Fiscaoeconomia
E-ISSN: 2564-7504
2023, Volume 7, Issue 3, 2219-2249
https://dergipark.org.tr/tr/pub/fsecon

Submitted/Geliş: 11.07.2023
Accepted/Kabul: 09.08.2023
Doi: 10.25295/fsecon.1325461

Research Article/Araştırma Makalesi

Intersectoral Production-Energy Consumption Linkages and Roles of Multifactor Productivity and Energy Inflation in Developed Countries

Gelişmiş Ülkelerde Sektörlerarası Üretim-Enerji Tüketimi Bağlantıları ve Toplam Faktör Verimliliği ile Enerji Enflasyonunun Rolü

Özge DEMİRAL[1], Mehmet DEMİRAL[2], Emine Dilara AKTEKİN-GÖK[3], Çağatay TUNÇSİPER[4]

Abstract

The vast literature on the relationship between production activities and energy consumption in high-income countries mostly ignores intersectoral energy linkages. Therefore, this study investigates the cross impacts of per capita production in agriculture, industry, and services sectors on per capita energy consumption in these sectors, as well as the transport sector, using a panel dataset covering 19 developed countries' 1990-2019 period. By also controlling the changes in multifactor productivity, energy prices, and population indicators, the study applies the CS-ARDL (cross-sectionally augmented autoregressive distributed lag) estimation procedure. The short-run and long-run estimations agreeably reveal the following key findings. Agricultural energy consumption is affected by neither its own production nor that of other sectors. Industrial energy consumption is positively associated with its own production but negatively associated with service production. Service energy consumption is increased by growing industrial production. Transport energy consumption is positively associated with agricultural and service production. Multifactor productivity change, which refers to technological progress, is positively associated with energy consumption in all sectors. Higher energy inflation decreases transport energy consumption but increases energy consumption in the industrial and services sectors. The study further discusses why and how developed countries should adjust overall energy efficiency targets to intersectoral energy linkages.

Jel Codes: *C33, O13, O14, Q41*
Keywords: *Sectoral Energy Consumption, Sectoral Production, Intersectoral Energy Linkages, Multifactor Productivity, Energy Inflation, CS-ARDL*

[1] Assoc. Prof., Niğde Ömer Halisdemir University, Department of International Trade and Logistics, odemiral@ohu.edu.tr, ORCID: 0000-0003-0165-2206
[2] Prof., Niğde Ömer Halisdemir University, Department of Economics, mdemiral@ohu.edu.tr,
ORCID: 0000-0002-8836-5682
[3] Niğde Ömer Halisdemir University, Department of Economics, dilaraktekin51@gmail.com,
ORCID: 0000-0002-4112-2456
[4] Ph.D., cagataytuncsiper@gmail.com, ORCID: 0000-0002-0445-3686

Citation/Atıf: Demiral, Ö., Demiral, M., Aktekin-Gök, E. D. & Tunçsiper, Ç. (2023). Intersectoral Production-Energy Consumption Linkages and Roles of Multifactor Productivity and Energy Inflation in Developed Countries. *Fiscaoeconomia, 7*(3), 2219-2249. Doi: 10.25295/fsecon.1325461

Demiral, Ö., Demiral, M., Aktekin-Gök, E. D. & Tunçsiper, Ç. (2023). Intersectoral Production-Energy Consumption Linkages and Roles of Multifactor Productivity and Energy Inflation in Developed Countries. *Fiscaoeconomia, 7*(3), 2219-2249. Doi: 10.25295/fsecon.1325461

