The impact of trade openness, export concentration and economic complexity on energy demand among G7 countries

Abstract

This research attempts to explore the scale (trade openness), composition (export concentration) and technique effect (economic complexity) of international trade on energy use in the sample of G7 nations over the period 1970 and 2020 separately. To do that, we build up three empirical models based on the Regression on Population, Affluence and Technology approach. The analysis outcomes indicated a positive long-run link between per capita income, urbanization, trade openness, export concentration, economic complexity and energy use across the three models. The outcomes obtained from long-run estimations provide evidence that economic complexity and export concentration decreases energy consumption. Besides, empirical findings show that trade openness boosts energy use. Based on the detailed empirical research, the direction for the policy is that they should harness more strength on energy conservation by increasing the composition and technical effects of international trade. They should also focus on improving the countries' economic freedom (trade openness) while maintaining energy consumption at a lower rate.

Keywords: International Trade; Trade Openness; Economic Complexity; Export Concentration; Energy Demand

1. Introduction

As most countries join the complex society, energy is essential for the durability of activities in our daily life. It is used in agriculture, industry, construction and all other daily life areas (Doğan, 2015). Especially following the industrial revolution, energy has become the primary input of all economic tasks (Shahbaz et al., 2013). In other words, the continuation of human life and national economies is closely related to energy (Sebri and Ben Salha, 2014). Energy is a determining parameter in the welfare and economic development of countries.

Trade is another crucial parameter in welfare and economic development because countries profit by selling the products they produce worldwide (Can et al., 2022b). In this way, economies grow faster. Besides, thanks to trade, countries can transfer technology (Berdell, 2002). Expansion of trade also allows the creation of new employment opportunities (Buysse et al., 2018).

Foreign trade impacts energy use through 3 channels. These are scale effect, composition effect and technique effect, respectively. Scale effect refers to countries' increase in their access to the market with their liberalization policies which leads to a boost in their production (Cole and Rayner, 2000). The scale effect is based on trade openness. Thanks to trade openness and liberalization policies, countries manufacture more products because of expanding international markets. This process means that more input is needed for output (Tsurumi and Managi, 2010), raising energy consumption (Shahbaz et al., 2014). However, with more liberalization policies, energy can be used more efficiently due to imported technology from developed countries (Nasreen and Anwar, 2014). Besides, import has the potential to affect countries' energy consumption. If the imported product mix mainly comprises automobile air conditioners and refrigerators, this may increase energy consumption (Sadorsky, 2011). In other words, the scale effect of trade may have a favourable or unfavourable influence on energy use.

Scholars test the link between energy consumption and trade predominantly through trade openness (scale effect). In other words, the literature generally excludes composition and technique effects during the research. However, as discussed in recent foreign trade literature, not only the "volume of trade" but also the composition of trade (product diversification or product concentration) is another critical parameter for countries (Jaimovich, 2012; Parteka and Tamberi, 2013). In energy economics, we can evaluate that trade composition may have a favourable or unfavourable effect on energy use. In the first step of the development path, as the development level increases, the diversity of products manufactured will expand (Herzer and Nowak-Lehmann, 2006). They aim to add more products to their export portfolio at this step. Thus, a boost in trade activity leads to substantially higher energy needs (Gozgor and Can, 2016b). With the transition from agriculture to industry, countries primarily manufacture energy-intensive products (e.g. cement, metal) (Hu et al., 2020), which causes increased energy consumption. Also, energy is needed to transport manufactured products from one location to another (Nasreen and Anwar, 2014). However, when they reach a threshold income level[1], their classification change regarding development level. At this step, developed countries narrow their export portfolio and concentrate their export basket (Mania, 2020; Can and Gozgor, 2018). In other words, while in the developing countries' diversification path, energy consumption is expected to increase, in the concentration path of developed countries, energy use is expected to lessen.

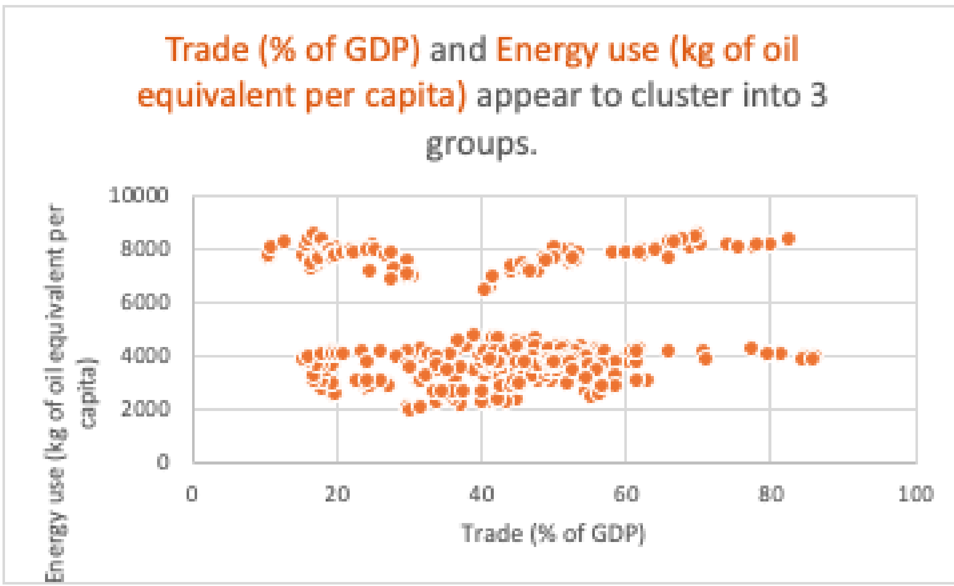


Figure 1b

Figure 1b, c, and d demonstrates the trend of trade which increases over time, as well as energy use for all G7 countries. This is also captured in the relationship between trade and energy use, which appears to cluster into three groups with an increasing trend.

[1] This income level is calculated around 22.500 and 25.000 US Dollars by different scholars, respectively. See for details Cadot et al. (2011) and Imbs and Wacziarg, (2003).

