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RESEARCH PAPER

Good Governance in Large Energy-Consuming Economies: The Role of Energy Security and Environmental Sustainability Policies

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Abstract
The cultural, political, social, and economic dimensions of global stability are sensitive to the contribution of portfolio decisions of primary energy sources, especially for the world's large energy-consuming economies (L.E.C.E). This research aims to assess the impact of energy security policies (E.S.P)—the diversification of primary energy supply (D.P.E.S) and primary energy demand (D.P.E.D), and the environmental sustainability policy (E.V.P)—the clean energy portfolio (N.C.F.P), with the control variables including human development index (H.D.I), per capita gross domestic product (G.D.P), and economic complexity (E.C) on the performance of governance indices in a panel of twenty-five L.E.C.Es from 1998 to 2020. The findings support the causal and long-run relationships across the governance systems, applying the dynamic panel and panel cointegration models. The results also show that the impacts of E.S.P and E.V.P on the governance indices are heterogeneous. Specifically, the D.P.E.D positively affects the voice and accountability, political stability, and regulatory quality. Moreover, the development of D.P.E.S enhances the voice and accountability, government effectiveness, and control of corruption. Further, the government effectiveness and control of corruption are also positively affected in response to the N.C.F.P. Collectively, the government effectiveness, regulatory quality, rule of law, and control of corruption are more challenging aspects of good governance to achieve in response to energy system development. Accordingly, the objective priorities of good governance are necessary to improve the stability of the countries, especially when the E.S.P and E.V.P are formulated and implemented.
Keywords: diversification of primary energy, dynamic panel model, energy policy, good governance, large energy-consuming economies.
JEL Classification: C26, M14, Q42, Q55.

Introduction[1]

The organizations of public sector worldwide are under growing pressure to enhance efficiency, increase accountability, and improve sustainability (Amalia,

[1]. All abbreviations and acronyms are defined in the Appendix (Table of Abbreviations).

2023). Based on Kaufmann et al. (2010), G is defined as the cultural, political, economic, and social proceedings—the mechanisms, enforcement, rules, institutions, and traditions, exercised by the countries' authorities. G enhancement, i.e., corruption reduction and an increase in accountability and transparency, is the essential effort to achieve sustainable development (de Ferranti et al., 2009). It is also worth noting that the scope of P.D.P.E.S is not restricted only to the customary tasks of explicitly protecting the producers, consumers, and the environment. However, it also comprises the contributions to promote the cultural, political, and economic characteristics of the societies (Gaspari and Lorenzoni, 2018). Specifically, the national security, independence, and sovereignty are the major prerequisites observed by the countries to ensure G.G and global stability, which rely on E.S.P and E.V.P (Shirazi et al., 2023; Nasr Esfahani et al., 2021; Šprajc et al., 2019).

Besides, many resource-rich economies are involved in weak G performance regarding the corruption, conflicts, dysfunctional institutions, unsustainability, and sluggish economic activity. However, G.G in dynamic and complex systems is a continuous multidimensional challenge, which requires the organizational and institutional resilience in reaction to the potential drawbacks and conformity as the S dynamics evolve (Kanyepe, 2026; Lenhart and Fox, 2022; Brisbois et al., 2019; Al-Mavhubi, 2004). These challenges endanger the long-term performance and viability of public sector organizations, as well as social and environmental well-being (Singh et al., 2024). Therefore, the development of S, i.e., the technological dynamics and complexity, needs to focus on the initiatives, e.g., the resource diversity, affordable energy, and environmental protection (Shirazi, 2025a; Shirazi, 2025b; Shirazi, 2023; Bale et al., 2015). In this regard, the management of a country's energy sector can be considered a strategy to develop the G (Fredson et al., 2025), which refers to "breaking the resource curse" (Corrigan, 2014).

Recently, the social outcomes of energy aspects, called the 4A's—the availability, affordability, accessibility, and acceptability, have been the focus of worldwide think tanks (McCauley and Heffron, 2018; Heffron and McCauley, 2015) since the management of S is a major factor affecting the process of adopting government policies (Gunningham, 2013). Specifically, the E.S.P and E.V.P affect national security, influence the foreign relations and cause considerable effects on the world's geopolitical issues (Shirazi et al., 2023; Šprajc et al., 2019), which complicates the long-term process of the governments' strategic planning (Gapa, 2024; Farah, 2015). In other words, the E.S.P and E.V.P contribute to food security, livelihoods, and the green economy, leading to lower social costs of S development and hence, facilitate the sustainable economic development and global stability (Shirazi et al., 2023; Gaspari and Lorenzoni, 2018; Chêne, 2017; Adom, 2015). Consequently, the E.S.P and E.V.P are closely linked with the G, global stability, and sustainable development (Yanhua and Yichen, 2018).

This paper aims to assess the contribution of the E.S.P and E.V.P to promote the G.G and identify the effect of S management on the cultural, economic, and political dimensions of G across the twenty-five L.E.C.Es (The Global Energy Institute, 2020) in respect of the S improvement, leading to the national and global vulnerability reduction and sustainable development. Hence, to have an appropriate structure for the analysis, this research adapts the conceptualizations of the G (Kaufmann et al., 2010) as the broad classifications of public policies, policy objectives, rules and regulations, and incentives. This adaptation clarifies how the E.S.P.I—the D.P.E.S and D.P.E.D (Kuzemko, 2015; Ross, 2001; Treisman, 2000), and N.C.F.P (Smith et al., 2005), along with the control variables—the G.D.P, E.C, H.D.I, and C.P.I, contribute to G performance in respect of the cultural, political, economic and social proceedings.

G.I and E.S.P.I[1]

G.I

Based on Kaufmann et al. (2010), this research adapts the conceptualizations of the G and analyzes its performance by focusing on (i) the process by which governments are selected, monitored, and replaced; (ii) the capability of governments in effective formulation and implementation of sound policies; and (iii) the respect of the institutions by the states and citizens, governing the social and economic interactions among them. Hence, each area of the definition consists of two measures of G, and therefore six indicators of G are presented. The value of each indicator lies between -2.5 and 2.5, where the greater values refer to a better governance performance.

a. The process by which governments are selected, monitored, and replaced:

1. Voice and Accountability (V.A). The V.A measures the extent of perceptions, experienced by a country's citizens through the ability to choose the interested government, free media, and freedom level of expression and association.

[1]. All abbreviations and acronyms are defined in the Appendix (Table of Abbreviations).

2. Political Stability (P.S). The P.S measures the extent of the likelihood of perceptions that a government will be faced destabilization and overthrow through violent and unconstitutional means, to examine whether and how the absence of violence and terrorism.

b. The capability of governments in effective formulation and implementation of sound policies:

3. Government Effectiveness (G.E). The G.E measures the quality of public services, policy formulation and implementation, civil service and its independence level from the political and special interests, and the credibility of the government's commitment to such policies.
4. Regulatory Quality (R.Q). The R.Q measures the government's ability to formulate and implement regulations and sound policies to facilitate and promote the development of the private sector.

c. The respect of the institutions by the states and citizens, governing the social and economic interactions among them:

5. Rule of Law (R.L). The R.L measures the extent of agents' confidence in and adherence to the rules of society, particularly the quality of the judicial system, contract enforcement, property rights, and the likelihood of violence and crime.
6. Control of Corruption (C.C). The C.C measures the extent of public power in the security of private gains, including both petty and grand forms of corruption, as well as state capture by elites and private interests.

E.S.P.I[1]

The E.S.P.I cover several aspects (Yergin, 2006), e.g., the immediate physical availability, price affordability, transportation and transmission accessibility, and environmental, political, and social acceptability of primary energy resources (Sutrisno et al., 2021). Particularly, in terms of the immediate physical availability, an energy source is available if it is abundant enough to constitute an important recoverable resource. Moreover, the affordability of energy-source acquisition explains the economic dimension of E.S.P. Furthermore, the accessibility dimension of E.S.P refers to the transportation and transmission barriers, e.g., massive infrastructure investments, geopolitical factors, and long-term sales contracts. Finally, from the aspect of environmental acceptability, the E.V.P relates to an economy's success in switching from a carbon-intensive portfolio to N.C.F.P to achieve lower potential environmental degradation (Esily

[1]. All abbreviations and acronyms are defined in the Appendix (Table of Abbreviations).

et al., 2025; Shirazi and Fuinhas, 2023; Shirazi et al., 2021; A.P.E.R.C, 2007). Accordingly, the E.S.P.I are presented as follows:

a. D.P.E.D and D.P.E.S[1]

The D.P.E.D refers to the equity dimension of energy sources and ensures sustainable energy consumption. Besides, the D.P.E.S entails harnessing new energy resources, which requires investments and new technologies throughout the S. Therefore, the D.P.E.D and D.P.E.S balance the energy mix to cope with energy-market shocks. Particularly, it leads to a reduction in the volatility of fuel prices, contributes to the energy price stability and promotes the energy security and environmental sustainability, i.e., reducing the risk of undesirable changes in the availability, affordability, accessibility, and acceptability of the E.S.P.I, based on the preferred objective priorities of the S (Francés et al., 2013). Therefore, the Shannon index is modified in this research to calculate the D.P.E.D and D.P.E.S, measuring the resource demand and supply diversity, which is presented by the first and second E.S.P indicators shown below:

$$\mathrm{D} = -\sum_{\mathrm{i}=1}^{\mathrm{T}} (\mathrm{P_i} \ln \mathrm{P_i}) \tag{1}$$

$$\mathrm{D.P.E.D} = \frac{\mathrm{D_d}}{\mathrm{D_{d,max}}} \times 100 \tag{2}$$

$$\mathrm{D.P.E.S} = \frac{\mathrm{D_s}}{\mathrm{D_{s,max}}} \times 100 \tag{3}$$

where D is the Shannon's diversity index (D_d and D_s are the Shannon's demand and supply diversity index, respectively), P_i shows the share of each primary energy source ($\mathrm{P.E.S}_i$) in total primary energy consumption and production for the D.P.E.D and D.P.E.S, respectively. Further, $i = (1, 2, \ldots, T)$ is used to indicate T types of the P.E.S. When the calculated D.P.E.D is close to zero, the country's energy consumption is dependent on one P.E.S. At the same time, a value close to 100% illustrates that the economy's energy sources are equally distributed among the major P.E.S. The benefits of D.P.E.D can be achieved when energy sources can be substituted in the energy mix supported by the availability of energy sources and negative correlations among energy prices (Costello, 2007).