Öz

Yüksek gelirli ülkelerde üretim faaliyetleri ve enerji tüketimi ilişkisi üzerine gelişen geniş literatür, sektörlerarası enerji bağlantılarını çoğunlukla dikkate almamaktadır. Bu çalışma ise, 19 gelişmiş ülkenin 1990-2019 dönemini kapsayan panel veri setini kullanarak, tarım, sanayi ve hizmetler sektörlerinde kişi başına üretimin bu sektörlerde ve ayrıca taşıma sektöründe kişi başına enerji tüketimine olan çapraz etkilerini araştırmaktadır. Ayrıca toplam faktör verimliliği, enerji fiyatları ve nüfus göstergelerindeki değişimlerin de etkisini kontrol eden çalışma, CS-ARDL (yatay kesit genişletilmiş gecikmesi dağıtılmış otoregresif) tahmin prosedürünü uygulamaktadır. Kısa ve uzun dönem tahminler uyumlu bir biçimde şu temel bulguları ortaya koymaktadır. Tarımsal enerji tüketimi kendi üretiminden ve başka sektörlerdeki üretimden etkilenmemektedir. Sanayi enerji tüketimi kendi üretimi ile pozitif ilişkili iken hizmet üretimiyle negatif ilişkilidir. Hizmetler enerji tüketimi, büyüyen sanayi üretimiyle birlikte artmaktadır. Taşıma enerji tüketimi tarımsal ve hizmet üretimiyle pozitif ilişkilidir. Teknolojik gelişmeyi ifade eden toplam faktör verimliliği değişimi, tüm sektörlerdeki enerji tüketimiyle pozitif ilişkilidir. Yüksek enerji enflasyonu taşıma sektörü enerji tüketimini azaltırken sanayi ve hizmet sektörlerinde enerji tüketimini artırmaktadır. Çalışma, gelişmiş ülkelerin genel enerji etkinliği hedeflerini niçin ve nasıl sektörlerarası enerji bağlantılarına göre ayarlamak durumunda olduklarını tartışmaktadır.

Jel Kodları: *C33, O13, O14, Q41*
Anahtar Kelimeler: *Sektörel Enerji Tüketimi, Sektörel Üretim, Sektörlerarası Enerji Bağlantıları, Toplam Faktör Verimliliği, Enerji Enflasyonu, CS-ARDL*

1. Introduction

Energy is a strategic production factor for socioeconomic development in every country. At the global level, the total demand for energy has an upward trend (Bogmans et al., 2020; IEA, 2022; OECD, 2023). On the other hand, the increasing use of energy causes both economic and environmental side-effects associated with the energy trilemma, i.e., energy insecurity, environmental degradation, and energy unaffordability (Goh & Ang, 2020). From the economic perspective, since energy is scarce and expensive in many countries, increasing energy consumption can cause supply shortage and energy inflation, which are typically followed by overall inflation, unemployment, and output reduction unless a significant energy efficiency improvement is achieved. From the environmental perspective, it is well-evidenced that growing exploration, exploitation, and use of energy threaten the ecosystem through depleting energy resources and exacerbating atmospheric concentration of energy-related pollutants (Lorente & Álvarez-Herranz, 2016; Shahbaz & Sinha, 2019; Chang et al., 2022; Li, 2022) unless a significant renewable energy transition is achieved. Countries can solve the energy trilemma by increasing energy diversification and/or decreasing the overall energy intensity, in both of which, the developed countries, on average, have witnessed a relative improvement during the past several decades (Patt et al., 2019; Liddle & Sadorsky, 2021; Komarova et al., 2022; OECD, 2023). The environmental quality contribution of the renewable energy transition is clear but cutting the persistent fossil energy use and investments in renewable energy production are still difficult and expensive (Patt et al., 2019). Therefore, reducing energy consumption through energy efficiency and energy productivity is a certain enabler of solving the energy trilemma and optimal integration of economic preferences and environmental concerns. On environmental grounds, many national economies notably developed countries consider improvements in energy efficiency as a priority in all decarbonization strategies and combine their low-carbon targets with energy efficiency solutions. Albeit large cross-country variations and untapped potentials, the energy efficiency is higher in developed countries compared to that of developing countries, in most of which lower energy consumption is increasing. The ambitious energy efficiency targets and promising green growth improvement in some developed countries have put hope for the future of energy sustainability in other countries. However, energy efficiency improvement is not easy as it is a complex and multidisciplinary concept with a wide spectrum of applications (Sueyoshi et al., 2017; McAndrew et al., 2021).