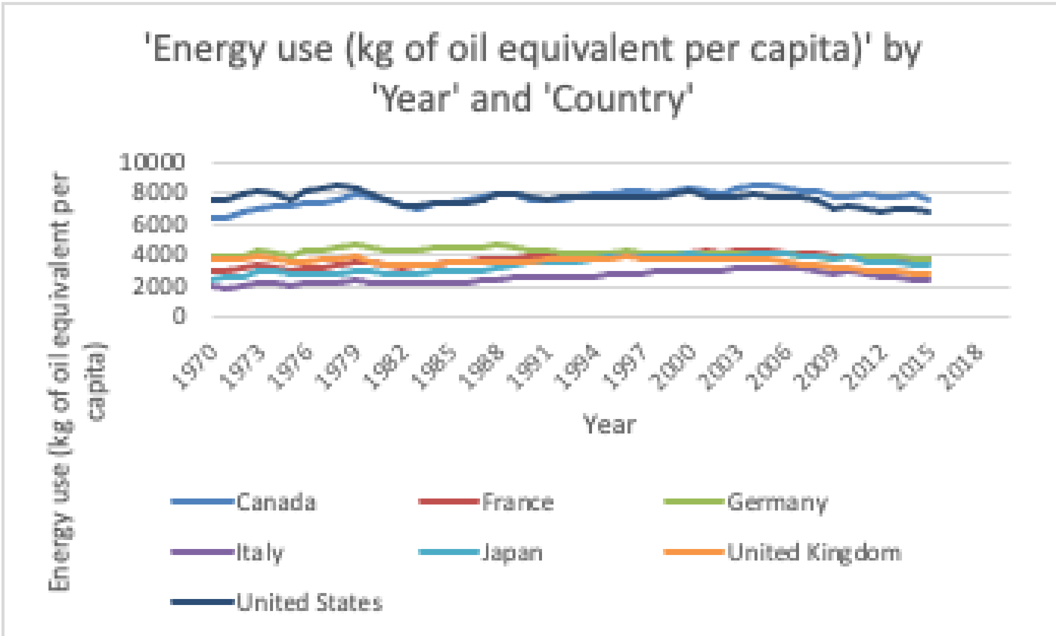


Figure 1c

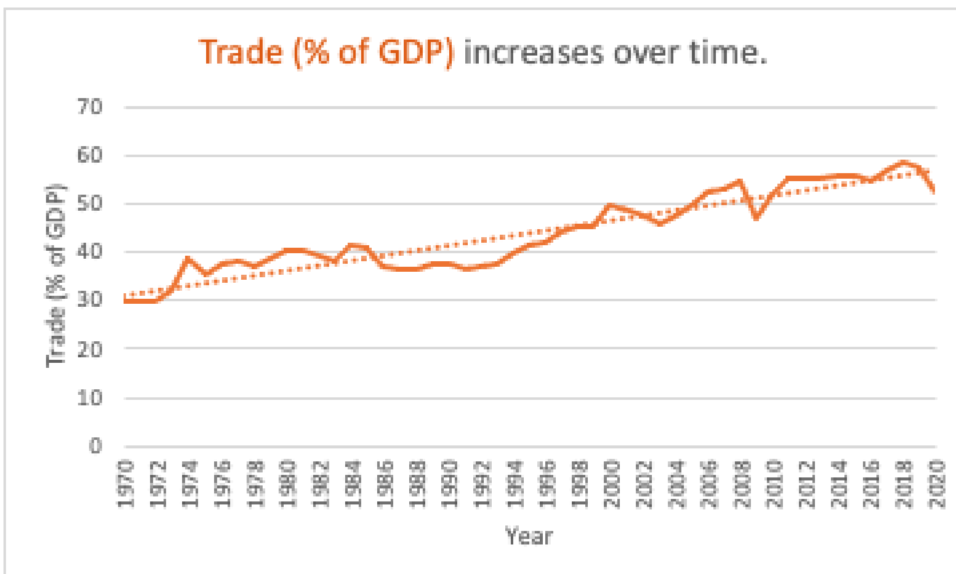


Figure 1d

In trade literature, several studies tested the composition influence of export on economic development in different nations or nation groups. In these studies, scholars concluded that export diversification/export concentration positively affects economic growth (e.g. Aditya and Acharyya, 2013; Gozgor and Can, 2016a; 2017; Markakkaran and Sridharan, 2022; Munir and Javid, 2018). These results gained more scholars' attention to the related topic in international trade literature. Besides, environmental economists pay attention to export composition's effect on the environment (Can et al., 2020). However, in the energy literature, a limited study explored the link between export composition (diversification or concentration) and energy use. It is highly significant to explain the relationship between the two variables since the export structure is essential during the countries' economic development process. Hence, for developing our study, we have decomposed emissions concerning proposed determining factors using an alternative STIRPAT (stochastic impacts by regression on affluence, population, and technology) model and their impacts on environmental degradation (Wu et al., 2021). Our study supposes an advance of the study proposed by Xue et al. (2022), who explored through an extended STIRPAT model and a coupling coordination degree model, analyzed the spatial and temporal evolution of energy efficiency and industrial structure.

The economic structure is another parameter that impacts the energy use of a nation. In other words, 'what countries produce' is as important as 'how they produce' (Ferranti et al., 2004). This process refers to the technique effect, which shows the technological level used in production. Energy consumption decreases as the technology and knowledge level used in production increases (Cole and Rayner, 2000; Dogan, 2025; Dogan et al., 2020). In the first stage of development, countries (less developed countries) have production structures that cause less energy consumption (e.g. agriculture). However, as the level of development increases, a change occurs in the country's production structure (Tsurumi and Managi, 2010). In this process, countries (developing countries) mainly operate in energy-intensive industries (Hu et al., 2020). Later, with the increased environmental sensitivity, developed countries acquired a more complex and sophisticated production structure (Can and Doğan, 2017), leading to a cut in energy needs.

Recently, in the studies conducted on foreign trade, the countries' economic structures based on knowledge and skills are represented with "economic complexity". Economic complexity is an index that presents countries' knowledge and skill-based manufacturing structure (Hausmann et al.,2014). As countries' knowledge and skill level expands, they have a more complex economic structure. Scholars concluded that economic complexity is essential for sustainable economic growth (e.g. Zhu and Li, 2017). From this point of view, it can be interpreted that while developed countries have a complex economic structure, developing countries have less complex economies (Can and Doğan, 2020). When we evaluate in the context of energy use, the economic structure of developed nations is expected to decline in energy consumption.

In this context, our main aim is to explore the scale (trade openness), composition (export concentration), and technique effect (economic complexity) of international trade on energy use separately (Figure 1) in a case study for G7 Countries. The main purpose of choosing this country group is that these countries can produce the most sophisticated products in the world, use advanced technological production techniques, and have the world's largest trading capacity in terms of international trade. The central point of separating trade here is to examine the impact of three different aspects of trade on energy use rather than examining the effect of trade on energy use. In this way, it will be possible to observe which aspect of trade has a more significant impact on energy use. Secondly, the effect of these variables on energy consumption was tested with three different econometric models. Behind this different model setup is the multicollinearity problem that may occur between the trade variables used. For example, the economic complexity index is calculated based on the export concentration index.

<PLEASE INSERT FIGURE 1>

The current study adds to the empirical literature on energy consumption and trade in several ways. Initially, most energy literature studies use trade openness (scale) as a proxy for international trade. However, in recent years, environmental economists have provided evidence that export composition and economic complexity (technique effect) plays a fundamental function in the environment (e.g. Apergis et al., 2018; Can and Gozgor, 2017; Doğan et al., 2019; Mania, 2020). According to our best knowledge, this is the initial research that considers the trade openness (scale effect), export concentration (composition effect) and economic complexity (technique effect) of trade on energy use separately by employing the same model in the literature. In other words, most previous studies only examine one trade variable, e.g. trade openness; this study covers trade openness, export product concentration, and economic complexity. Secondly, while some studies analyze the impact of diversification of export products on energy use, no study examining the effect of export concentration on energy use has been found in the literature. Thirdly, we consider the G7 countries classified as developed countries based on the United Nations (UN) (World Economic Situation and Prospects, 2018).

We construct the remaining paper as follows: Section 2 presents the literature review; Section 3 provides the data and the econometric methodology; Section 4 displays the interpretation and discussion of findings, and Section 5 concludes.

2. Literature Review

Many studies in energy literature explored the link between international trade and energy use. Generally, trade openness, export or import, is adopted as a proxy of international trade. In other words, researchers predominantly analyze the relationship "scale effect of trade" and energy consumption. This captures both cause and effect relationships and the regions analyzed in the studies reviewed. Alam and Murad (2020) analyzed the effect of international trade on energy use in OECD countries. The obtained finding demonstrates that international trade is vital in boosting energy use. Pan et al. (2019) attempted to explore the effect of trade openness on energy intensity in Bangladesh from 1986-2015. Their results reveal that trade openness is having an adverse impact on energy intensity. From 1990-2012, Amri (2019) analyzed the impact of international trade on renewable and non-renewable energy use in a case study of 72 developing and developed nations. The empirical results reveal an inverted-U relationship between international trade and non-renewable energy use in developed nations during the same variables and a U-shaped relationship in developing nations. In the sample of 22 emerging economies, Rafiq et al. (2016) inspected the effect of trade openness on energy intensity. Empirical findings provide evidence that trade openness has a suppressing effect on energy intensity. Using an extended Cobb-Douglas production function, Rafindadi and Ozturk (2016) examined the impact of export and import on electricity consumption in Japan from 1970-2012. The findings reveal that export and import present a crucial effect on increasing electricity use.

In a case study of Algeria, Adom (2015) tested the effect of trade openness on energy intensity. The empirical outcome shows that energy intensity negatively correlates with trade openness. Kyophilavong et al. (2015) tested trade openness's impact on Thailand's energy use from 1971 to 2012. Their results demonstrate that there is a long-run link among the variables. They detected a bidirectional causality between international trade and energy use in the short run. Nasreen and Anwar (2014) attempted to investigate the impact of international trade on energy use in 15 Asian countries. They concluded that there is a long-run link among the variables. Besides, their findings demonstrate that trade boosts energy use. In the sample of OECD countries, Dedeoğlu and Kaya (2013) checked the impact of export and import on energy use. Their results confirm that export and import have an escalating effect on increasing energy use. Sadorsky (2011) examined the export and import of energy use in a case study of 8 Middle Eastern countries. His results provide a long-run effect between the variables, and international trade is an important parameter that leads to increased energy usage.

In recent years, scholars noticed the importance of the composition impact of trade on energy use. However, this literature is minimal. In these researches, diversification of export products is considered a proxy of the composition impact of international trade. For example, in the sample of the United States of America, Shahbaz et al. (2019) examined the effect of the diversification of export products on energy needs over the period 1975-2016. Their findings reveal that diversification of export products decreases energy use. In a case study for OECD countries, Bashir et al. (2020) explored the effect of the diversification of export products on energy efficiency. They concluded that diversification of export products is a moderating impact on energy intensity in this country group.[2] In another research, Shahzad et al. (2020) analyzed the effect of the diversification of export products on energy use in a sample of 10 newly industrialized nations between 1971 and 2014. The outcome confirms that export product diversification lessens energy use in this group of nations. Olasehinde-Williams et al. (2023) explored the impact of the diversification of export products on energy demand in a case study for 30 nations located in the Global North between 1980 and 2014. The obtained empirical outcome confirms that the diversification of export products decreases energy use. Fatima et al. (2022) checked the impact of the diversification of export products on renewable energy use in a case study for the Gulf Cooperation Council (GCC) between 1990 and 2019. The outcomes from empirical findings confirm that diversification in the export basket leads to decreased renewable energy use. However, in the literature, there is no study to analyze the effect of export concentration on energy use.

