term impact of export policies, adopting a more flexible licensing system, and strengthening governance levels are critical for promoting sustainable energy transition. These findings provide substantive insights into developing more progressive and sustainable policies to better position countries in the Global South toward a clean energy future.

**6. Conclusions**

This study focuses on export controls for base metals and ores and explores the impact of these measures on renewable energy consumption based on data from 31 countries in the Global South from 2009 to 2021.

The results indicate that the export prohibition on minerals significantly inhibits renewable energy consumption and hindered energy transition. The energy transition performs more positively when only licensing requirements are implemented, excluding export prohibitions and taxes. In contrast, the impacts of export taxes and prohibitions on energy transition are not significantly different. Improving governance indicators such as corruption control, regulatory quality, the rule of law, and voice/accountability can mitigate the negative impact of export prohibition on energy transition.

*6.1. Theoretical implications*

The theoretical implications of this study underscore the role of the international trade theory, which posits that countries should leverage their comparative advantages. However, export prohibitions have disrupted this balance, resulting in inefficient resource allocation and poor economic performance. Furthermore, the energy transition theory stresses the indispensable role of minerals in renewable energy technologies. Effective governance, characterized by transparency, regulatory quality, and accountability, has emerged as a crucial moderating factor that can mitigate the adverse effects of stringent export controls, thereby fostering a conducive environment for energy transition.

This study extends the current body of literature by empirically investigating the differential impacts of various mineral export control measures on energy transition. It fills a critical research gap by providing comprehensive insights into the unique effects of export prohibitions, licensing requirements, and export taxes on renewable energy consumption. In addition, the introduction of governance indicators as moderating variables offers a novel perspective on the interaction between policy measures and governance quality, further enriching the discourse on sustainable development and energy transition.

These findings support the implementation of transparent and predictable licensing systems as a strategic policy measure. Such systems not only support energy transition but also enhance investor confidence and technological innovation, which are crucial for the long-term development of renewable energy industries.

*6.2. Policy implications and recommendations*

This study also shows that stringent export controls, especially prohibitions, hinder energy transition by disrupting the supply of minerals critical for the development of renewable energy technologies. Effective governance, including corruption control, regulatory quality, and legal regulations, mitigates these effects. Flexible regulatory frameworks such as licensing requirements are preferable to bans or high taxes. Therefore, policymakers should focus on transparent licensing systems, strong governance, and international cooperation to balance resource conservation with economic development and sustainable energy transition.

When formulating mineral export prohibition policies, governments should carefully assess the costs and benefits. The impact of these policies on domestic market prices should be considered to minimize the adverse effects on producers and consumers, and the potential harm to mineral resource development should be evaluated to protect the interests of mineral producers. A precise exit mechanism for prohibition policies should be defined for timely adjustments. Governments should also engage stakeholders to consider the needs of renewable energy technologies and ensure policy rationality and feasibility, thereby reducing the use of prohibitions where possible.

Furthermore, governments should establish transparent and predictable licensing systems to attract investors and innovators to the renewable energy sector. Strengthening the supervision and management of the licensing process can reduce investor uncertainty and inspire confidence. Clear policies, consistent regulations, and online licensing systems can simplify processes, improve efficiency, and lower participation thresholds, thereby making renewable energy projects more attractive.

Strengthening governance is essential for reducing the negative impact of export prohibitions on energy transition. Governments can improve governance by ensuring just legal systems, combating corruption, formulating reasonable regulatory policies, and building transparent information platforms. A well-governed system will attract clean energy investments, promote technological innovation, and enhance industrial efficiency.

*6.3． Limitations and prospects*

6.3.1 Limitations

Although this study makes meaningful findings in exploring the impact of mineral export controls on energy transitions, it has certain limitations. First, owing to the lack of data and complexity of the model set, other export control measures that only exist among a small number of individuals, such as export quotas and captive mining, are not fully considered. Second, it is impossible to fully consider all external factors affecting energy transition, such as economic cycles and international trade. Finally, this study primarily focused on countries in the Global South without investigating other regions or regional disparities. Consequently, there are certain limitations to the generalizability and applicability of the findings.

6.3.2 Prospects

Future research could address the limitations of this study and drive the advancements in this field further by investigating several avenues. First, efforts can be made to gather more comprehensive and detailed data, coupled with diverse model specifications, to explore the impacts of other export control measures such as export quotas and self-mining. Second, future studies should consider additional external factors that may influence energy transitions, such as economic cycles and international trade dynamics. By incorporating these factors into an analytical framework, it would be possible to conduct a more holistic assessment of the effects of export control policies, leading to targeted policy recommendations. Finally, expanding the scope of this study to include other regions for cross-regional comparisons may be beneficial. Alternatively, focusing on a specific country’s environmental, policy, and economic conditions can provide a more detailed understanding of its responses to mineral export bans. For instance, examining government support policies for the clean energy industry, levels of technological innovation, and domestic market demand can offer comprehensive insights into a country’s energy transition pathways under export bans.

The relevance of mineral resources extends beyond immediate economic gains to include the sustainability and prosperity of future generations. Ensuring a steady supply of critical minerals for the development of renewable energy technologies can accelerate the global energy transition, reduce reliance on fossil fuels, and mitigate the impacts of climate change. Policymakers must consider the long-term implications of resource conservation to balance economic development with the sustainable use of mineral resources. By doing so, they can help ensure that future generations will inherit a world capable of supporting clean, renewable energy technologies and foster both environmental sustainability and intergenerational equity.

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1. The initial data source for instrumental variables is OECD-Trade in raw materials. [↑](#footnote-ref-1)