On the other hand, an economy succeeds in harnessing the new energy sources as the final value of D.P.E.S is close to 100%. While a value close to zero

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indicates that the country highly requires investments and new technologies throughout the S. Thus, the lower risks of availability, affordability, and accessibility dimensions of the E.S.P are identified as the higher values of the indicators being assessed (A.P.E.R.C, 2007). Notably, the major factors determining the benefits of D.P.E.S are classified as: (i) technology improvement, (ii) access to raw materials, (iii) production and exploitation cost, (iv) political factors, and (v) environmental conditions (E.I.A, 2021).

b. N.C.F.P[1]

The N.C.F.P reflects an economy's success in switching from a carbon-intensive portfolio to a clean energy portfolio. Accordingly, the N.C.F.P implies the contribution level of hydro, nuclear, and new and renewable energy sources (N.R.E) to the total primary energy demand (P.E.D), presented as follows (A.P.E.R.C, 2007):

$$\mathrm{N.C.F.P} = \frac{\mathrm{Hydro\ P.E.D} + \mathrm{Nuclear\ P.E.D} + \mathrm{N.R.E\ P.E.D}}{\mathrm{Total\ P.E.D}} \tag{4}$$

The N.C.F.P quantifies a country's progress toward alternative energy sources by improving the share of non-fossil fuel energy sources, applied to meet energy consumption, which satisfies the acceptability dimension of E.S.P.I. Therefore, a marked potential offset for lower environmental degradation of a country is concluded when a higher value of the indicator is obtained. Most importantly, if the switch to non-carbon-based fuels does not grow enough to cover the growth of future primary demand, the associated emissions will increase in the future. In this case, most countries will need to intensify their targeted efforts on potential CO_2 capture, utilization, and storage technologies (A.P.E.R.C, 2007) to achieve the United Nations sustainable development goals on CO_2 emissions reductions (Shirazi, 2025b; Shirazi and Šimurina, 2022).

Contributions of the Study

As the contribution of this paper, the applicable P.D.P.E.S—the essential adjustment factors affecting G and stability across both energy exporting and importing countries—are suggested. First, and based on the A.P.E.R.C (2007) classifications, the actual time series (A.T.S) of D.P.E.D, D.P.E.S, and N.C.F.P are calculated for the twenty-five L.E.C.E during 1998–2020. Secondly, the time

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series of the short-term fluctuations (S.T.F) and long-term trends (L.T.T) of the actual E.S.P.I are extracted using the Hodrick–Prescott (H.P) filter (1997) suggested by Ewing and Thompson (2007), to analyze the cross-country E.S.P.I. This decomposition helps to recognize the L.T.T and the intensity, time duration, and the number of S.T.F (ups and downs) of the mentioned indicators to follow the behavioral characteristics—risk and resilience—of the cross-systems stability through the E.S.P.I. Also, the potential endogeneity is mentioned as an issue in the relationship between the G.I and E.S.P.I, e.g., the D.P.E.D, D.P.E.S, and N.C.F.P, as the key E.S.P.I, and the major controlling variables, e.g., the H.D.I and per capita G.D.P adjusted by the purchasing power parities. The H.D.I is applied as the measurement of human development, provided by the United Nations Development Programme. It combines three indices, e.g., the income, educational attainment, and life expectancy, into a composite H.D.I. It is illustrated as a value in the range of 0 to 1, where 1 expresses the maximum level of human development. Since the G.D.P is considered one of the main components of H.D.I and has already been employed as the index of economic development, the non-income-based H.D.I is used in this paper to exclude its income component or dimension that is estimated by the United Nations Development Programme (Rontos et al., 2015). Then, the G.D.P and H.D.I are replaced by the E.C and energy prices (C.P.I), respectively, for a robustness check. Notably, G.G is affected by the behavior of economic agents, objects—the infrastructures and technologies, and the environment. In this regard, the E.C illustrates the combination of knowledge, innovation, productive structure, structural changes, and capabilities of the economic systems, shaping the patterns of G.D.P and H.D.I (Shirazi et al., 2023; Hidalgo and Hausmann, 2009). From the other aspect, the E.C is mentioned as the quality of the G.D.P (Shirazi, 2025a; Shirazi and Fuinhas, 2023; Laverde-Rojas et al., 2021). Also, the theoretical connectedness channel between the G.G and economic growth explains the influence of E.C on the G.G performance, where the productivity plays an intermediate affecting role in the innovation and technological improvements (Alvarez et al., 2017).

Economies are ranked based on how and to what extent their export portfolio is diversified. The countries that experience a great diversification of the “productive know-how”, particularly the “complex and specialized know-how”, can produce a considerable diversity of sophisticated commodities. The complexity of an economy is recognized to forecast current income volumes highly, or where the complexity is more than expectations for an economy’s income value, the economy is expected to experience more rapid growth.

Therefore, the E.C provides a convenient measure of a country's economic development (the Atlas of Economic Complexity, 2023). Moreover, the C.P.I complements the E.C to fill the gap related to the issue of purchasing power parities among countries since the C.P.I indicates the fluctuations in the prices through a basket of "consumer goods and services". Also, it has been widely applied as a proxy for the energy prices within the energy-related literature (Shirazi, 2025a; Shirazi and Fuinhas, 2023; Dabbous and Tarhini, 2021; Carfora et al., 2019, among others). Notably, the performance of the energy systems considers the effect of C.P.I on D.P.E.S (Roques et al., 2008). The higher the energy prices, the higher the D.P.E.S assessed, which entails harnessing the new energy sources. Particularly, it is conducive to the resource equity and abundance and a switch to the N.C.F.P (Li et al., 2016). Hence, it is necessary to control for the energy prices while studying the dynamics of G.G. Moreover, the C.P.I is used to represent energy prices as they are not available for all the economies considered in the sample as well. Specifically, regardless of the suggested determinants, any unobserved country-specific characteristics may affect the performance of G.I (Antonietti and Fontini, 2019). To this end, a two-fold procedure is applied in this study. First, a panel cointegration analysis is used to assess a non-spurious long-run relationship between the G.I and the major affecting factors. In the next step, a two-step difference generalized method of moments (G.M.M) technique is utilized to identify how the E.S.P.I affect G performance.

Accordingly, the following research questions are investigated to understand the energy-related G dynamics across the world's L.E.C.E:

- What are the patterns of A.T.S, S.T.F, and L.T.T of the E.S.P.I, e.g., D.P.E.D, D.P.E.S, and N.C.F.P, across the L.E.C.E?
- How and to what extent are the G.I, e.g., V.A, P.S, G.E, R.Q, R.L, and C.C, affected in response to the E.S.P (e.g., the D.P.E.D and D.P.E.S) and the E.V.P (e.g., the N.C.F.P), and the key control variables?
- What are the contributions of G.I to the G.G?

The overall findings of this research demonstrate that the contribution of V.A and P.S to the G.G is more elastic than the rest in the L.E.C.E, as the share of E.S.P.I and the control variables increases. Consequently, the role of P.D.P.E.S in G.G is identified as a necessary but not sufficient condition to overcome all the barriers in achieving the operational complexity and system reliability across the L.E.C.E. Hence, a trade-off process among the cultural, political, economic, and social objective priorities is required.

This paper is structured as follows. Section 2 presents the link between G.G and its determinants. Section 3 introduces the materials and methods. Sections 4 and 5 provide the results and discussion, respectively. Finally, the conclusions and policy implications are covered in section 6.

Literature Review

Linking the G. G and the G. D. P, E. C, H. D. I, and C. P. I

A wide range of dimensions of countries' economic systems is captured by the natural resource equity, trade openness, and economic development. They are the most relevant set of factors affecting G.G. Especially, institutions aim to increase legitimacy, deepen civil society and be pragmatic (Szulecki, 2018; Taylor, 2015), and satisfy social efficiency, which takes place if the created social returns are greater than the transaction costs (Konschnik, 2019; Fung, 2015; 2006). Accordingly, richer economies are more interested in better G since the sustainable economic development requires the cultural, social, and political improvements. Clearly, satisfying this requirement leads to a higher premium on countries' better G (Rontos et al., 2015, 2013; Lalountas et al., 2011; Huynh and Jacho-Chávez, 2009; Bardhan, 2006; Al-Marhubi, 2004; Leonardi et al., 2001; Harrison, 2000, among others). Harrison (2000) indicates that some scholars support a significant causal relationship between economic development and G.G. On the other hand, the opposite direction of causality is also concluded by Watari et al. (2021) and Kraay et al. (2013). Accordingly, from one side, G enhancement can lead to a sustainable energy transition (Watari et al., 2021) and a greater steady-state level of income (Giddens, 2015; Johansson et al., 2012; Steward, 2012; Grübler, 2003, among others). On the other side and based on Hidalgo and Hausmann (2009), the adequacy of exercised G principles (Simeone, 2021), gender diversity and human development (Ahmad et al., 2020), market monitoring and transparency in the decision-making (Kavulla, 2019; Edelenbos and Van Meerkerk, 2016), the independence of expert officials (Taylor, 2019), organizational learning (Newig et al., 2018), stakeholder engagement (Szulecki, 2018), and economic development (Gaspari and Lorenzoni, 2018) are the factors determining the G.G. Nevertheless, these factors can also create structural advantages for the institutions' interests and allow authorities to limit the scope of consideration of alternatives and decision-making. These processes fail to achieve balanced discourse and hence, reduce transparency (Crow et al., 2020; Brisbois et al., 2019; Newig et al., 2018; Scott and Thomas, 2017). These studies recognize the complexities of G in broadly technical policy settings but do not specifically focus on the relationship between the E.S.P.I and G performance.