In recent times, in energy economic literature, the researcher began to analyze the effect of economic complexity as a potential parameter for determining energy use. However, the literature is minimal. For example, Nawaz et al. (2020) investigated the effect of economic complexity on energy use over the period 1972-2018 in Pakistan. Their findings provide evidence that economic complexity decreases total energy use. Fang et al. (2021) explored the impact of energy consumption in a sample of OECD nations. Empirical results indicate that economic complexity has an essential indicator for decreasing energy use. In recent research, Can et al. (2022) tested the effect of economic complexity on energy use. Their findings provided evidence that while economic complexity boosts energy use in developing nations, it reduces energy use in developed nations. In a recent study, Can and Ahmed (2022) inspected the effect of economic complexity on renewable and non-renewable energy consumption in a case study for 14 European Union (EU) member states between 1990 and 2017. Their empirical outcomes confirm that economic complexity boosts renewable energy use and decreases non-renewable energy use. The summary of the literature is presented in Table 1.

3. Data and empirical methodologies

3.1 Data Measurement

[2] In these two studies, although scholars prefer to use "export product diversification" as a proxy for composition effect, it is suitable to evaluate the results in terms of "export product concentration" because of international trade theory. See Mania (2020) for details.

For the empirical inspection, we gather annual data from 1970 to 2020 on G7 countries such as Canada, France, Germany, Italy, Japan, the United Kingdom and the United States of America.[3] We measure energy consumption using several independent variables. Specifically, we employ the following variables in the model: energy use per in kg of oil equivalent per capita (ENPC), the real Gross Domestic Product per capita measured in constant 2010 US$ (GDPPC), urbanization in % of total population (URB), trade openness in % of GDP (OPEN), Theil export product concentration (CON) and economic complexity (ECI) indices.

The ENPC, GDPPC, URB, and OPEN data have been sourced from the World Development Indicators (WDI) database. In contrast, data on CON and ECI are sourced from the International Monetary Fund (IMF) and the Observatory of Economic Complexity online databases (OEC), respectively.

3.2. Model setting and estimation strategies

This paper used the Regression on Population, Affluence and Technology (STIRPAT) model introduced by Dietz and Rosa (1994) to conduct the empirical hypothesis and statistical analysis of the relationship between the energy use, scale, composition, and technology effect of international trade. STIRPAT model (Stochastic Impact by Regression on Population, Affluence and Technology) is an empirical framework derived from the IPAT model's principles (Impact, Population, Affluence, and Technology). Ehrlich and Holdren (1971) derived an IPAT model – a theoretical framework that examines the link between environmental quality, population, growth, and technological advancement. Following Giambona et al. (2005), we assume that the relationship between a country's population, wealth, and technology consumption greatly influences the country's environmental quality.

However, due to dependency and causal links between variables, the IPAT model has the limitation of not being able to estimate empirical hypothesis and statistical analysis. As such, some academic literature has tried to modify the model. Our paper is based on the STIRPAT methodology (Dietz and Rosa 1994), applied to estimate hypothesis and statistical analysis. The empirical model explores the interaction between the independent variables and the environments and their causal effect (Wei, 2011).

To demonstrate and analyze the mechanism via which all variables connect, we document their linkage and theoretical as well as hypothetical underpinning as follows. To start

[3] Among the series included in the analysis, while the ECI series ends in 2017, the CON variable ends in 2014. To include more observations in the analysis, Berger et al. (2010), Busse et al. (2010), Tekin (2012) studies were followed. Considering that there was no structural break in the relevant period in the series, missing data until 2020 were included in the analysis by taking the weighted averages of the last four years (Includes less than 4% of the total observations). It was observed that there was no significant difference in the models established with the original series and the extended series in the analysis stages.

with, trade openness refers to the extent to which a country allows the free flow of goods and services between its borders and the rest of the world. This can be measured by the ratio of a country's total trade (exports plus imports) to its gross domestic product (GDP). A country with a high level of trade openness relies heavily on international trade to support its economy. Also, export concentration refers to the degree to which a few products or industries dominate a country's exports. For example, a country that exports a large share of its goods as oil or natural gas, is said to have a high level of export concentration.

On the other hand, a country with a diverse export base, producing and exporting a wide range of goods, is said to have a low level of export concentration. Additionally, economic complexity refers to the diversity and sophistication of a country's production structure. Countries with a high level of economic complexity produce a diverse range of goods, often using advanced technologies and skilled labour. In contrast, countries with a low level of economic complexity typically produce a narrow range of goods, often using low-skilled labour and simple technologies.

It is also commonplace in the literature that energy demand refers to the amount of energy consumed by a country's economy. This can be measured in terms of primary energy, which includes all forms of energy used by the economy (such as oil, natural gas, coal, and renewables), or in terms of final energy, which refers to the energy used by end-users (such as electricity, transport fuels, and heating and cooling). Consequently, there is a strong empirical link between trade openness, export concentration, economic complexity, and energy demand. Countries with a high level of trade openness tend to have higher energy demand levels, as they rely on international trade to support their economies and therefore require more energy to produce and transport goods. Similarly, countries with a high level of export concentration tend to have higher levels of energy demand, as they rely heavily on a few energy-intensive industries to drive their economies. On the other hand, countries with a high level of economic complexity tend to have lower energy demand levels, as they rely on a diverse range of industries and technologies to drive their economies. This is because more advanced and sophisticated technologies tend to be more energy efficient, and a diverse range of industries allows for more balanced and sustainable development.

Overall, the empirical link between trade openness, export concentration, economic complexity, and energy demand highlights the importance of diversification and sustainability in economic development. While international trade and specialization can drive economic growth in the short term, a reliance on a few energy-intensive industries can lead to long-term vulnerabilities and ecological risks. On the other hand, a diverse and sophisticated production structure can support sustainable and balanced economic growth.

Given the foregoing, the model is given as follows:

$$I = \delta P^{\alpha} A^{\beta} T^{\gamma} \varepsilon \quad (1)$$

Where we denote the dependent variables under study (energy consumption in this case), δ denotes the constant value, $\alpha, \beta, and\ \gamma$ are the coefficients of the independent variables. P denotes population, which is urbanization in % of the total population, *A* denotes affluence which is the real Gross Domestic Product per capita measured in constant 2010 US$ (GDPPC), T denotes technology which captures the trade openness, economic complexity, and export product concentration, and ε is the nuisance term.

Following Wang and Li (2016) and Shahbaz et al. (2015), we use the STIRPAT model, which accounts for different potential trade parameters separately, as described in the following equation:

$$ENPC_{i,t} = \beta_0 + \beta_1 GDPPC_{i,t} + \beta_2 URB_{i,t} + \beta_3 ECI_{i,t} + e_{i,t} \quad (2)$$

$$ENPC_{i,t} = \beta_0 + \beta_1 GDPPC_{i,t} + \beta_2 URB_{i,t} + \beta_3 CON_{i,t} + e_{i,t} \quad (3)$$

$$ENPC_{i,t} = \beta_0 + \beta_1 GDPPC_{i,t} + \beta_2 URB_{i,t} + \beta_3 OPEN_{i,t} + e_{i,t} \quad (4)$$

where *i* stands for the country; t refers to time; and ENPC, GDPPC, URB, ECI, CON, and OPEN indicate energy use per capita, income per capita, urbanization, economic complexity, export product concentration and trade openness, respectively. Before the empirical analysis, ENPC, GDPPC, and URB are taken in the logarithmic form. The descriptive statistics are provided in Table 2.

<PLEASE INSERT TABLE 2>

4. Empirical findings and discussion

To analyze any panel or longitudinal data, some pre-diagnostic analysis, such as the cross-section dependence (CD), the unit root test, and the evidence of a cointegration relationship (that is, the long-run link), needs to be established. After that, the cointegration test's coefficient assesses the significant impact of independent variables on the dependent one. This part of the study introduces the stepwise analysis of the research before the final discussion and conclusions are made.

<PLEASE INSERT TABLE 3>

In the first part of the analysis (Table 3), the CD of the variables and models were tested using Breusch-Pagan (1980), Pesaran (2004) and Pesaran et al. (2008) test.

The result of the three tests showed that the null hypothesis of the cross-section dependence of the variables was rejected at a 1% significance level. This result indicates a cross-sectional dependence between the cross-sections of the series. Hence, the second-generation panel units root test, which considers the cross-section dependence, will be fitted to investigate the stationary of the series. In first-generation unit root tests, it is assumed that when a shock occurs, all units in the panel are equally affected by the resulting shock. However, the units that make up the panel may be affected at different levels by the resulting shocks. Thus, we use second-generation unit tests in this research (Katircioglu et al., 2015). In the second part, the panel unit root test, which examined the order of integration of the variables, was examined using PANKPSS (Panel Kwiatkowski, Phillips, Schmidt and Shin) technique introduced by Carrioni et al. (2005). The PANKPSS test whether the series has a unit root while considering the CD and multiple structural breaks.