Despite its underlying socioeconomic origins, the social sciences literature on energy efficiency remains relatively underrepresented (Dunlop, 2019), which limits the formulation and efficacy of inclusive policies to enhance energy efficiency. For practitioners, the identification of the socioeconomic factors affecting the energy consumption structures of societies has important implications at all levels of individuals and households (Kim, 2020; Perret et al., 2022; Sharma, 2022), firms (Cagno et al., 2017; Brinkerink et al., 2019), sectors (Wachsmuth & Duscha, 2019; Ferreira et al., 2022), countries (Metcalf, 2008; Bergquist & Söderholm, 2016), and the world distinguished between different country groups (Sineviciene et al., 2017; Eder & Provornaya, 2018; Canh et al., 2021; Demiral & Demiral, 2023) from both the consumption and production perspectives. Nonetheless, the available evidence is widely restricted to the EKC (Environmental Kuznets Curve) literature based on the STIRPAT (STochastic Impacts by Regression on Population, Affluence, and Technology) approach mostly at the macro level. For the affluence (income) factor, the EKC refers to a bell-shaped pattern with a threshold that environmental degradation first ascends and then descends as per capita income continues to grow. The EKC-dominant literature has developed on both the pollution-income (Lorente & Álvarez-Herranz, 2016; Shahbaz & Sinha, 2019) and energy-production (energy Kuznets curve) nexuses (Bogmans at al., 2020; Mahmood et al., 2021), albeit the prevalence of the former. In the first stream at the sectoral level, studies are increasingly examining the environmental pollution impacts of production for different sectors (Chang et al., 2022; Htike et al., 2022) with a specific interest in agriculture (Gokmenoglu & Taspinar, 2018; Balogh, 2022), industry (Aden, 2018; Chikezie Ekwueme et al., 2022), service (Rosenblum et al., 2000; Demiral & Akça, 2022), and transport (Pablo-Romero et al., 2017; Gota et al., 2019). In most of the previous research, energy (non-renewable and renewable forms) is widely taken as a control variable and found an important determinant of environmental pollution indicators (Ahmad et al., 2022; Nassani et al., 2017; Chikezie Ekwueme et al., 2022; Htike et al., 2022).

Studies examine the relationship between energy and production, again mostly at the macro level building on the decoupling theory, which looks at the strength and direction of the relationship between economic growth and energy consumption (Payne, 2010; Omri, 2014; Wu et al., 2018; Shahbaz et al., 2019; Demiral & Demiral, 2023; Singh & Vashishtha, 2022; Zeng et al., 2022). Yet, the available evidence lacks consensus with varying coupling, decoupling, and neutrality associations. Notably, the decoupling performance of developed countries is superior to that of developing countries, some of which have even a coupling trend. The decline of industry in favor of the service sector may explain some of the decline in overall energy intensity in advanced economies. However, the impacts of the increasing deindustrialization and tertiarization processes on energy consumption in other sectors are scarce in the literature. Although it is recently argued that the aggregated measures of energy consumption and domestic production may mask sectoral heterogeneities (Karakaya et al., 2020), limited research has considered the energy-production association at the sectoral level (Bowden & Payne, 2010; Mendiluce et al., 2010; Deichmann et al., 2019; Flores-Chamba et al., 2019). More importantly, to our best knowledge, no study has been concerned with the cross-sectoral impacts, i.e., the effect of the production in one sector on the energy consumption in another sector. This research gap becomes more significant given the fact that no industry is independent of others. Indeed, sectors are closely interconnected, such that one sector's production uses inputs from other sectors and provides inputs for other sectors' production. Sectoral studies that investigate the direct nexus within a sector cannot fill this gap as they do not capture the recently pointed intersectoral indirect energy use and rebound effects (Moreau & Vuille, 2018; Vélez-Henao et al., 2019; Freire-González, 2020; Amjadi et al., 2022). Furthermore, the overall energy saving efforts need to know the intersectoral energy linkages for a better assessment of the potential overall decarbonization contribution of energy efficiency and renewable energy transition in all economic activities. In this context, it has practical importance to clarify the relationship between production and energy consumption at the sectoral level by also considering the intersectoral energy linkages for developed countries that have been experiencing dynamic structural shifts both within and between sectors.

Besides production activities, technological progress and energy cost may have decisive forces in energy consumption varying across sectors. For the technology factor, the existing research lacks consensus on how to represent technology. The existing studies mostly take one-data technology indicators, such as high-tech production, research-development activities, as well as technology patents and inventions (Habiba et al., 2022; Wang et al., 2022; Zeng et al., 2022). However, these indicators have limitations in reflecting the total factor productivity related to technological change. Again, it should not be ignored that high energy prices are causing a large transfer of wealth from consumer to producer countries together with structural shifts between low- and high-energy-intensive economic activities within countries (IEA, 2022).

Many developed countries have recorded significant achievement in decoupling economic growth from energy consumption after the global energy shocks (Blanchard & Riggi, 2013; Bergquist & Söderholm, 2016; Wu et al., 2018; Zeng et al., 2022). Thus, decision-makers in developed countries always need new evidence on the energy intensity consequences of energy prices, as the sectoral energy use impacts of varying energy costs provide a practical policy instrument. Notably, the messages that the short-run and long-run common experiences of high-income countries provide have not been highlighted sufficiently, which would shed light on the developing regions' energy efficiency trajectories.