Linking the G. G and E. S. P. I

The impact of natural resource demand and supply diversity on G is theoretically different. The first group of studies that are aligned with the purpose of this research suggests that G performance suffers explicitly from the E.S.P.I. Ross (2001) implies (i) a "rentier effect", suggesting a resource-rich government uses patronage policies and low tax rates to mitigate pressures for more accountability; (ii) a "repression effect", mentioning the resource wealth postpones democratization through enabling the government to boost its funding for national security; and (iii) a "modernization effect", holding that growth driven by the exploitation of resources fails to cause the cultural and social changes that are important to stimulate the creation of a democratic government. Also, Collier (2007) indicates that if the resource rents support a government through the substantial revenue, democracy is undermined by the corruption and patronage policies. This result is because the checks and balances process breaks down. Consequently, the institutions cannot remain strong.

The second classification of the studies indicates both explicit and implicit effects of the E.S.P.I. Busse and Gröning (2013) argue that a resource-rich government receives considerable revenues from the resource rents, leading to relatively independent taxation. Therefore, the accountability to the taxpayers is not needed. Hence, such a government does not have enough motivation to follow the sustainable development goals and remain democratic. Bhattacharyya and Hodler (2010) find that the resource rents lead to corruption, which explicitly decreases the accountability and effectiveness of the government and implicitly can cause distortion in the economy. In other words, the level of effectiveness achieved by the government in high-quality policy adoption can be lessened by vast inflows of the revenue provided by the resource rents (Collier and Hoeffler, 2009; Iimi, 2007). Iimi (2007) indicates that the C.C and R.Q are particular prerequisites to promote the quality of institutions and the efficiency of resource management and hence, reverse the resource curse. Also, some studies expose that the E.S.P.I significantly affects a country's stability. Collier (2006) concludes that the probability of civil war rises by approximately 22.5% when a country experiences a primary energy dependence of 26% of its gross domestic product. Moreover, as the type of energy sources is considered, the effects of setting off a civil war and time duration become more transparent (Ross, 2002).

Accordingly, it is argued that the equity of energy sources (D.P.E.D), which ensures sustainable energy consumption, may develop the institutions of the government if low revenues are a considerable constraint for the government on its allocation, distribution, and stabilization functions. Therefore, the G.G can be enhanced in response to the D.P.E.D since the institutional reforms are dependent on the availability, affordability, and accessibility of the P.E.S. On the other hand, weak G is expected to be an outcome of the D.P.E.D because the corruption may cause greater potential benefits to the country's officials, especially those who set the E.S.P.I and allocate exploitation rights for such energy sources. Moreover, the G performance may be improved when the D.P.E.S increases since the major factors determining the benefits of the D.P.E.S (E.I.A, 2021), e.g., (i) technology improvement, (ii) environmental conditions, (iii) production and exploitation cost, (iv) political factors, and (v) access to raw materials, unlike the income derived from energy supply diversity, may lead to better G. Notably, the availability of a country's external energy sources, which expands the revenue opportunities, may also decrease the government's dependence on the tax receipts and thereby reduces citizens' appeal for the transparency and qualified G from their governments (Treisman, 2000; Ades and Di Tella, 1999, among others).

Regarding the acceptability dimension of E.S.P.I, the dynamics of N.C.F.P provide information on the cleaner technologies and S decarbonization. It therefore moderates the climate change, helps to upgrade the developing measures utilized throughout the environmental protection, and mitigates the global warming (Romero and Gramkow, 2020). There is not yet a straightforward way to explain the outcomes of decarbonization in the G performance and find how the innovation relates to the public regulatory framework. The possible channel is that the incumbents will not easily accept changes. Hence, the market power and influence of traditional utilities cannot completely explain unbundling and liberalization processes in the countries (Van Koten and Ortmann, 2008). So, the market structures will be expected to work improperly, and then inadequate infrastructure and institutions hamper switching to the N.C.F.P (Smith et al., 2005). Conversely, the advantages of cleaner energy technologies, in terms of lower CO_2 emission-related environmental degradation and reduced social costs are expected to improve G, preparing the conditions to promote the S innovations.

Consequently, and due to the existence of different affecting channels, it is necessary to examine the social outcomes of the E.S.P.I aspects empirically. Therefore, this research focuses on the impact of E.S.P and E.V.P on the G.I performance through a panel framework. It is analyzed how and to what extent the cultural, political, economic, and social proceedings of the governments react to the E.S.P, e.g., the D.P.E.D and D.P.E.S, and the E.V.P, e.g., the N.C.F.P, and the control variables, e.g., the G.D.P, E.C, H.D.I, and C.P.I, across the twenty-five L.E.C.E with the heterogeneous G performance (World Bank, 2021) and energy security risk scores (The Global Energy Institute, 2020). Consequently, the research framework monitors a chain of country-specific characteristics regarding the culture, policy, economy, and society. In this regard, there is no doubt considering the necessity for the countries to devise their E.S.P and E.V.P to mitigate the S vulnerability and improve the G performance through the P.D.P.E.S, on which scholars have not explicitly focused.

Materials and Methods

Materials

To calculate the time series data of the E.S.P.I, including the D.P.E.D, D.P.E.S, and N.C.F.P, the energy consumption and production data for the twenty-five L.E.C.E, including Australia, Brazil, Canada, China, Denmark, Germany, France, India, Indonesia, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Poland, Russia, South Africa, South Korea, Spain, Thailand, Turkey, the United Kingdom, Ukraine, and the United States (The Global Energy Institute, 2020) in billion cubic feet for each P.E.S—coal, natural gas, crude oil, hydroelectric power, nuclear, and new and renewable energy, are collected from the Energy Information Administration/Monthly Energy Review (2022) during 1998–2020. Also, the time-series data of the six G.I—V.A, P.S, G.E, R.Q, R.L, and C.C—of the countries under consideration are obtained from the World Bank Worldwide Governance Indicators (2021). Furthermore, the time-series data of the C.P.I and E.C of the selected countries are retrieved from the World Bank database and the Observatory of Economic Complexity (2021), respectively. Finally, the H.D.I time-series data are collected from the United Nations Development Programme database. Accordingly, a balanced panel of twenty-five countries covering 23 years contains 575 observations.

Mathods

The method of this research follows two major steps. First, it is assessed whether the six G.I as the dependent variables, the E.S.P and E.V.P as the explanatory variables, and the control variables are connected through a non-spurious and long-run relationship. To this end, a preliminary test is made to observe whether the variables under consideration are non-stationary due to the potential existence of a unit root process. If yes, it is further tested whether they follow a joint unit root process, applying the panel cointegration approaches. The Levin, Lin, and Chu (L.L.C) unit root statistic is used to test for the existence of a unit root process that is consistent with the time trends and effects. The test's null hypothesis suggests that all mentioned panel series follow the non-stationary process. At the same time, the alternative assumes the fraction of panel-series that shows the stationary process is non-zero. It is used up to two time lags to test the serial autocorrelation of the error terms. If the dependent, explanatory, and control variables are not stationary at the level, the analysis proceeds to check for the cointegration test. Under the null hypothesis of no cointegration, the Pedroni's Engle-Granger (P.E.G) technique is applied to be well-compatible with the small-sample features. It is concluded that a long-run relationship within the model is not spurious, as the results reject the null hypothesis. Alternatively, the Kao residual approach is also performed to test for the cointegration, showing all mentioned panels are cointegrated and checking for the common time effect by subtracting the cross-sectional dependency (C.D)'s mean from the actual series.

The second step determines the impacts of the explanatory and control variables on the G.I via the regression analysis. Since the interest lies in estimating the long-run elasticities of all six G.I to the explanatory and control variables, the following equation is estimated:

$$\begin{aligned}\ln(\mathrm{GI}_{j,i,t}) = \beta_0 + \beta_1 \ln(\mathrm{D.P.E.D}_{i,t}) + \beta_2 \ln(\mathrm{D.P.E.}S_{i,t}) \\ + \beta_3 \ln(\mathrm{N.C.F.P}_{i,t}) + X'_{i,t}\beta_4 + \theta_t + U_{i,t}\end{aligned} \tag{5}$$

the jth G.I, D.P.E.D and D.P.E.S are the diversification of primary energy demand and supply measurements, N.C.F.P is the non-carbon-based fuel portfolio, and X is the vector of control variables—the G.D.P and H.D.I. For the robustness check, the G.D.P and H.D.I are replaced by the E.C and C.P.I, respectively. Notably, all variables are used in natural logarithm form to remove the potential serial correlation effects. Moreover, θ is a year-specific effect used to capture the effects of market shocks and cycles, and finally, U_{it} is the stochastic error term.

Based on Kao and Chiang (1999), the equation (5) is estimated by the panel dynamic least squares models, e.g., the panel dynamic least squares (D.O.L.S) and panel fully modified least squares (F.M.O.L.S), within the pooled method. The D.O.L.S technique considers the potential endogeneity and leads to the asymptotically efficient and unbiased estimations through the long-run relations, even if the model encompasses the endogenous regressors (Herzer and Strulik, 2012). According to Wagner and Hlouskova (2009), in the panel data samples with small T, the D.O.L.S method performs more comprehensively than other estimators, like the F.M.O.L.S. Additionally, the mean variance inflation factor (V.I.F) statistic is used to test for the probable existence of any multicollinearity within the model (Belsley et al., 2005). However, some limitations might be considered through the results of the D.O.L.S model. The first possible anomaly refers to the heterogeneity issue going unanswered in the relationship between the G.I and the suggested determinants because of unobserved characteristics that may affect the dependent and the major explanatory variables, which further correlates with the error term and leads to the biased D.O.L.S estimations.