<*PLEASE INSERT TABLE 4*>

<*PLEASE INSERT TABLE 5*>

According to Table 4, the PANKPSS test revealed that all the series have unit roots (non-stationary) at the first level since the bootstrap's critical value is less than the PANKPSS test statistics. However, at the first difference, the series were stationary, thus indicating that the variables' integration is of order one I(1). The structural break dates for each country are presented in Table 5. We also re-check the panel unit root by employing the CIPS test based on Pesaran (2007). The findings confirmed the outcomes of PANKPSS. The results are provided in Table 6.

<*PLEASE INSERT TABLE 6*>

After the CD and stationary test, the long-run link between the studied variables was investigated using panel cointegration techniques developed by Westerlund-Edgerton (2008). This test accounts for the CD and structural break tests in its cointegration.

As shown in Table 7, when structural breaks are considered, the null hypothesis of no cointegration was rejected at a 5% level for model 1 and a 1% level for model 2 and model 3, respectively.

<*PLEASE INSERT TABLE 7*>

<*PLEASE INSERT TABLE 8*>

The structural break in the cointegration panel equation for each country is presented in Table 8. After this cointegration test, the Durbin-H cointegration approach based on Westerlund (2008) was used to inspect whether the results obtained were consistent. This test offers two different statistics, the Durbin-H group and Durbin-H panel statistics, respectively. Based on the Durbin-H Panel, the series is cointegrated in the long run in all three models. The outcomes from Durbin-H group statistics also verify previous findings at different significance levels.

<PLEASE INSERT TABLE 9>

In either case, there is proof of a cointegration link between the examined variables. Thus, further analysis can proceed, such as estimating the coefficient of the long-run relationship for the model. Firstly, the Augmented Mean Group (AMG) method of Eberhardt and Bond (2009) was employed to obtain long-term coefficients. Then, the long-term coefficients were re-estimated with FMOLS to check whether the collected findings were robust.[4]

The empirical analysis in Table 10 and Table 11 present the main models' long-run relationship, with attempts to assess the influence of three different predictors on energy consumption. The findings of each model were presented as follows:

<PLEASE INSERT TABLE 10>

<PLEASE INSERT TABLE 11>

<PLEASE INSERT FIGURE 2>

4.1. Model 1: Energy Consumption and Technical Effect.

Column 2 in Table 10 revealed the economic complexity coefficient (ECI), a proxy for technical effect, on energy use in G7 countries. The outcome indicates that the long-run link between GDP per capita and energy consumption is positive and significant. This outcome suggests that a per cent boost in GDP per capita in G7 countries contributes to the 0.39% increment in energy consumption. Also, a percentage increase in urbanization decreases energy consumption by 0.01%. Moreover, the ECI has a long-run coefficient of -0.1002 at a 5% significance level. This evidence indicates that as the government increases one percentage in the technical effect of international trade, there will be a 0.10% reduction in energy consumption. After this step, the same model was re-estimated using the FMOLS approach. The outcomes are presented in Table 11. It was confirmed that the signs of all the coefficients were consistent at a 1% significance level (except ECI). These findings show that an increase in ECI can be viewed as an expansion in production capacity due to technological influences linked to an increase in energy efficiency. Thus, an expansion in ECI affects energy savings. This outcome aligns with Fang et al. (2021) and Can et al. (2022).

[4] Structural break dates obtained from the cointegration test were added to the model as a dummy variable in the long-term analysis.

4.2. Model 2: Energy Consumption and Composition Effect.

Table 10, Column 3 revealed the coefficient of export product concentration (CON), a proxy for the composition effect on energy use in G7 countries. The result provides that the long-run link between GDP per capita and energy use is positive and significant. This indicates that a 1% rise in GDP per capita in G7 countries contributes to the 0.32% increment in energy consumption. Also, a 1% rise in urbanization decreases energy consumption by 0.02%. Moreover, the CON has a long-run coefficient of -0.1862 at a 1% significance level. This indicates that as the government increases one percentage in the composition effect of international trade, there will be a 0.18% reduction in energy consumption. The outcomes collected from FMOLS verify the results at different statistical significance levels. It seems possible to deduce the following from these results. As the income level of the countries increases, they give up products that require intensive energy in their production. In this process, they mainly produce knowledge-intensive products requiring less energy. This process increases countries' concentration levels on more sophisticated products, which can result in a decline in total energy use. According to our knowledge, this is the first outcome in the literature.

4.3. Model 3: Energy Consumption and Scale Effect.

In Table 10, Column 4 revealed the coefficient of trade openness (OPEN), a proxy for the scale effect on energy use in G7 countries. The result demonstrates that the long-run link between GDP per capita and energy use is positive and significant. This finding indicates that a 1% rise in GDP per capita in G7 countries contributes to the 0.47% increment in energy consumption. Also, a 1% increase in urbanization decreases energy consumption by 0.02%. Moreover, OPEN has a long-run coefficient of 0.1006 at a 1% significance level. This evidence implies that as government increase 1% in the composition effect of international trade, there will be a 0.09% increase in energy usage. The findings gained from FMOLS in Table 11 approve that all signs of coefficients are the same at the 1% level. The empirical finding for trade openness aligns with Rafindadi and Ozturk (2016) and Dedeoğlu and Kaya (2013). When countries increase their foreign trade volume, the energy required for production will also increase. Such a situation may arise, especially based on exports. When evaluated in terms of imports, the increase in imports in terms of volume means that more energy will be consumed for transporting and distributing these products. In addition, if the imported products are mainly energy-consuming (cars, refrigerators, air conditioners), a volumetric increase in foreign trade will increase energy consumption.

5. Policy Recommendations

Obtained empirical findings allow us to present various policy recommendations. Empirical findings show that an increase in economic complexity reduces total energy use. First, to increase the economic complexity, policymakers should especially attach great importance to the country's education policies. Education policies that enable innovation and innovative skills to emerge will potentially affect the economic system overall since advancement in the education system will boost the quality of human capital. This enables the country's economic structure to attain a more technological, more information-intensive production structure. In addition, while the rise in economic complexity causes a boost in the countries' income, it also contributes positively to the increase in well-being in society with the decrease in energy consumption.

Empirical findings show that export concentration reduces energy consumption. In this direction, policymakers should separate the products that consume high energy in their production from the export baskets. At this point, a long-term strategic plan should be prepared as a priority. Thanks to this strategic plan, it should be determined which products will be abandoned at the first stage and which knowledge-based products should be included in the export basket instead of these products. In this way, the foreign trade basket will be sorted out, and products that need less energy in their production will be added to the basket. However, this is due to the increase in Research and Development (R&D) activities in the state. Because, thanks to R&D, countries can produce new and knowledge and technology-based products. Consequently, policymakers need to provide R&D incentives to companies. In addition, providing tax incentives to companies investing in technology also increases the export concentration in the country.

Empirical findings show that trade openness increases energy consumption. In this context, policymakers should carefully examine the country's export and import items. In terms of export, especially during the transfer of products, using vehicles such as trains will reduce the total energy consumption. In addition, by imposing more tax on products with low energy efficiency in product imports, consumers can be directed to those with a high energy efficiency of similar products.

6. Conclusion

This study attempts to explore the scale (trade openness), composition (export concentration) and technique effect (economic complexity) of international trade on energy consumption. To achieve the aims, pre-diagnostic analysis, such as cross-sectional dependence (CD), panel unit roots test for multiple structural breaks, and evidence of cointegration test, were examined. After that, the long-run effect coefficients were investigated. The empirical result revealed that there is CD, demonstrating that the predictive factors of energy use in one country may be the same in other countries. There is also evidence of a stationary test at the integration of order one I(1). Evidence of long-run relationships was also examined and established.

Further results of the analysis showed there is a positive long-run link between the GDP per capita and energy use across the three models. Hence, a rise in the GDP per capita boosts energy use in G7 countries. There is also a negative long-run relationship linking urbanization and energy use. As people are more civilized, the rate at which energy will be consumed will be diminished by at least 0.02% of the initial use. Furthermore, the research presented a long-run link between the scale effect (trade openness), composition effect (export concentration), and technique effect (economic complexity) on energy consumption.

Trade openness has a positive influence on energy use. This is in tandem with the outcome of Alam and Murad (2020), who found that international trade has a vital role in boosting energy use, and it contradicts the use of Pan et al. (2019) and Rafiq et al. (2016), which revealed that trade openness and energy intensity are negatively related. Regarding export concentration, it negatively influences energy use, meaning that if export product concentration improves in G7 countries, energy consumption will be compressed. Although at the time of writing this paper, some studies have examined the energy-export product diversification nexus, such as Shahbaz et al. (2019), Bashir et al. (2020), and Shahzad et al. (2020), the export concentration is the total indicates the opposite of export product diversification. Thus, according to our limited knowledge, this result is the first finding in the literature. In other words, our result does not support the studies above. Finally, a negative long-run relationship was established between economic complexity and energy use. Our findings demonstrate that ECI has been a significant variable in reducing or lessening environmental emissions. The findings are in line with the research of Nawaz et al. (2020) and Fang et al. (2021). This study also established that increased ECI leads to decreased energy use.