In response to these needs, this study examines the cross impacts of production in agriculture, industry, and services on the energy consumption in these sectors, as well as transport activities, in the case of high-income countries over the 1990-2019 period. The study also controls for the changes in MFP (multifactor productivity), energy inflation, and population indicators. The study uses advanced techniques to estimate the short-run and the long-run associations that are robust to recently argued issues in panel data analysis. The study is structured as follows. The next section outlines the research gap and study motivation in light of the reviewed literature. Then, the 'model and data' section describes the modeled variables and measurements of indicators. After the applied methods are explained in the 'methodology' section, the empirical results are given and reasoned in the 'results and discussions' section. The study draws some implications in the last section.

2. Literature and Research Gap

The STIRPAT approach (Dietz & Rosa, 1994; 1997) is widely adopted in the energy and environmental literature to explore the anthropogenic driving forces of environmental degradation (Wang et al., 2022; Habiba et al., 2022). In the energy use interpretation of the STIRPAT modeling, the production of goods and services (affluence), is the key driver of energy consumption (Vélez-Henao et al., 2019; Canh et al., 2021). Accordingly, studies are increasingly examining the energy impacts of production and showing that production in many countries is still strongly reliant on energy use, albeit temporal, country, sectoral, and regional heterogeneities (Csereklyei et al., 2016; Shahbaz et al., 2019; Dokas et al., 2022). For the sectoral heterogeneity, the research interest in the production-energy nexus at the sectoral level is slight but increasing (Mendiluce et al., 2010; Voigt et al., 2014; Deichmann et al., 2019; Chang et al., 2022). Commonly, it is more practical conceptually and more convenient statistically to divide all economic activities into agriculture, industry, and service sectors together with transport activities.

Agricultural energy consumption is mostly related to machinery, powering, and heating in farming, ranching, hunting, and forestry activities. The shares of agriculture in GDP (gross domestic product) and total energy consumption are low in developed countries. For example, the 1990-2019 average of the OECD (Organisation for Economic Co-operation and Development) countries is around 2% in both indicators (OECD, 2023). Agricultural energy intensity has been relatively underrepresented in both political and academic arenas as practitioners usually focus on increasing agricultural production for meeting the basic needs of societies, rather than improving energy efficiency. Policymakers give priority to protecting agricultural production from such environmentally harmful impacts as soil pollution, drought, excessive land use, deforestation, deteriorating biodiversity, etc., which are usually stemmed from non-agricultural activities. The data reflects that there was a coronavirus pandemic-related decline in total energy consumption in 2020 for many developed countries but the energy consumption in agriculture did not change considerably (OECD, 2023). Yet, the agriculture sector has some untapped energy efficiency potentials which may be realized by technical progress and energy-efficient machinery; improvement of productive chemicals, plants and livestock, and irrigation systems; better planning customized by water, weather, soil, and temperature conditions; and moving away from energy-intensive agricultural activities (Metcalf, 2008). Local food-saving systems are also an indirect contributor (Schneider & Smith, 2009). The success of these strategies, however, may be restricted by urbanization and population growth, as well as economic growth as evidenced by Liu et al. (2021).

Industrial activities, especially manufacturing, are responsible for a significant share of global energy demand and emission pollution (Cagno et al., 2017; Renna & Materi, 2021). The industry has a large GDP share in many countries, whereas developed countries are experiencing a common downward trend over the past several decades (e.g., the OECD average was 29% in 1990 but fell to about 24% in 2019). This is also true for industrial energy consumption share in total energy consumption (e.g., the OECD average was 27% in 1990 but declined to around 21% in 2019) (OECD, 2023). The industrial energy intensity may be reduced by changing the industry mix as shown by Voigt et al. (2014). Consistently, a lower but technology-intensive proportion of industrial value-added is found a driver of energy decoupling in developed countries (Wu et al., 2018). Yet, some part of the energy intensity reduction witnessed especially in developed countries is attributed to the declining manufacturing in favor of services (Sineviciene et al., 2017; Bogmans et al., 2020), although this link is not stable and mostly depends on the technology level as shown by Zeng (2022).