In the next phase, it is considered that the previous period values may also explain the G.I at time t and that the dependent and explanatory variables can be defined simultaneously. Accordingly, a linear dynamic model of panel data series is estimated through the G.M.M method in a two-step difference that accounts for the simultaneity, persistence, and fixed effects, as suggested by Arellano and Bond (A.B) (1991). The G.M.M method covers the cause-effect relations among the variables, e.g., the dependent and independent, over time supported through the lagged dependent variables as the explanatory and instrumental variables. Also, the lagged regressors are included as the instrumental variables for the linear equations with the autoregressive (A.R) terms to control the endogeneity. They are considered the internal instrumental variables since they are employed from the estimated econometric model. In addition, different forms of endogeneity, including dynamic endogeneity, unobserved heterogeneity, and simultaneity, are eliminated via the internal data transformation. Moreover, the value subtraction captures each variable's internal data transformation in the past and present dates. Hence, the unbiased estimations are expected through the G.M.M model (Roodman, 2009).

Furthermore, and based on Roodman (2009), it is suggested that the idiosyncratic error terms are uncorrelated across the individuals. Therefore, there may be no necessity for some of the determinants to be strictly exogenous. Moreover, the second-order transformation of the G.M.M model is used to avoid unnecessary data loss, as recommended by Arellano and Bover (1995). The second-order transformation approach of the G.M.M method subtracts the average value of all future and available observations of each variable via the "forward orthogonal deviation" rather than subtracting the previous amounts of the variable from its present observation (Roodman, 2009). Then, the A.B test is used to check for serial correlation in the residuals. Finally, the over-identifying restrictions of the models are examined by the Sargan J (S.J) statistics. Hence, and based on

Antonietti and Fontini (2019) and Roodman (2009), the G.M.M method is used in this paper as follows:

$$\Delta\ln\left(GI_{j,i,t}\right) = \rho\,\Delta\ln\left(GI_{j,i,t-1}\right) + \beta_1\,\Delta\ln\left(D.P.E.D_{i,t}\right) + \beta_2\,\Delta\ln\left(D.P.E.S_{i,t}\right) + \beta_3\,\Delta\ln\left(N.C.F.P_{\,i,t}\right) + \Delta X'_{i,t}\beta_4 + \Delta\varepsilon_{i,t} \quad (6)$$

It is noted that the fixed effects are removed by using the first difference (Δ) of all the variables through the G.M.M model. In addition, the equation (6) is estimated to follow the performance of the six G.I in response to the Δ of the major affecting factors.

Results

a. A.T.S, S.T.F, and L.T.T of E.S.P.I

The P.D.P.E.S of an economy develops as higher values of E.S.P, e.g., the D.P.E.D and D.P.E.S, and E.V.P, e.g., N.C.F.P, are detected. However, the different potential reactions of the E.S.P and E.V.P in response to the market shocks may be explained by the sensitivity level of energy sources (e.g., the renewable and non-renewable) consumption or production for the specified indicators. Also, the different roles of crude oil and other mentioned energy sources should not be neglected to analyze the suggested reactions (Lin and Du, 2015). For instance, the renewable energy technologies, e.g., the wind, solar, hydro, and biomass, require considerable investment for significant reduction in the dependency and vulnerability of economies to oil price shocks as the prices of renewables are insensitive to the oil price shocks (Bai and Lam, 2019). Accordingly, the H.P filter (Hodrick and Prescott, 1997) is applied to answer the first research question by decomposing the calculated A.T.S of D.P.E.D, D.P.E.S, and N.C.F.P into the S.T.F and L.T.T (Figures 1–3). This decomposition process helps in finding any potential changes experienced by each country and understanding the behavioral characteristics, e.g., risk and resilience, of the cross-systems E.S.P.I.

b. D.P.E.D

Based on Figure 1, the calculated D.P.E.D shows a markedly increasing trend in the last years for Australia, Brazil, China, Germany, Indonesia, Italy, Mexico, Netherlands, Poland, South Africa, South Korea, Spain, Thailand, Turkey, and Ukraine, indicating the energy sources have been getting more equally distributed among the major P.E.S in the suggested economies. Therefore, these countries have lower energy security risks. On the other hand, the findings expose higher risks and lower resilience of the S for Canada and France since a decreasing trend is detected in their D.P.E.D. The rest of the countries show no significant change in their D.P.E.D. For all countries, the S.T.F of D.P.E.D is affected by the market shocks of their S regarding the intensity and the number of ups and downs, especially in the last years.

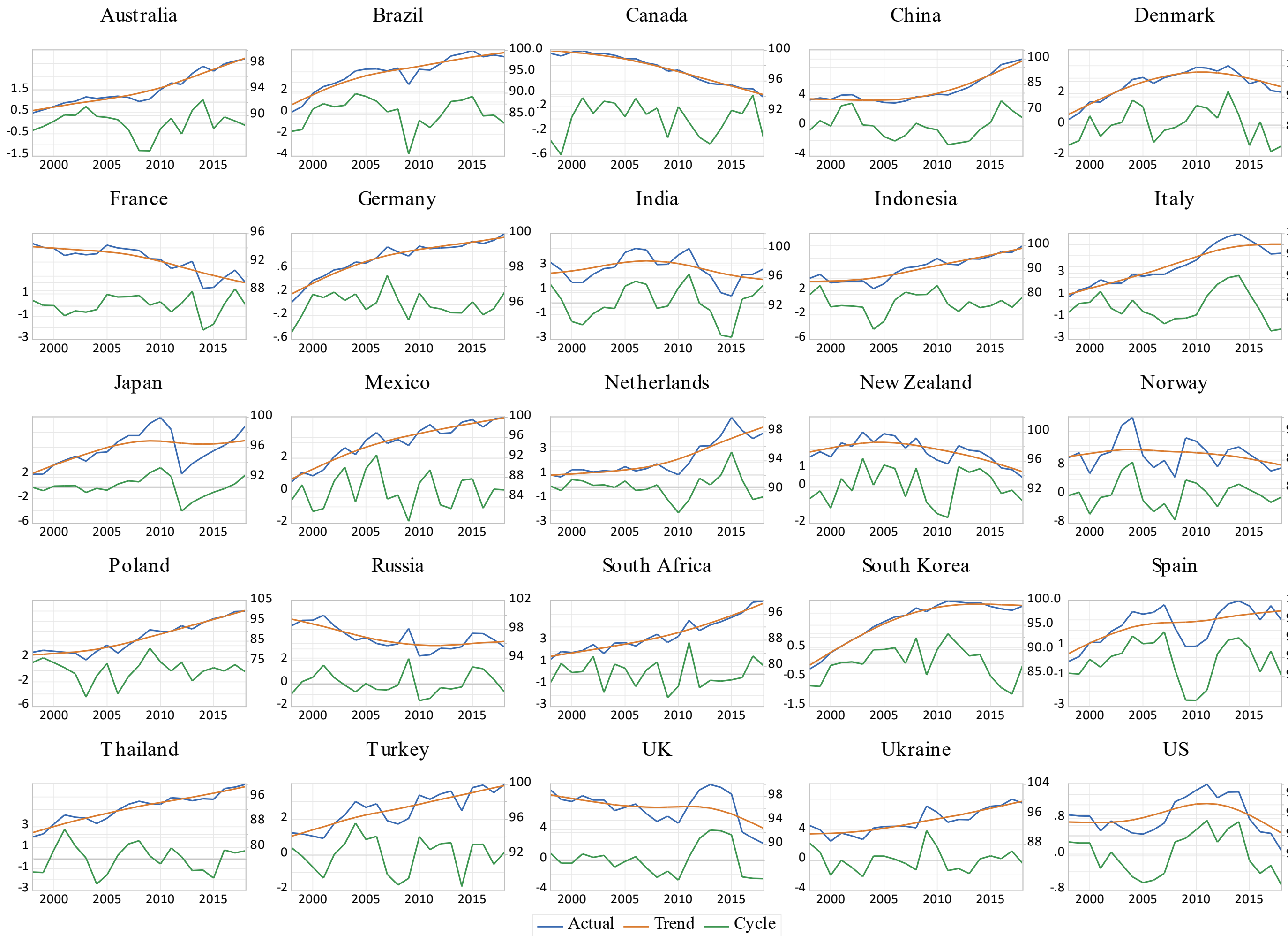

Figure 1. A. T. S, S. T. F, and L. T. T of D. P. E. D.

Source: Research finding.