In conclusion, the concerned policymakers should harness energy conservation strength by increasing international trade's composition and technical effects. The governments in G7 countries need to prepare long-term plans for their export basket. The goods should be reduced from the export basket according to their energy consumption during manufacturing. Moreover, governments should focus on producing sophisticated products based on knowledge. They should also focus on improving economic freedom (trade openness) in the countries while simultaneously maintaining energy consumption, as this will reduce the degradation effects on the environment.

References:

Aditya, A., and Acharyya, R. (2013). Export diversification, composition, and economic growth: Evidence from a cross-country analysis. *The Journal of International Trade & Economic Development: An International and Comparative Review*, *22*(7), 959-992.

Adom, P.K. (2015). Business cycle and economic-wide energy intensity: the implications for energy conservation policy in Algeria, *Energy*, *88*, 334–350.

Aissa, M. S., Jebli, M. B. and Youssef, S. B. (2014). Output, renewable energy consumption and trade in Africa, *Energy Policy*, *66*, 11-18.

Alam, M. M. and Murad, M. W. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organizations for economic cooperation and development countries. *Renewable Energy, 145***,** 382-390.

Amri, F. (2019). Renewable and non-renewable categories of energy consumption and trade: Do the development degree and the industrialization degree matter? *Energy*, *173***,** 374-383.

Apergis, N., Can, M., Gozgor, G., and Lau, C. K. M. (2018). Effect of export concentration on CO_2 emissions in developed countries: an empirical analysis. *Environmental Science and Pollution Research*, *25*, 14106-14116.

Bashir, M. A., Sheng, B., Doğan, B., Sarwar, S. & Shahzad, U. (2020). Export product diversification and energy efficiency: Empirical evidence from OECD countries. *Structural Change and Economic Dynamics, 55***,** 232-243.

Berdell, J. (2002). International Trade and Economic Growth in Open Economies, Cheltenham, UK: Edward Elgar.

Berger, A., Busse, M., Nunnenkamp, P. and Roy, M. (2010). More stringent BITs, less ambiguous effects on FDI? Not a bit! WTO Staff Working Paper.

Breusch, T. S. and Pagan, A. R. (1980). The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics. *The Review of Economic Studies*, *47*, 239–253. https://doi.org/10.2307/2297111.

Brini, R., Amara, M. and Jemmali, H. (2017). Renewable energy consumption, International trade, oil price and economic growth inter-linkages The case of Tunisia. *Renewable and Sustainable Energy Reviews*, *76*, 620-627.

Busse, M., Königer, J., Nunnenkamp, P. (2010). FDI promotion through bilateral investment treaties: more than a bit? *Review of World Economics*, *146* (1), 147–1.

Buysse, J., Can, M. and Gozgor, G. (2018). Globalization outcomes and the real output in the sub-Saharan Africa LICs: a cointegration analysis. *Economic Research*, *31*(1), 338-351.

Cadot, O., Carrere, C. and Strauss–Kahn, V. (2011). Export diversification: What's behind the hump?. *Review of Economics and Statistics*, *93* (2), 590–605.

Can, M. and Doğan, B. (2017). The effects of economic structural transformation on employment: an evaluation in the context of economic complexity and product space theory. In: Yenilmez F, Kilic E (eds), *Handbook of research on unemployment and labour market sustainability in the era of globalization*. IGI Global Publishing, Hershey, 275–306. DOI: 10.4018/978-1-5225-2008-5.ch016.

Can, M. and Doğan, B. (2020). The Effect of Knowledge and Skill-Based Production on Agricultural Employment: An Empirical Analysis in the Sample of South Korea. In: Sikdar S., Das R.C., Bhattacharyya R. (eds), *Role of IT- ITES in Economic Development of Asia*. Springer, Singapore. https://doi.org/10.1007/978-981-15-4206-0_17.

Can, M. and Gozgor, G. (2017). The impact of economic complexity on carbon emissions: evidence from France. *Environmental Science and Pollution Research*, *24*, 16364-16370.

Can, M. and Gozgor, G. (2018). Effect of export product diversification on quality upgrading: an empirical study. *The Journal of International Trade & Economic Development: An International and Comparative Review*, *27*(3), 293-313.

Can, M., Brusselaers, J. and Mercan, M. (2022a). The effect of export composition on energy demand: A fresh evidence in the context of economic complexity. *Review of Development Economics*, 26, 687-703. DOI: 10.1111/rode.12854.

Can, M., Dogan, B. and Saboori, B. (2020). Does trade matter for environmental degradation in developing countries? New evidence in the context of export product diversification. *Environmental Science and Pollution Research*, *27*, 14702-14710. https://doi.org/10.1007/s11356-020-08000-2.

Carrioni , S. J. L., Barrio-Castro, T. D. and Lopez-Bazo, E. (2005). Breaking the panels: An application to the GDP per capita. *The Econometrics Journal*, *8*(2), 159-175.

Cole, M. A. (2006). Does trade liberalization increase energy use? *Economic Letters*, *92*, 108–112.

Cole, M. A., and Rayner, A. J. (2000). The Uruguay Round and air pollution: estimating the composition, scale and technique effects of trade liberalization. *The Journal of International Trade & Economic Development: An International and Comparative Review*, *9*(3), 339-354.

Dedeoglu, D. and Kaya, H. (2013). Energy use, exports, imports and GDP: new evidence from the OECD countries. *Energy Policy*, *57*, 469–476.

Dietz, T. and Rosa, E.A. (1994). Rethinking the Environmental Impacts of Population, Affluence and Technology. *Human Ecology Review*, 1, 277 – 300.

Dogan, E. (2015). The relationship between economic growth and electricity consumption from renewable and non-renewable sources: A study of Turkey. *Renewable and Sustainable Energy Reviews*, *52*, 534-546.

Dogan, E., Altinoz, B., Madaleno, M., & Taskin, D. (2020). The impact of renewable energy consumption to economic growth: a replication and extension of. *Energy Economics*, 90, 104866.

Doğan, B., Saboori, B., and Can, M. (2019). Does economic complexity matter for environmental degradation? An empirical analysis for different stages of development. *Environmental Science and Pollution Research*, *26*, 31900–31912.

Eberhardt, M. and Bond, S. (2009). Cross-section dependence in non-stationary panel models: A novel estimator. MPRA Paper 17692, University Library of Munich. http://mpra.ub.unimuenchen.de/17692.pdf.

Ehrlich, P. and J. Holdren. 1971. Impact of population growth. Science 171: 1212–1217

Erkan, C., Mucuk, M. and Uysal, D. (2010). The impact of energy consumption on exports: The Turkish case. *Asian Journal of Business Management*, *2*(1), 17-23.

Fang, J., Gozgor, G., Mahalik, M. K., Padhan, H. and Xu, R. (2021). The impact of economic complexity on energy demand in OECD countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-020-12089-w.

Fatima, T., Mentel, G., Doğan, B., Hashim, Z. and Shahzad, U. (2022). Investigating the role of export product diversification for renewable, and non-renewable energy consumption in GCC (gulf cooperation council) countries: does the Kuznets hypothesis exist? Environment, Development and Sustainability, 24, 8397-8417.

Ferranti, D. D., Guillermo, E. P., Francisco, H. G. F. and Walton, M. (2004). *Inequality in Latin America: Breaking with History?* World Bank Latin American and Caribbean Studies, Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/15009.

Giambona, F., Jacono, V. and Scuderi, R. (2005). The IPAT Model: an Empirical Evidence Il modello IPAT: un'evidenza empirica. http://www.old.sis-statistica.org/files/pdf/atti/CIMe0905p125-128.pdf.

Giles, J. A. and Williams, C. L. (2000). Export-led growth: a survey of the empirical literature and some non-causality results. *The Journal of International Trade & Economic Development*, *9*(3), 261-337.

Gozgor, G. and Can, M. (2016a). Effects of the product diversification of exports on income at different stages of economic development. *Eurasian Business Review*, *6*(2), 215-235.