From the tertiarization perspective, the service sectors are widely considered with larger energy-saving potentials. These potentials pertain to teleworking, alternative energy-efficient services, education/training in the consumption and production of energy-efficient technologies, relatively faster technological spillovers, and substituting teleconferencing services for business travel, etc. (Rosenblum et al., 2000). On the other hand, increasing digital content, electronic commercial services, and internet traffic are also scaling up the service sector's energy use. The service sector's energy consumption share in total energy consumption is relatively low (e.g., the OECD average is around 12% over the 1990-2019 period) compared to its high GDP share (e.g., the OECD average is 72% over the 1990-2019 period) in many developed countries (OECD, 2023). In line, Atalla & Bean (2017) and Wu et al. (2018) verified that economic shifts from industry to service sectors upgraded overall energy efficiency and the growth of industrial production tended to hinder further energy efficiency for different country groups. Again, from the environmental pollution perspective, Demiral & Akça (2022) showed that deindustrialization improved decarbonization in the case of the EU (European Union) countries.

The transport sector is the key facilitator of logistics and contributes to all economic activities. Despite its huge energy-saving potential through energy-efficient green transportation, the transport sector is persistently among the top energy-intensive (and pollutive) industries in developed countries. The 1990-2019 average of the transport sector's share in total energy consumption is about 33%, which increased from 30% in 1990 to 34% in 2019 in OECD countries (OECD, 2023). Transport energy consumption is altered by many socioeconomic factors and affects overall energy use indicators in countries. From the developed countries' perspective, for example, Pablo-Romero et al. (2017) showed that rises in per capita production increased energy use for transport in the case of the 27 EU countries covering the 1995-2009 period. In the context of developing countries, Rehermann and Pablo-Romero (2018) analyzed panel data of 22 Latin American and Caribbean countries over the period 1990-2014 and showed that total GDP had a significant but nonlinear effect on transport energy consumption with different GDP thresholds. Demiral & Demiral (2023) confirmed that transport capacity was positively associated with energy intensity in the world sample (125 countries) and for the low-income and middle-income subsamples during 2000-2018.

The energy-STIRPAT model builds on an absolute energy-intensifying impact of population growth as extra individuals consume more energy. However, the energy impact of population indicators is not that certain (Sheng et al., 2017), as it changes for per capita income. When per capita income increases, if the other factors remain constant and energy-efficient infrastructure is not improved, the energy impacts of population become more significant as the depletion of energy resources increases. This premised impact is confirmed by the earlier research for both developing and developed countries (Atalla & Bean, 2017; Rehermann & Pablo-Romero, 2018; Liddle & Sadorsky, 2021; Komarova et al., 2022).

The last variable in the energy-STIRPAT model is technology. Technological progress incorporates not only the advancement in production techniques, but also social organization, institutions, culture, and all other factors that affect human impact on energy use other than population and affluence (Dietz & Rosa, 1994; 1997). The technology has channels through which it alters energy consumption. The production, use, and disposal of technology directly consume energy and the facilitation of technology development and maintenance of technological utilities require energy-intensive large infrastructures. However, the technology adoption of economic agents directly may save time and energy and promotes the transition toward a service economy. The technological advancement also decreases energy consumption by replacing energy-inefficient production technologies and energy-intensive obsolete information and commutation systems. The net effects of the technology depend on the relative importance of its adverse impacts (Voigt et al., 2014; Demiral & Demiral, 2023). From a broader perspective, as the key element of economic efficiency and sustainable development, MFP is a representative of technological progress (Hasanov & Mikayilov, 2021). MFP growth, by definition, may save the amount of the production factors including energy resources that are used to produce goods and services. Despite this, only a few studies considered its causal and associative effects on energy use. Tzeremes (2020) found one-way causalities running from MFP to energy consumption for some developed countries over the 1971-2017 period. Hasanov & Mikayilov (2021) showed that MFP was negatively associated with the consumption of (electricity) energy for the 1990-2019 period of a large panel of income-heterogenous countries.