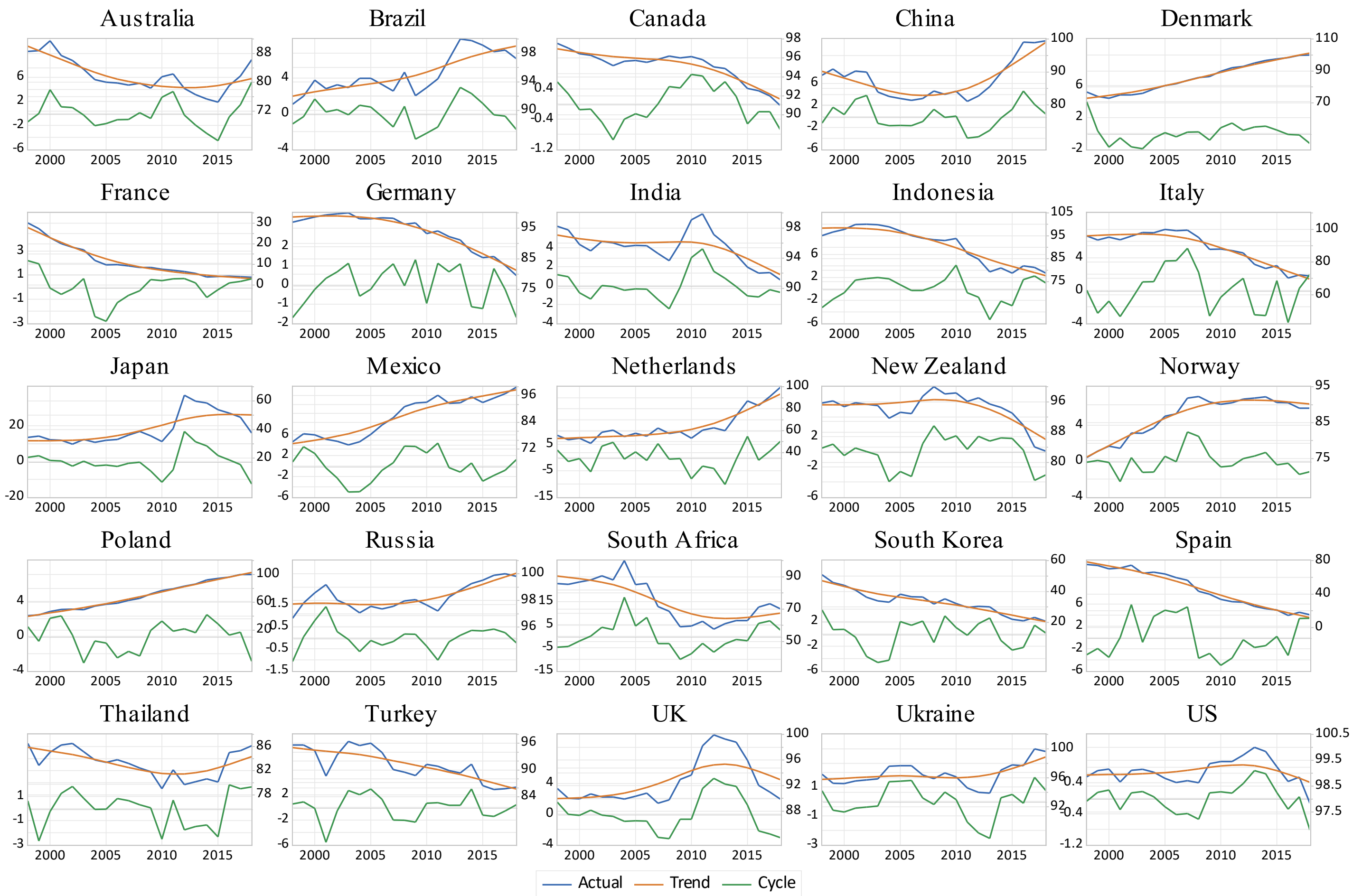

Figure 2. A. T. S, S. T. F, and L. T. T of D. P. E. S.

Source: Research finding.

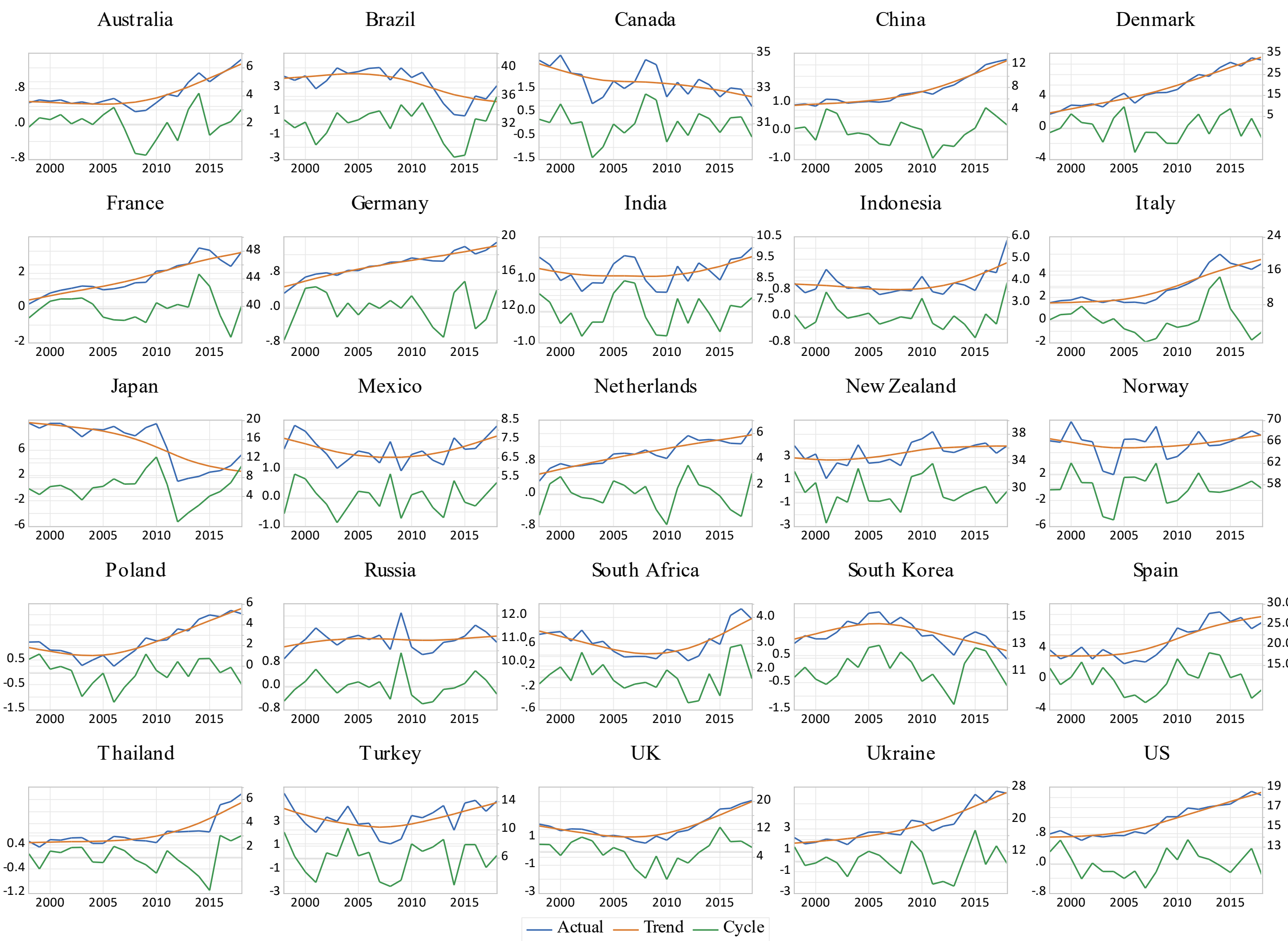

Figure 3. A. T. S, S. T. F, and L. T. T of N. C. F. P.

Source: Research finding.

c. D. P. E. S

According to Figure 2, an upward (downward) trend is found for the D.P.E.S in Brazil, China, Denmark, Japan, Mexico, Netherlands, Norway, and Poland (Canada, France, Germany, India, Indonesia, Italy, New Zealand, South Africa, South Korea, Spain, and Turkey). This behavior shows they are upgraded (downgraded) in the innovation capability and technological improvements through the energy supply diversity, especially in the past few years. Also, neither a specific upward nor a downward trend is concluded for Australia, the UK, Ukraine, and the US. Furthermore, except for Canada, Russia, and the US, the significant changes in the intensity and number of ups and downs for the S.T.F of D.P.E.S have been detected for all countries in the last years, indicating that the energy supply diversity is vulnerable to the market shocks. Therefore, it can cause the S.T.F and uncertainty throughout the S of L.E.C.E.

d. N. C. F. P

The third calculated E.S.P.I is the N.C.F.P which shows the environmental degradation in Brazil, Japan, and South Korea in the past few years, as a downward trend is found in switching from a carbon-intensive to the N.C.F.P. Also, neither a specific upward nor a downward trend is met through the N.C.F.P in Canada, New Zealand, Norway, and Russia. Moreover, a markedly offset to lower environmental degradation of the rest of the countries' S is concluded, since they expose an upward trend in their N.C.F.P during the period. Furthermore, the results indicate no significant changes in the intensity and number of ups and downs for the S.T.F (resilience) of Norway's N.C.F.P in the last years. At the same time, the rest of the economies successfully switched toward the alternative energy sources by improving the share of non-fossil fuel energy sources applied to meet the energy consumption (Figure 3).

The potential impact of D.P.E.D, D.P.E.S, and N.C.F.P on the behavioral characteristics of the G.I, e.g., the V.A, P.S, G.E, R.Q, R.L, and C.C, should be analyzed since the country's stability depends on the modes and specifications of any changes experienced by each P.E.S, particularly through the S of L.E.C.E (Lenhart and Fox, 2022; Šprajc et al., 2019; Gaspari and Lorenzoni, 2018; Corrigan, 2014).

Descriptive Statistics, Correlations, Unit Root Tests, and Cointegration

In the next step, this study investigates the descriptive statistics, correlations, unit root test, and cointegration relationship among the utilized variables to satisfy the prerequisites of the applied econometric models. The results reveal the existence of weak correlations between the regressors, which support no concern regarding the potential multicollinearity issue (Antonietti and Fontini, 2019). Also, all mentioned variables are skewed and leptokurtic via their distribution functions (Table 1). Therefore, and based on Bai and Lam (2019), the static methods are inappropriate for modeling the behavioral characteristics of the G.G indices in response to the changes in the E.S.P.I. Table 2 presents the test results of the unit root process and cointegration relationships. The upper part of the Table shows the L.L.C unit root test results at the level and Δ of the utilized variables.