Gozgor, G. and Can, M. (2016b). Export product diversification and the environmental Kuznets curve: evidence from Turkey. *Environmental Science and Pollution Research*, *23*(21), 21594–21603.
Gozgor, G. and Can, M. (2017). Causal linkages among the product diversification of exports, economic globalization and economic growth. *Review of Development Economics, 21***,** 888-908.
Hausmann, R., Hidalgo, C. A., Bustos, S., Coscia, M., Simoes, A. and Yildirim, M. A. (2014). The Atlas of Economic Complexity: Mapping Paths to Prosperity, Cambridge: MIT Press.
Herzer, D., and Nowak-Lehmann, F. D. (2006). What does export diversification do for growth? An econometric analysis. *Applied Economics*, *38*(15), 1825-1838.
Hu , G., Can, M., Paramati, S. R., Doğan, B., and Fang, J.(2020). The effect of import product diversification on carbon emissions: New evidence for sustainable economic policies. *Economic Analysis and Policy*, *65*, 198-210.
Imbs, J., and Wacziarg, R. (2003). Stages of diversification. *The American Economic Review*, *93*(1), 63–86.
Jaimovich, E. (2012). Import diversification along the growth path, *Economic Letters*, *117* (1), 306–310.
Jena, P. R. and Grote, U. (2008). Growth-trade-environment nexus in India. In: Proceedings of the German Development Economics Conference, Zurich, Verein für Socialpolitik, Research Committee Development Economics.
Kyophilavong, P., Shahbaz, M., Anwar, S. and Massod, S. (2015). The energy-growth nexus in Thailand: Does trade openness boost energy consumption? *Renewable and Sustainable Energy Reviews*, *46*, 265-274.
Mania, E. (2020). Export diversification and CO2 emissions: an augmented environmental Kuznets curve. *Journal of International Development*, *32*, 168-185.
Narayan, P. K. and Smyth, R. (2009). Multivariate granger causality between electricity consumption, exports and GDP: evidence from a panel of middle eastern countries. *Energy Policy*, *37*, 229–236.
Nasreen, S. and Anwar, S. (2014). Causal relationship between trade openness, economic growth and energy consumption: A panel data analysis of Asian countries. *Energy Policy*, *69*, 82-91.
Nawaz, K., Lahiani, A., and Roubaud, D. (2020). Do natural resources determine energy consumption in Pakistan? The importance of quantile asymmetries. *Quarterly Review of Economics and Finance*, https://doi.org/10.1016/j.qref.2020.10.003.
Nondo, C. and Kahsai, M. (2009). Energy Consumption and Economic Growth: Evidence from COMESA Countries. Selected paper Prepared for Presentation at the Southern Agricultural Economics Association Annual Meeting, Atlanta, Georgia, January 31–February 3, 2009.
Noor, S. and Siddiqi, W. (2010). Energy consumption and economic growth in South Asian Countries: A cointegrated panel analysis. *World Academy of Science: Engineering and Technology, International Journal of Energy and Power Engineering*, *4*(7), 1731-1736.
Olasehinde-Williams, G., Lee, CC. and Folorunsho, A. (2022). What does export diversification do for energy demand? Evidence from the Global North. *Environmental Science and Pollution Research*, 30, 547-556. https://doi.org/10.1007/s11356-022-22202-w.
Pan, X., Uddin, M. K., Saima, U., Jiao, Z., and Han, C. (2019). How does industrialization and trade openness influence energy intensity? Evidence from a path model in case of Bangladesh, *Energy Policy*, *133*, 110916.
Parteka, A. and Tamberi, M. (2013). Product diversification, relative specialization and economic development: Import-export analysis. *Journal of Macroeconomics*, *38*,121–135.
Pesaran, M. H. (2004). *General Diagnostic Tests for Cross Section Dependencec in Panels*. University of Cambridge, Cambridge Working Papers in Economics, 435.
Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265-312.

Peseran, M. H., Ullah, A. and Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence. *The Econometrics Journal*, *11*(1), 105-127.
Rafindadi, A. A., and Ozturk, I. (2016). Effects of financial development, economic growth and trade on electricity consumption: Evidence from post-Fukushima Japan. *Renewable and Sustainable Energy Reviews*, *54*, 1073-1084.
Rafiq, S., Salim, R. and Nielsen, I., (2016). Urbanization, openness, emissions, and energy intensity: a study of increasingly urbanized emerging economies. Energy Economics, 56, 20-28.
Sadorsky, P. (2011). Trade and energy consumption in the Middle East. *Energy Economics*, *33*, 739-749.
Sadorsky, P. (2012). Energy consumption,output and trade in South America. *Energy Economics*, *34*, 476–488.
Sebri, M. and Ben Salha, O. (2014). On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries. *Renewable and Sustainable Energy Reviews*, *39*, 14-23.
Shahbaz, M., Gozgor, G. & Hammoudeh, S. (2019). Human capital and export diversification as new determinants of energy demand in the United States. *Energy Economics,* 78**,** 335-349.
Shahbaz, M., Khan, S. and Tahir, M. I. (2013). The dynamic links between energy consumption, economic growth, financial development and trade in China: Fresh evidence from multivariate framework analysis. *Energy Economics*, *40*(13), 8-21.
Shahbaz, M., Loganathan, N., Sbia, R., and Afza, T. (2015). The effect of urbanization, affluence and trade openness on energy consumption: A time series analysis in Malaysia. *Renewable and Sustainable Energy Reviews*, *47*, 683-693.
Shahbaz, M., Nasreen, S., Ling, C. H., and Sbia, R. (2014). Causality between trade openness and energy consumption: What causes what in high, middle and low income countries. *Energy Policy*, *70*, 126-143.
Shahzad, U., Doğan, B., Sinha, A. and Fareed, Z. (2020). Does Export product diversification help to reduce energy demand: Exploring the contextual evidences from the newly industrialized countries. *Energy*, 118881.
Tekin, R. B. (2012). Economic growth, exports and foreign direct investment in Least Developed Countries: A panel Granger causality analysis. *Economic Modelling*, *29*, 868-878.
Tsurumi, T., and Managi, S. (2010). Decomposition of the environmental Kuznets curve: scale, technique, and composition effects. *Environmental Economics and Policy Studies*, *11*, 19-36.
Wang, Q. and Li, R. (2016). Drivers for energy consumption: A comparative analysis of China and India. *Renewable and Sustainable Energy Reviews*, *62*, 954-962.
Wei, T. (2011). What STIRPAT tells about effects of population and affluence on the environment?. *Ecological Economics*, *72*, 70-74.
Westerlund, J. and Edgerton, D. L. (2008). A simple test for cointegration in dependent panels with structural breaks. *Oxford Bulletin of Economics and Statistics*, *70*(5), 665-704.
World Economic Situation and Prospects, (2018). https://www.un.org/development/desa/dpad/wpcontent/uploads/sites/45/publication/WESP2018_Full_ Web-1.pdf. (Access:13.02.2020).
Wu, R., Wang, J., Wang, S., & Feng, K. (2021). The drivers of declining CO2 emissions trends in developed nations using an extended STIRPAT model: A historical and prospective analysis. *Renewable and Sustainable Energy Reviews*, 149, 111328.
Xue, L., Li, H., Xu, C., Zhao, X., Zheng, Z., Li, Y., & Liu, W. (2022). Impacts of industrial structure adjustment, upgrade and coordination on energy efficiency: Empirical research based on the extended STIRPAT model. *Energy Strategy Reviews*, 43, 100911.
Zeren, F. and Akkuş, H. T. (2020). The relationship between renewable energy consumption and trade openness: New evidence from emerging economies. *Renewable Energy, 147*, 322-329.

Zhu, S., and Li, R. (2017). Economic Complexity, Human Capital and Economic Growth: Empirical Research Based on Cross-Country Panel Data. *Applied Economics*, *49*(38), 3815-3828.

Can, M., Ahmad, M., & Khan, Z. (2021). The impact of export composition on environment and energy demand: evidence from newly industrialized countries. *Environmental Science and Pollution Research*, *28*(25), 33599-33612.

Can, B., Ahmed, Z., Ahmad, M., & Can, M. (2022b). Do renewable energy consumption and green trade openness matter for human well-being? Empirical evidence from European Union countries. *Social Indicators Research*, 1-17. https://doi.org/10.1007/s11205-022-02981-y.

Magazzino, C., Mele, M., Schneider, N., & Shahzad, U. (2022). Does export product diversification spur energy demand in the APEC region? Application of a new neural networks experiment and a decision tree model. *Energy and Buildings*, *258*, 111820.

Dingru, L., Onifade, S. T., Ramzan, M., & AL-Faryan, M. A. S. (2023). Environmental perspectives on the impacts of trade and natural resources on renewable energy utilization in Sub-Sahara Africa: Accounting for FDI, income, and urbanization trends. *Resources Policy*, *80*, 103204.

Markakkaran, S., & Sridharan, P. (2022). Impact of export diversification on economic growth: a system GMM approach. *International Journal of Development Issues*, *21*(2), 309-320. https://doi.org/10.1108/IJDI-10-2021-0210.

Munir, K., & Javed, Z. (2018). Export composition and economic growth: evidence from South Asian countries. *South Asian Journal of Business Studies*, *7*(2), 225-240.

Katircioglu, S. T., Sertoglu, K., Candemir, M., & Mercan, M. (2015). Oil price movements and macroeconomic performance: Evidence from twenty-six OECD countries. *Renewable and Sustainable Energy Reviews*, *44*, 257-270.

Table 1: Summary of the literature

Authors	**Country/Country Group**	**Period**	**Core Trade Variable**	**Energy Indicator**	**Outcomes**
Sadorsky (2011)	8 Middle Eastern countries	1980-2007	Export and import	Total energy use	International trade leads to increase energy use.
Dedeoğlu and Kaya (2013)	OECD	1980-2010	Export and import	Total energy use	Trade has a positive effect on increasing energy use.
Adom (2015)	Algeria	1971-2010	Trade openness	Energy intensity	Energy intensity has a negative correlation with trade openness
Rafiq et al. (2016)	22 emerging economies	1980-2010	Trade Openness	Energy intensity	Trade openness lessens the energy intensity.
Rafindadi and Ozturk (2016)	Japan	1970-2012	Export and import	Electricity consumption	Export and import increase energy use.
Pan et al. (2019)	Bangladesh	1986-2015	Trade Openness	Energy intensity	Trade openness has a negative impact on energy intensity.
Amri (2019)	72 developing and developed countries	1990-2012	Sum of exports and imports	Renewable and non-renewable energy use	Inverted-U relationship between international trade and non-renewable energy use for developed nations, U-shaped relationship in developing nations.
Shahbaz et al. (2019)	United States of America	1975-2016	Export diversification	Total energy use	Trade decreases energy consumption.
Alam and Murad (2020)	OECD	1970-2012	Trade Openness	Renewable energy	Trade openness has a significant positive impact on energy use.
Nawaz et al. (2020)	Pakistan	1972-2018	Economic complexity	Total energy use	Economic complexity lessens the total energy use
Bashir et al. (2020)	OECD	1990-2015	Export product diversification	Energy intensity	Export product diversification helps decrease energy intensity
Shahzad et al. (2020)	10 newly industrialized countries	1971-2014	Export product diversification	Total energy use	Export diversification is helpful for the reduction of total energy consumption.
Fang et al. (2021)	OECD	1971-2014	Economic complexity	Total energy use	Economic complexity helps the reduction of total energy consumption.
Can et al. (2021)	10 newly industrialized		Economic complexity	Total energy use	Economic complexity increases energy use

	countries				
Can et al. (2022a)	Developed and developing countries	1971-2014	Economic complexity	Total energy use	Economic complexity increases energy use in developing nations and lessens it in developed nations group.
Magazzino et al. (2022)	APEC member countries	1995-2018	Export product diversification	Total energy use	Export diversification is helpful for the reduction of total energy use
Olasehinde-Williams et al. (2022)	30 nations located in Global North	1980-2014	Export product diversification	Total energy use	Export diversification is helpful for the reduction of total energy use.
Fatima et al. (2022)	6 GCC countries	1990-2019	Export product diversification	Renewable energy use	Export diversification is helpful for the reduction of renewable energy use.
Can and Ahmed (2022)	14 member nations to EU.	1990-2017	Economic complexity	Renewable energy and non-renewable energy use	Economic complexity boosts renewable energy consumption and lessens non-renewable energy use.
Dingru et al. (2023)	Sub-Sahara African States	1990-2015	Trade Openness	Renewable energy use	Trade increases renewable energy use

Table 2: Descriptive Statistics

Variable	Mean	Standard Deviation	Coefficient of Variation	Skewness	Kurtosis
LENPC	3.6339	0.1739	0.0301	0.3765	-1.0338
LGDPPC	4.5232	0.1159	0.0134	-0.4179	-0.7626
LURB	1.8808	0.0300	0.0009	-0.0278	0.6492
ECI	1.6479	0.4944	0.2438	-0.5115	-0.0448
CON	1.6537	0.3274	0.1069	0.3861	-0.9124
OPEN	43.9907	17.1541	293.4394	0.2300	-0.3313

Table 3: Testing the cross-section dependency of the variables and models

CD-test for Developing Countries								
Variable	CDLM1-test	p-value	CDLM2-test	p-value	CDLM3-test	p-value	LMadj-test	p-value
					Level			
LENPC	258.514	0.000***	36.649	0.000***	15.458	0.000***	123.087	0.000***
LGDPPC	322.245	0.000***	46.483	0.000***	17.451	0.000***	150.599	0.000***
LURB	167.493	0.000***	22.604	0.000***	9.183	0.000***	102.529	0.000***
ECI	215.059	0.000***	29.944	0.000***	10.482	0.000***	143.679	0.000***
CON	88.752	0.000***	10.454	0.000***	8.093	0.000***	150.599	0.000***
OPEN	398.161	0.000***	58.197	0.000***	19.286	0.000***	141.828	0.000***
Model 1:	15.889	0.000***						
Model 2:	4.686	0.000**						

		*
Model 3:	7.855	0.000***

*Notes: ** and *** imply the rejection of the null hypothesis at the 5% and 1% significance levels, respectively; CDLM1 test is based on Breusch-Pagan (1980), CDLM2, CDLM3 test is based on Pesaran (2004) and LMadj test is based on Pesaran et al. (2008).*

Table 4: Testing the order of integration of the variables

Carrioni et al. (2005) Pankpss test for Countries						
Variable	Level					
	Test Stat.	P-value.	Bootstrap C. Value	Test Stat.	P-value.	Bootstrap C. Value
LENPC	6.220	0.000	5.380	3.84***	0.000	5.535
LGDPPC	6.056	0.000	4.974	3.352***	0.000	10.443
LURB	7.716	0.000	6.237	1.949***	0.026	4.716
ECI	36.19	0.000	16.89	0.456***	0.324	3.735
CON	17.26	0.000	12.11	-1.354***	0.912	4.639
OPEN	5.790	0.000	5.036	-0.865***	0.806	4.000

*Notes: ** and *** imply accepting the null hypothesis at the 5% and 1% significance levels, respectively; This test is based on Carrioni et al. (2005). Critical values are for 5.000 samples with bootstrap. The model allowing the structural breaks in constant has been chosen as a test model. The critical bootstrap values are used because of the cross-sectional dependency.*

Table 5: Break Dates in Series

	LENPC			**LGDPPC**			**LURB**			**ECI**			**CON**			**OPEN**		
	Break Dates			**Break Dates**			**Break Dates**			**Break Dates**			**Break Dates**			**Break Dates**		
Canada	1976	1993	2008	1978	1996	2004	1991	1998	2007	1984	1994	2010	1977	1988	2009	1977	1993	2006
Germany	1976	1991	2008	1977	1989	2005	1992	1999	2006	1976	1984	2006	1985	1997	2009	1979	1998	2005
France	1977	1988	2010	1976	1987	1998	1976	1994	2005	1995	2005	2012	1987	1997	2009	1976	1996	2010
Italy	1986	1994	2011	1977	1986	1995	1976	2001	2010	1995	2002	2012	1985	1998	2009	1976	1994	2005
Japan	1987	1994	2011	1978	1987	2002	1976	2001	2008	1983	1990	2006	1976	1984	2008	1985	2003	2012
U.K	1979	1986	2008	1977	1986	1998	1976	2002	2009	1997	2004	2011	1979	1998	2009	1976	1985	2005
USA	1980	1987	2008	1977	1986	1998	1990	1997	2006	1991	2005	2012	1983	1996	2009	1976	1993	2005

Table 6: Testing the order of integration of the variables

	CIPS test for Countries				
Variable	Level	First Difference	Critical Value		
			1%	5%	10%
LENPC	-2.17	-5.24***	-2.57	-2.33	-2.21
LGDPPC	-1.89	-3.87***	-2.57	-2.33	-2.21
LURB	-1.72	-2.78***	-2.57	-2.33	-2.21
ECI	-1.99	-4.64***	-2.57	-2.33	-2.21
CON	-2.06	-4.26***	-2.57	-2.33	-2.21
OPEN	-2.31*	-4.67***	-2.57	-2.33	-2.21

*Notes: ** and *** imply the rejection of the null hypothesis at the 5% and 1% significance levels, respectively; CIPS test is based on Pesaran (2007).*

Table 7: Westerlund-Edgerton (2008) One break-panel cointegration test

	Model 1:		Model 2:		Model 3:	
Variable	Test-stat	p-value	Test-stat	p-value	Test-stat	p-value
$Z_{\tau}(N)$ stat.	-1.665	0.047**	-3.305	0.000***	-2.544	0.005***
$Z_{\varphi}(N)$ stat.	-7.121	0.000***	-6.642	0.000***	-5.692	0.000***

***Notes**: ***, ** & * indicate significance levels at the 1%, 5% and 10%, respectively. The cointegration test is based on Westerlund and Edgerton (2008).*

Table 8: Number and dates of structural breaks G7 countries in the panel in the cointegration equation

	Model 1	**Model 2**	**Model 3**
Canada	1980	1980	1980
Germany	1984	1984	1984
France	1990	1990	1990
Italy	1994	1994	1994
Japan	1974	1974	1974
U.K	2010	2010	2010
USA	1980	1980	1980

Table 9: Durbin-H panel cointegration test

	Model 1:		Model 2:		Model 3:	
Variable	Test-stat	p-value	Test-stat	p-value	Test-stat	p-value
Durbin-H Group stat	1.304	0.096*	1.632	0.051*	6.143	0.000***
Durbin-H Panel stat	3.057	0.001***	3.999	0.000***	9.701	0.000***

***Notes**: ***, ** & * indicate significance levels at 1%, 5% and 10%, respectively. H_0: No Cointegration Cointegration test is based on Westerlund (2008).*

Table 10: Long-run panel cointegration coefficients (AMG)