Table 1. Descriptive Statistics and Correlations

Descriptive statistics	Mean	Median	Max	Min	Std. Dev	Skewness	Kurtosis	Normality (Prob)
V. A	0.74	1.01	1.27	-13.8	0.92	-8.7	123	0.00
P. S	0.70	0.90	1.35	-13.8	0.84	-10.3	170	0.00
G. E	0.37	0.62	1.17	-13.9	0.92	-7.6	110	0.00
R. Q	0.26	0.56	1.06	-13.8	0.94	-6.8	96	0.00
R. L	0.34	0.73	1.17	-13.8	0.99	-6.2	82	0.00
C. C	0.45	0.65	1.32	-13.8	0.99	-6.1	83	0.00
D. P. E. D	4.54	4.56	4.6	4.3	0.06	-1.6	5.6	0.00
D. P. E. S	4.27	4.5	4.6	1.3	0.55	-2.97	12.7	0.00
N. C. F. P	2.43	2.53	4.25	-11.2	1.1	-3.7	45	0.00
G. D. P	9.9	10.2	11.1	7.5	0.76	-0.8	3	0.00
H. D. I	-0.2	-0.1	-0.04	-0.7	0.14	-1.03	3.4	0.00
E. C	0.2	0.4	1.04	-14.2	0.8	-10.5	175	0.00
C. P. I	4.5	4.6	5.6	2.08	0.3	-2.2	14	0.00

Correlations	V. A	P. S	G. E	R. Q	R. L	C. C	D. P. E. D	D. P. E. S	N. C. F. P	G. D. P	H. D. I	E. C	C. P. I
V. A	1.00	-	-	-	-	-	-	-	-	-	-	-	-
P. S	0.24	1.00	-	-	-	-	-	-	-	-	-	-	-
G. E	0.29	0.37	1.00	-	-	-	-	-	-	-	-	-	-
R. Q	0.37	0.85	0.64	1.00	-	-	-	-	-	-	-	-	-
R. L	0.39	0.42	0.65	0.62	1.00	-	-	-	-	-	-	-	-
C. C	0.37	0.43	0.96	0.68	0.7	1.00	-	-	-	-	-	-	-
D. P. E. D	0.39	0.06	0.13	0.19	0.16	0.13	1.00	-	-	-	-	-	-
D. P. E. S	-0.12	-0.14	-0.2	-0.18	-0.21	-0.18	0.07	1.00	-	-	-	-	-
N. C. F. P	0.15	0.14	0.13	0.15	0.16	0.18	0.36	-0.14	1.00	-	-	-	-
G. D. P	0.42	0.46	0.61	0.66	0.6	0.62	0.36	-0.23	0.34	1.00	-	-	-
H. D. I	0.4	0.48	0.54	0.63	0.54	0.56	0.33	-0.22	0.33	0.95	1.00	-	-
E. C	0.17	0.3	0.29	0.32	0.25	0.28	0.23	-0.19	0.23	0.45	0.47	1.00	-
C. P. I	0.04	0.1	0.3	0.2	0.26	0.26	0.24	-0.1	0.08	0.42	0.35	0.25	1.00

Source: Research finding.

The findings at the level exhibit that the null hypothesis is not rejected for all the variables, indicating the probable existence of a unit root process in all applied panels at a 1% significance level. Besides, the results support that all the utilized variables are stationary at a 1% significance level in their Δ. It shows that the estimation of Equation (5) using the ordinary least square method might lead to spurious regressions. Therefore, the econometric techniques suggested in section (3.2) are statistically reasonable for justifying the behavioral characteristics of the G.I in reaction to the changes in the E.S.P.I and the control variables.

Moreover, the lower parts of Table 2 provide the results of cointegration tests. Due to the applied sample, one lag and one lead are chosen for Equations (5-6). The Pedroni's Engle-Granger (P.E.G) cointegration statistics null hypothesis (no cointegration) is strongly rejected for all six dimensions of the G.I. It represents that Equations (5-6) will support no spurious relationships. The Kao statistics are also used for the robustness check for cointegration and show that all mentioned panels are cointegrated.

Table 2. Unit Root Tests and Cointegration

L. L. C unit root statistics	**At level (Individual trend & intercept)**		**At Δ (Intercept)**	
Variable	**Statistic**	**Prob**	**Statistic**	**Prob**
V. A	1.41	0.92	-6.76	0.00
P. S	0.4	0.7	-3.65	0.00
G. E	-0.62	0.27	-7.57	0.00
R. Q	-1.13	0.19	-3.26	0.00
R. L	-1.5	0.2	-11.3	0.00
C. C	-1.6	0.2	-11.6	0.00
D. P. E. D	-1.4	0.08	-8.76	0.00
D. P. E. S	0.84	0.8	-5.9	0.00
N. C. F. P	1.53	0.9	-10.5	0.00
G. D. P	-1.6	0.1	-5	0.00
H. D. I	-2.7	0.07	-7.6	0.00
E. C	1.4	0.9	-12	0.00
C. P. I	0.4	0.7	-5	0.00
Pedroni Residual Cointegration Test – Null Hypothesis: No cointegration; Control variables: G. D. P & H. D. I				
Model 1	**P. P-Statistic**	**Prob**	**A. D. F-Statistic**	**Prob**
V. A	-9.25	0.00	-2.33	0.00
P. S	-18.7	0.00	-5.1	0.00
G. E	-30.3	0.00	-21.5	0.00
R. Q	-18	0.00	-6	0.00

R. L	-14.6	0.00	-9.1	0.00
C. C	-16.8	0.00	-20.4	0.00

Pedroni Residual Cointegration Test – Null Hypothesis: No cointegration; Control variables: E. C & C. P. I

Model 2	**P. P -Statistic**	**Prob**	**A. D. F-Statistic**	**Prob**
V. A	-12.4	0.00	-3.7	0.00
P. S	-18	0.00	-5	0.00
G. E	-13	0.00	-11.7	0.00
R. Q	-15	0.00	-5.4	0.00
P. L	-7.9	0.00	-3.8	0.00
C. C	-12.1	0.00	-14	0.00

Kao Residual Cointegration Test – Null Hypothesis: No cointegration; Control variables: G. D. P & H. D. I

Model	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
t-Statistic	3.66	3.12	-6.35	3.8	3.4	-7.2
Prob	0.00	0.00	0.00	0.00	0.00	0.00

Kao Residual Cointegration Test – Null Hypothesis: No cointegration; Control variables: E. C & C. P. I

Model	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
t-Statistic	3.8	-3.5	-4.8	3.25	3.23	-6.3
Prob	0.00	0.00	0.00	0.00	0.00	0.00

Source: Research finding.

Panel Model Estimations

Table 3 reports the D.O.L.S and F.M.O.L.S estimations of Equation (5) for all six G.I. The D.O.L.S estimated coefficients of D.P.E.D are positive (negative) and statistically significant for the V.A, P.S, G.E, and R.L (R.Q and C.C) models, showing a 1% increase in the D.P.E.D leads to an average 3.28%, 1.03%, 0.55%, and 1.83% increase in the V.A, P.S, G.E, and R.L, and 0.4% and 1.8% decrease in the R.Q and C.C, respectively. The estimations also indicate that the G.E, R.Q, and C.C (the V.A, P.S, and R.L) increase (decrease) with the amount of D.P.E.S. Moreover, it is found that except for the C.C, the N.C.F.P correlates negatively with the V.A, P.S, G.E, R.Q, and R.L. In respect of the control variables, the G.D.P relates positively to the V.A, P.S, R.Q, R.L, and C.C, whereas it shows a negative relationship with the G.E. On the other hand, the results correspond to the reverse effects for the H.D.I compared with the G.D.P. The estimates of D.O.L.S and F.M.O.L.S models are partially dissimilar in signs and values. Furthermore, the D.O.L.S shows a considerably higher R^2 than the F.M.O.L.S. Notably, in the panel data samples with small T, the D.O.L.S method performs more comprehensively than the F.M.O.L.S (Wagner and Hlouskova, 2009). Also, all six suggested models are re-estimated, including the squared term of the explanatory variables, indicating that non-linearity through the relationships is not a deterministic issue (Antonietti and Fontini, 2019).

Furthermore, the models do not suffer from the multicollinearity issue since the mean V.I.F statistics meet low values, compatible with the correlation results presented in Table 1 (Antonietti and Fontini, 2019). The results of all six models indicate that the V.I.F statistics of the explanatory and control variables and the specified mean V.I.F value are lower than the suggested standard values, which are 10 and 6, respectively (Belsley et al., 2005).

Table 3. D. O. L. S vs. F. M. O. L. S estimates of G. I

D. O. L. S	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Variable	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
D. P. E. D	3.28***	1.03***	0.55***	-0.4***	1.83***	-1.8***
D. P. E. S	-0.13***	-0.02**	0.05***	0.05**	-0.2***	0.14***
N. C. F. P	-0.02	-0.08***	-0.07***	-0.14***	-0.12***	0.006
G. D. P	0.17**	0.32***	-0.09**	0.7***	0.74***	0.2***
H. D. I	-6.44***	-4.25***	0.86***	-4.4***	-5.14***	-1.6***
R^2	0.95	0.77	0.99	0.82	0.98	0.99
Mean V. I. F	0.06	0.04	0.01	0.03	0.002	0.01
No. Obs	500	500	500	500	500	500
F. M. O. L. S	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Variable	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
D. P. E. D	2.55***	1.02***	-0.57***	1.04***	0.55***	-0.25***
D. P. E. S	-0.05***	-0.1***	0.11***	-0.09***	-0.007	0.1***
N. C. F. P	-0.05***	-0.04**	0.02	-0.08***	-0.02	-0.01
G. D. P	-0.1***	-0.15***	0.48***	0.26***	0.68***	0.3***
H. D. I	-1.19***	0.53***	-0.7***	-0.9***	-3.32***	-0.7***
R^2	0.67	0.37	0.63	0.61	0.67	0.66
Mean V. I. F	0.00	0.00	0.00	0.00	0.00	0.00
No. Obs	550	550	550	550	550	550

Source: Research finding.

Note: ***, **, * indicate 0.01, 0.05, 0.1 significant level, respectively.