Model 1 : LENPC=F(LGDPPC, LURB, ECI)
Model 2 : LENPC=F(LGDPPC, LURB, CON)
Model 3 : LENPC=F(LGDPPC, LURB, OPEN)

	Model 1	Model 2	Model 3
Variable	coefficient	coefficient	coefficient
LGDPPC	0.3896**	0.3280**	0.4730***
	[2.08]	[1.88]	[2.89]

LURB	-0.0142**	-0.0222**	-0.0206***
	[-1.90]	[-2.32]	[-2.39]
ECI	-0.1002**	-	-
	[-1.64]	-	-
CON	-	-0.1862***	-
	-	[-2.38]	-
OPEN	-	-	0.1006***
	-	-	[2.57]
DUMMY	0.0075**	-0.0068	0.0037
	[1.70]	[-1.27]	[0.90]
CONSTANT	0.5102	0.5723	0.6388
	[0.60]	[0.64]	[0.63]

***Notes**: ***, ** & * indicate significance levels at 1%, 5% and 10%, respectively. [.]t-stat. While calculating the t statistic, Newey-West heteroscedasticity standard error was used. The Augmented Mean Group (AMG) method of Eberhardt ve Bond (2009) has estimated panel cointegration coefficients, considering the cross-sectional dependency.*

Table 11: Long-run panel cointegration coefficients (FMOLS)

Model 1 : LENPC=F(LGDPPC, LURB, ECI)
Model 2 : LENPC=F(LGDPPC, LURB, CON)
Model 3 : LENPC=F(LGDPPC, LURB, OPEN)

Variable	coefficient	t-stat	coefficient	t-stat	coefficient	t-stat
LGDPPC	0.8167	24.35***	0.8324	24.88***	0.8711	24.37***
LURB	-0.9729	-57.45***	-1.0629	-64.02***	-1.3048	-77.83***
ECI	-0.0524	-1.40*				
CON			-0.0986	-2.58***		
OPEN					0.1011	2.66***
DUMMY	0.0997	2.54***	0.0809	2.13**	0.0754	1.97**

Notes: ***, ** & * indicate significance levels at 1%, 5% and 10%, respectively. Panel cointegration coefficients have been estimated by FMOLS.

FIGURES

Figure 1: Scale, Composition and Technical effect of International Trade

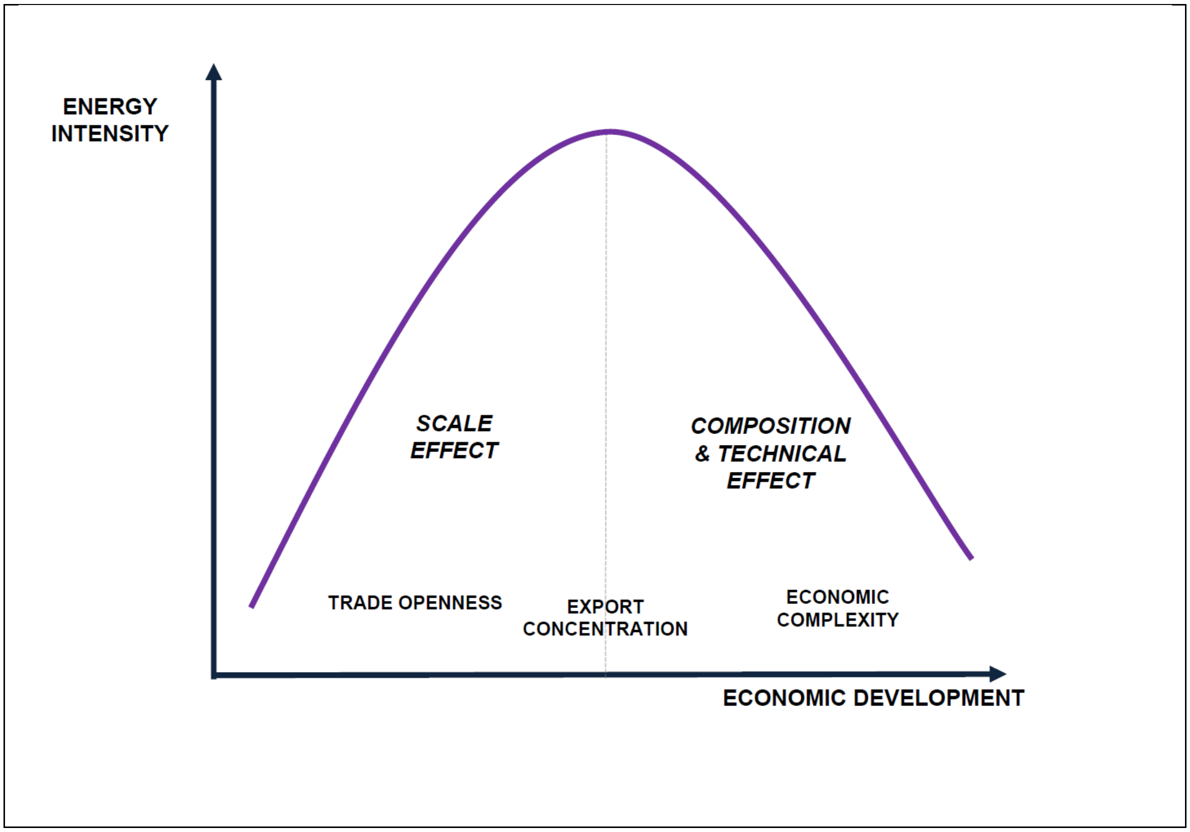
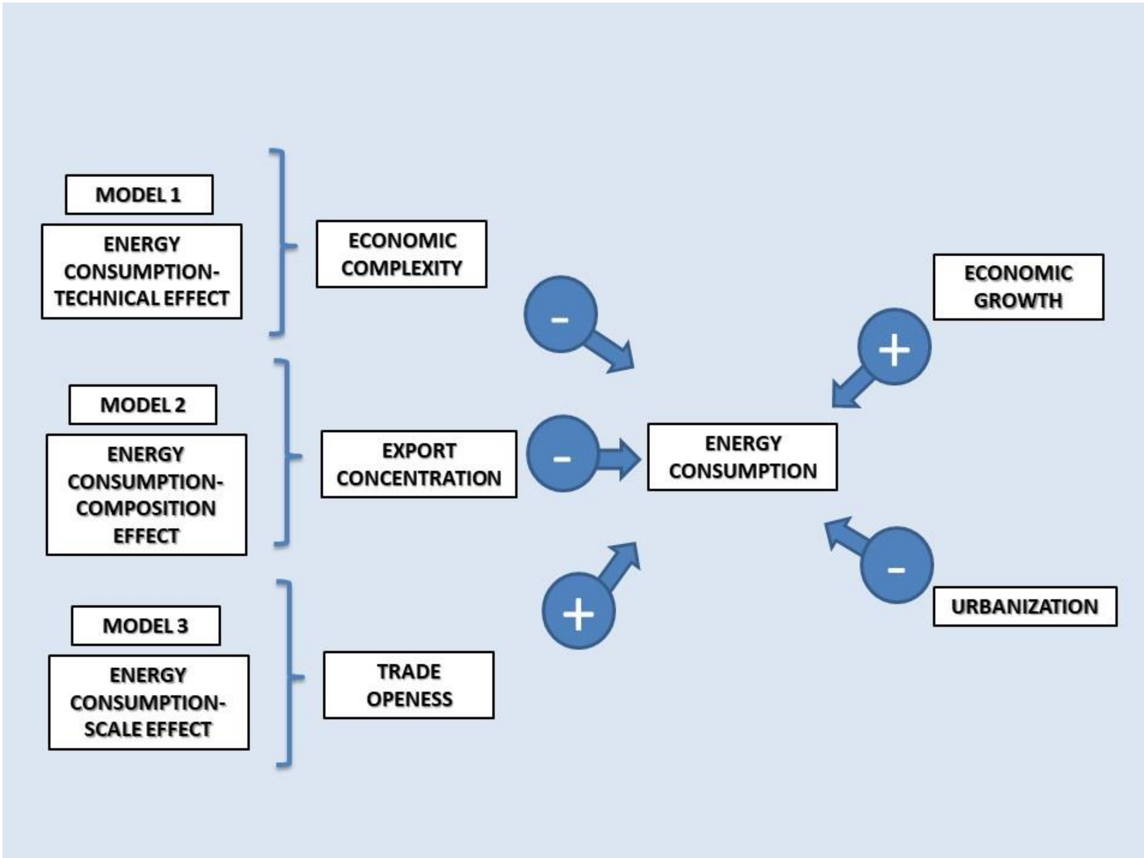


Figure 2: Graphical abstract


MODEL 1
ENERGY CONSUMPTION-TECHNICAL EFFECT
ECONOMIC COMPLEXITY
MODEL 2
ENERGY CONSUMPTION-COMPOSITION EFFECT
EXPORT CONCENTRATION
MODEL 3
ENERGY CONSUMPTION-SCALE EFFECT
TRADE OPENESS
ENERGY CONSUMPTION
ECONOMIC GROWTH
URBANIZATION