In the next step, the G.M.M method is used to estimate the parameters of the G models, which covers the simultaneity, persistence, and fixed effect issues (Hoecle, 2007). Table 4 indicates the estimations of equation (6) for all six models, applying the two-step difference G.M.M method. The findings show that the relationships with all suggested determinants are different compared with the results drawn by the D.O.L.S and F.M.O.L.S when the instrumental variables are added to control past values of the G.I (Lenhart and Fox, 2022). Specifically, as the long-run growth rate of D.P.E.D increases, which ensures sustainable energy consumption, the growth rate of V.A, P.S, R.Q, and R.L develop, leading to the G.G improvement and hence, the global stability (Šprajc et al., 2019; Gaspari and Lorenzoni, 2018; Corrigan, 2014) across the L.E.C.E. On the other hand, the G.E and C.C dimensions of G are negatively affected by a positive change in the long-run growth rate of D.P.E.D. In all models except for the R.Q, the estimates of D.P.E.S are statistically significant. Specifically, the positive coefficient of D.P.E.S is found by the G.M.M models of V.A, G.E, and C.C, while the results exhibit a negative response in the P.S and R.L models. So, a 1% increase in the growth rate of D.P.E.S causes an average increase of 0.4, 0.75, and 0.99 percent in the V.A, G.E, and C.C and 0.97 and 0.17 percent decrease in the P.S and R.L growth rates, respectively.

Moreover, the estimated coefficient of N.C.F.P in the C.C model is positive, while the coefficient turns to a negative value in the V.A, P.S, R.Q, and R.L models. Notably, the G.E positively responds to a change in the N.C.F.P but it is insignificant. Regarding the control variables, the G.D.P relates positively to the R.L, whereas it shows a negative relationship with the P.S, G.E, R.Q, and C.C. On the other hand, the results reveal the reverse effects for the H.D.I in comparison with the G.D.P. Furthermore, the post-estimation tests of the G.M.M method, e.g., the S.J and A.B tests, show that the utilized instrumenting approach is statistically valid. The former reassures no over-identification through the models, while the latter confirms no serial correlation in the residuals. The result of the S.J statistic indicates that the instrumental variables included in all suggested models are exogenous. Also, the lagged mentioned variables are found uncorrelated with the specified error terms in all the estimated equations since the results of the A.R test presents a serial correlation for the first order residuals but no serial correlation for the second order. Consequently, the results provided by the G.M.M models confirm the robustness check for the dynamic endogeneity, unobserved heterogeneity, and simultaneity (Antonietti and Fontini, 2019).

Table 4. G. M. M estimates of G. I

G. M. M Regression	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Variable	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
G. I (-1)	-0.01***	0.15***	0.09***	0.16***	0.03***	0.13***
D. P. E. D	7.07***	5.71***	-1.7***	1.73***	0.85***	-2.81***
D. P. E. S	0.4***	-0.97***	0.75***	0.17	-0.17**	0.99***
N. C. F. P	-0.03***	-0.11***	0.03	-0.05**	-0.04***	0.06***
G. D. P	0.12	-0.32***	-0.8***	-0.22***	0.79***	-1.19***
H. D. I	-3.73***	-0.22	9.35***	3.4***	-3.25***	10.75***
S. J-Test (prob)	0.3	0.3	0.4	0.2	0.3	0.3
A. R (1) p-value	0.00	0.00	0.00	0.00	0.00	0.00
A. R (2) p-value	0.6	0.4	0.3	0.7	0.2	0.2
No. Instrument	27	25	25	26	25	25
No. Obs	525	525	525	525	525	525

Source: Research finding.

Note: ***, **, * indicate 0.01, 0.05, 0.1 significant level, respectively.

Robustness check for the panel model estimations

For the robustness check, the G.D.P and H.D.I are replaced by the E.C and C.P.I. The D.O.L.S and G.M.M regressions' estimates of Equations (5-6) for the models 1 to 6 are displayed in Table 5. The D.O.L.S estimates of D.P.E.D in all G models are statistically significant. The impact of D.P.E.D on the V.A, P.S, G.E, and R.Q are positive but the response of R.L and C.C indices are negative. Also, all mentioned G.I are positively affected by a positive change in the D.P.E.S. These estimates are statistically significant for all G models except for the V.A model. The coefficients of N.C.F.P are positive for the G.E and R.Q models, while they are negative for the V.A, P.S, R.L, and C.C models. Additionally, all these estimates are statistically significant. Regarding the control variables, the E.C positively relates to the R.L and C.C, whereas it shows a negative relationship with the V.A, P.S, R.Q, and C.C. Except for the R.L model, the results correspond to the negative effects of C.P.I on all G dimensions. The results of the G.M.M method with different control variables are relatively similar through the sign of coefficients. The estimates of D.P.E.D in all models are statistically significant. Specifically, as the long-run growth rate of D.P.E.D increases, the growth rate of V.A, P.S, and R.Q develops, leading to the G.G improvement and global stability (Šprajc et al., 2019; Gaspari and Lorenzoni, 2018; Corrigan, 2014) across the L.E.C.E. On the other hand, the G.E, R.L, and C.C dimensions of G are negatively affected by a positive change in the long-run growth rate of D.P.E.D. The estimates of D.P.E.S in all models except for the P.S and R.Q are statistically significant. The positive coefficient of D.P.E.S is found in the G.M.M models of V.A, G.E, and C.C, while the results exhibit a negative response for the R.L dimension. So, a 1% increase in the growth rate of D.P.E.S causes an average increase of 0.4, 0.4, and 0.72 percent in the V.A, G.E, and C.C, and a 0.14 percent decrease in R.L growth rates, respectively. Moreover, the estimates of N.C.F.P in all models except for the R.Q and R.L are statistically significant. The estimated coefficient of N.C.F.P in the G.E and C.C models is positive, while the coefficient turns to a negative value in the V.A and P.S models. Notably, the R.Q and R.L dimensions negatively respond to a change in the N.C.F.P but they are statistically insignificant.

Regarding the control variables, the E.C negatively relates to the R.L dimension, whereas it shows a positive relationship with the rest of the indices. On the other hand, the results correspond to the reverse effects for the H.D.I compared with the G.D.P. The results exhibit the positive impact of C.P.I on the G.E, R.L, and C.C dimensions, while the negative relationship is detected for the V.A, P.S, and R.Q indices. Furthermore, the post-estimation tests of the G.M.M method, e.g., the S.J and A.B tests, show that the utilized instrumenting approach is statistically valid. The former reassures no over-identification through the models, while the latter confirms no serial correlation in the residuals. The result of the S.J statistic indicates that the instrumental variables included in all suggested models are exogenous. Also, the lagged mentioned variables are found uncorrelated with the specified error terms in all estimated equations since the results of the A.R test present a serial correlation for the first order residuals but no serial correlation for the second order. Consequently, the results provided by the G.M.M models confirm the robustness check to the dynamic endogeneity, unobserved heterogeneity, and simultaneity (Antonietti and Fontini, 2019). Furthermore, all six suggested models are re-estimated, including the squared term of the explanatory variables, indicating that non-linearity through the relationships is not a deterministic issue (Antonietti and Fontini, 2019).

Table 5. D. O. L. S vs. G. M. M estimates of G. I

D. O. L. S	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Variable	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
D. P. E. D	1.32***	1.5***	1.01***	0.78***	-0.93***	-1.04***
D. P. E. S	0.05	0.28***	0.1***	0.14***	0.08***	0.1***
N. C. F. P	-0.01	-0.12***	0.06***	0.04**	-0.002	-0.01**
EC	-0.16***	-2.6***	-0.014	-1.15***	0.09***	0.12***
CPI	-0.35***	-0.98***	-0.09***	-0.74***	0.33***	-0.09***
R^2	0.96	0.94	0.99	0.95	0.99	0.99
Mean- V. I. F	0.03	0.02	0.006	0.02	0.001	0.007
No. Obs	500	500	500	500	500	500
G. M. M Regression	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Variable	**V. A**	**P. S**	**G. E**	**R. Q**	**R. L**	**C. C**
G. I (-1)	-0.02***	0.12***	0.04***	0.11***	0.016***	0.12***
D. P. E. D	6.62***	2.96***	-2.6***	1.00***	-2.44***	-1.9***
D. P. E. S	0.4***	-0.1	0.4***	-0.23	-0.14***	0.72***
N. C. F. P	-0.04***	-0.09***	0.02***	-0.05	-0.001	0.04***
E. C	-0.2***	1.26***	0.93***	1.96***	2.82***	0.87***
C. P. I	-0.4***	-0.21**	0.53***	-0.16*	0.34***	0.12***
S. J-Test (prob)	0.4	0.3	0.4	0.7	0.3	0.5
A. R (1) p-value	0.008	0.00	0.00	0.00	0.00	0.00
A. R (2) p-value	0.5	0.4	0.3	0.4	0.3	0.2
No. Instrument	28	25	25	25	26	25
No. Obs	525	525	525	525	525	525

Source: Research finding.

Note: ***, **, * indicate 0.01, 0.05, 0.1 significant level, respectively.

Discussion

In this section of the discussion, the second research question is analyzed. Comparing D.P.E.S and N.C.F.P using D.O.L.S estimates with different control variables, the results indicate that a 1% increase in the D.P.E.D has an average greater positive impact on all G.I dimensions. In particular, the levels of P.S, V.A, C.C, G.E, R.L, and R.Q are affected by changes in D.P.E.D. In contrast, the responses of all G.I dimensions to changes in D.P.E.S and N.C.F.P are relatively small and comparable.

endogeneity, simultaneity, and unobserved heterogeneity, by considering the lagged values of G.I (previous performance) and using an internal transformation process, the results of the G.M.M method differ significantly from the D.O.L.S estimates (Tables 3–5). Accordingly, some limitations should be considered when interpreting the results of these models, as the impact of E.S.P.I on the specified dimensions of G is heterogeneous (Kuzemko, 2015). Based on the results, it is concluded that the D.P.E.D promotes sustainable energy consumption and develops the institutions of G, e.g., V.A, P.S, and R.Q, across the L.E.C.E. The findings also indicate that the G.G, e.g., V.A, G.E, and C.C, develops in response to the D.P.E.S. Drawing on governance theory (Treisman, 2000; Ades and Di Tella, 1999), low revenue levels are a considerable constraint for the government on its allocation, distribution, and stabilization functions. Consequently, in contrast to Ross (2001), the D.P.E.D can reverse the "rentier effect". Besides, the D.P.E.S can reverse the "rentier", "repression", and "modernization" effects in the L.E.C.E. To further examine how innovation relates to the public regulatory framework across the L.E.C.E panel, the energy policies related to the N.C.F.P enhance the G.E and C.C dimensions of G.G. Hence, the advantages of cleaner energy technologies in terms of lower environmental degradation and reduced social costs improve the G.G, thereby creating the conditions for promoting S innovations. Particularly, the dynamics of decarbonization provide information on cleaner technologies and S decarbonization, mitigate climate change, help improve the measures used for environmental protection, and reduce global warming (Romero and Gramkow, 2020). Therefore, G.G can be strengthened because institutional reforms depend on the availability, affordability, accessibility, and acceptability of the P.E.S.

On the other hand, weak G, e.g., G.E, R.L, and C.C, is observed across the L.E.C.E in response to D.P.E.D because corruption may provide greater potential benefits to a country's officials who set energy policies and allocate the exploitation rights for such resources, which is compatible with Ross (2001).

Moreover, the performance of P.S, R.Q, and R.L deteriorates when D.P.E.S develops since the income derived from resource supply diversity may lead to a decline in G.G. Specifically, the availability of a country's energy sources, which expands the sources of revenue, may decrease the government's dependence on tax receipts, thereby reducing citizens' demand for transparency and good G from their governments (Ross, 2001; Treisman, 2000; Ades and Di Tella, 1999, among others). The results also show that V.A, P.S, R.L, and R.Q are negatively affected in response to reduced environmental degradation. It is argued that the incumbents do not easily accept the transition from carbon-based energy sources to N.C.F.P. Hence, the market power and influence of the traditional utilities cannot completely explain unbundling and liberalization processes in the countries (Van Koten and Ortmann, 2008). Therefore, market structures are expected to function inefficiently, and inadequate infrastructure and institutions hamper the transition to N.C.F.P (Smith et al., 2005).

Regarding economic development, G.D.P is not associated with improvements in G.G, whereas E.C has a positive effect on P.S, G.E, R.Q, R.L, and C.C. It is also concluded that the relative contribution of H.D.I to promoting G.G is higher than that of G.D.P. As G.G is explained through the behavior of economic agents, objects—infrastructures and technologies—and the environment, the combination of knowledge, innovation, productive structure, structural changes, and capabilities of economic systems, referred to as E.C, shapes the patterns of G.D.P and H.D.I (Hidalgo and Hausmann, 2009). Therefore, E.C provides a convenient measure of a country's economic development (The Atlas of Economic Complexity, 2022).

Concerning energy prices (C.P.I), energy security considers the effect of energy prices on D.P.E.S (Roques et al., 2008). Higher energy prices promote D.P.E.S, which entails harnessing new energy resources, is conducive to energy equitability and abundance, and facilitates the transition to N.C.F.P (Shirazi, 2025a; Shirazi, 2022; Li et al., 2020; Li et al., 2016). Hence, it is necessary to control for energy prices when studying the dynamics of G.G.

Regarding the third research question, the comparative analysis demonstrates that the contribution of V.A and P.S to G.G is more elastic than in the rest of the L.E.C.E, as the share of E.S.P.I—i.e., E.S.P, E.V.P, and the control variables—increases. Therefore, the G.E, R.L, R.Q, and C.C dimensions of G.G are more challenging to enhance than the V.A and P.S through S dynamics. Hence, the opportunity cost of E.S.P and E.V.P in developing G.E, R.L, R.Q, and C.C is high across the L.E.C.E. It is considered one of the reasons that G performance has been more engaged with the perceptions experienced by the countries' citizens. This occurs through the ability to contribute to choosing the government of interest, free media, the level of freedom of expression and association, as well as the extent of confidence of agents in adherence to the rules of society—particularly the quality of the judicial system, contract enforcement, property rights, and the likelihood of violence and crime (Kaufmann et al., 2010).

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Accordingly, the findings identify how P.D.P.E.S can decrease the cultural, political, economic, and social costs of transforming energy sources into production. They refer to (i) "rentier effect", (ii) "repression effect", and (iii) "modernization effect" (Ross, 2001) across the world's L.E.C.E to promote economic development by figuring out its main strengths and weaknesses. Specifically, G performance is directly affected by E.S.P.I, influencing foreign relations and causing considerable effects on global geopolitical issues (Šprajc et al., 2019; Gaspari and Lorenzoni, 2018; Corrigan, 2014), which complicates the long-term process of government strategic planning (Farah, 2015). Consequently, E.S.P.I is closely linked to the global stability and sustainable development (Lenhart and Fox, 2022; Brisbois et al., 2019; Yanhua and Yichen, 2018). Therefore, G.G needs to focus on the necessary conditions—efficient management of a country's energy sector and development of S strategies (Kuzmenko and Lawrence, 2019; Lior et al., 2018), bearing in mind (i) energy equity, (ii) energy security, and (iii) environmental sustainability—collectively called the energy trilemma (World Energy Council, 2025; Bale et al., 2015). Also, the trade-off process among cultural, political, economic, and social objective priorities is considered a sufficient condition, which helps promote stability in both developing and developed countries (Lior et al., 2018) and their citizens (Jarmon, 2014), especially across the world's L.E.C.E.

The comprehensive application of E.S.P.I to the broad concepts of G.G calls for interdisciplinary research—political science, cultural and social sciences, economics, engineering, and mathematics, which is considered a major constraint of this research. Moreover, it is suggested that further research analyze G.G through the concept of the energy trilemma index. However, addressing G.G through energy trilemma poses methodological and analytical limitations that cannot be properly captured using standard linear econometric methods, given the inherent weaknesses of the energy trilemma—simultaneous synergies/trade-offs and endogeneity among energy equity, energy security, and environmental sustainability. To overcome these challenges, a non-linear and regime-switching estimation framework is proposed for adoption by further studies, to capture complex and non-linear interdependencies. Particularly, asymmetric and time-varying analysis of the behavioral regimes of G.I can lead to vulnerability reduction in terms of risk and resilience.

Conclusion and Policy Implication

The scope of energy systems is not only restricted to the customary tasks of explicitly protecting economic agents and the environment but also comprises contributions to promote the cultural, political, and economic characteristics of a society, especially through portfolio decisions of primary energy sources—energy security, energy equity, and environmental sustainability. Accordingly, this research explores the impact of energy security policies—the diversification of primary energy supply and demand, and the environmental sustainability policy—the non-carbon-based fuel portfolio, comprising the control variables—the human development index and per capita gross domestic product adjusted by the purchasing power parities, on the good governance indices—voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption, in a panel of twenty-five large energy-using countries during 1998-2020. Then, gross domestic product and human development index are replaced by economic complexity and energy prices, respectively, for a robustness check. The overall findings of this research support causal and long-run relationships across governance systems, using dynamic panel data techniques and panel cointegration approach. The results also show that the impact of energy security and environmental policy measurements on the governance indices is heterogeneous. Specifically, a statistically significant and positive effect of diversification of primary energy demand on voice and accountability, political stability, and regulatory quality is detected. Moreover, diversification of primary energy supply enhances voice and accountability, government effectiveness, and control of corruption. Furthermore, only government effectiveness and control of corruption are positively affected in response to decarbonization policies. The comparative analysis demonstrates that the voice and accountability and political stability dimensions of good governance are more elastic in the large energy-consuming economies when the share of energy security and environmental policy measurements and control variables increases. Hence, these policies directly affect governance performance, influencing foreign relations and causing considerable effects on global geopolitical issues. In addition, this complicates the long-term process of government strategic planning. From the aspect of control variables, the contribution of human development index to good governance is higher than that of gross domestic product. Also, economic complexity provides an appropriate measure of a country's economic development to explain good governance. Consequently, innovation in energy systems utilized by research and development investments is closely linked to global stability and sustainable development. However, it is characterized by a significant role in operational complexity and system reliability. Therefore, good governance requires a combination of efficient management of a country's energy sector and development of energy security and environmental strategies, bearing in mind the energy trilemma and a trade-off process among cultural, political, economic, and social objective priorities. Hence, it is crucial to improve stability in developing and developed countries and for their citizens, especially across the large energy-consuming economies.

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- Ethical Approval: The research did not involve human participants and/or animals.
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Appendix

Table I. Abbreviations and Acronyms

G. G	good governance	G. I	governance indices
G	governance	E. S. P. I	energy security & environmental policy indices
E. S. P	energy security policies	P. D. P. E. S	portfolio decisions of primary energy sources
E. V. P	environmental sustainability policy	P. E. D	primary energy demand
S	energy systems	D. P. E. D	diversification of primary energy demand
P. E. S	primary energy source	D. P. E. S	diversification of primary energy supply
C. P. I	consumer price index	L. E. C. E	large energy-consuming economies
E. C	economic complexity	N. C. F. P	non-carbon-based fuel portfolio
G. D. P	per capita gross domestic product	H. D. I	human development index
V. A	voice and accountability	C. C	control of corruption
P. S	political stability	R. Q	regulatory quality
G. E	government effectiveness	R. L	rule of law
H. P	Hodrick-Prescott	E. I. A	the US' energy information administration
L. T. T	long-term trends	A. P. E. R. C	Asia pacific energy research center
S. T. F	short-term fluctuations	N. R. E	new & renewable energy sources
L. L. C	Levin, Lin & Chu	A. T. S	actual time series
P. E. G	Pedroni's Engle-Granger	A. R	auto-regressive
C. D	cross-sectional dependency	F.M.O.L.S	panel fully modified least squares
A. B	Arellano-Bond	D.O.L.S	panel dynamic least squares
Δ	first difference	V. I. F	variance inflation factor
S. J	Sargan J	G. M. M	generalized methods of moments
P. P	Phillips–Perron	A. D. F	Augmented Dickey-Fuller

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