Energy prices are important but not modeled in the STIRPAT approach. Notably, large increases in global energy prices in the 1970s caused huge output loss and inflation, especially in developed countries that were using imported oil inputs intensively in their production. These energy shocks forced and/or motivated developed countries, especially resource-poor economies, to improve energy efficiency such that later larger increases in global oil prices have been followed by much milder effects on output and inflation (Blanchard & Riggi, 2013; Bergquist & Söderholm, 2016). While rising energy prices increase the energy cost, on the one hand, it also makes the other production factors relatively cheaper, on the other hand, when these non-energy factors' prices do not change. However, the substitution of other factors for energy is limited and as the key component of the overall inflation, energy inflation is mostly accompanied by inflation in non-energy sectors, as well, which limits the economywide energy efficiency improvement. Despite its well-documented theoretical ground, not much research has been concerned with the energy prices' impacts on energy consumption. Metcalf (2008) and Shahbaz et al. (2019) showed that rising energy costs and oil prices played an important role in lessening energy intensity and energy demand in the United States. Flores-Chamba et al. (2019) showed a negative effect of oil prices on per capita energy consumption in the case of European countries during 2000-2016. Hasanov & Mikayilov (2021) consistently showed that electricity prices were negatively associated with electricity consumption in the case of the income-heterogenous panel of 49 countries. Tajudeen (2021) found some evidence showing that increasing energy prices were driving energy efficiency improvement for 32 OECD countries. Liu (2022) also showed that energy inflation increased (decreased) overall energy efficiency (energy intensity) in the case of the G7 (Group of Seven) economies.

After an extensive review of the energy literature outlined above, we have identified mainly four shortcomings of the existing empirical research, to which our study will contribute as follows: Firstly, the available evidence on the production-energy consumption at the sectoral level is scant and no panel study has been conducted from the intersectoral perspective within a unified regression framework for developed countries. Our study addresses this constraint by investigating the separate and cross impacts of production in agriculture, industry, and services sectors on energy consumption in these sectors, as well as transport, for 19 high-income countries. Secondly, although many studies have examined the technological progress-energy use nexus, the role of the MFP concept is overlooked. Moreover, the sectoral energy consumption effects of energy costs in developed countries have been underexamined. Therefore, our study also considers the impacts of the changes in MFP, energy prices, and population. Thirdly, policymakers and scholars always need robust evidence for both the short-run and the long-run while combining economic growth and energy policies optimally. Therefore, we estimate the short-run and the long-run associations considering the recently arisen methodological concerns. Finally, the ever-growing STIRPAT literature is weak on the energy side and at the sectoral level. Again, the prevailing use of quadratic form in the EKC literature is increasingly criticized because of the multicollinearity problem. Thus, we provide some energy-EKC evidence at both sectoral and intersectoral levels by comparing the short-run and long-run associations based on the extended energy-STIRPAT model.

3. Model and Data

This study argues that energy consumption in a sector is affected by other sectors' production. We test this premise using a 30-year (1990-2019) panel dataset of 19 high-income developed countries selected based on the data availability. These countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, South Korea, Netherlands, New Zealand, Portugal, Spain, Sweden, the United Kingdom (UK), and the United States (US). The baseline model builds on the application of the energy-STIRPAT approach customized to the sectoral level and extended with energy inflation. Consequently, we have four models shown in equation (1), where, *i* and *t* respectively denote the sampled individual countries (N=19) and years (T=30), while α_0 and *e* are the regression constant and the stochastic error term, respectively. The α_k parameters (k=1–6) are partial slope coefficients to be estimated.

$$\begin{pmatrix} AGREC_{it} \\ INDEC_{it} \\ SEREC_{it} \\ TREC_{it} \end{pmatrix} = \alpha_0 + \alpha_1 AGRP_{it} + \alpha_2 INDP_{it} + \alpha_3 SERP + \alpha_4 MFP_{it} + \alpha_5 ENCPI_{it} + \alpha_6 POP_{it} + e_{it} \quad (1)$$

The dependent variables are per capita energy consumption in agricultural (*AGREC*), industrial (*INDEC*), service (*SEREC*), and transport (*TREC*) sectors. The independent variables are per capita production in agricultural (*AGRP*), industrial (*INDP*), and service (*SERP*) sectors, and changes in multifactor productivity (*MFP*), energy prices (*ENINF*), and population (*POP*). Table 1 describes the indicators, measures, and data sources of these variables.

Like Deichmann et al. (2019), sectoral production is measured based on value-added creation to hinder the multiple-counting problem. The primary energy measure is more pertinent than the final energy measure as it better captures energy efficiency gains along the intersectoral energy supply chains with upstream characters (Bogmans et al., 2020). Sectoral clustering is based on the fourth revision of the ISIC (International Standard Industrial Classification).

Agricultural energy consumption includes energy consumed by users in agriculture, hunting, and forestry. Industrial energy consumption includes the energy used in the production of iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, transport equipment and machinery, mine and quarry, food and tobacco, paper, pulp and print, wood products, construction, textile, leather, and other manufactures. Energy consumption in services includes energy consumed by both commercial and public services, while transport energy consumption covers the energy used by all transport activities (OECD, 2017; 2023).

Table 1: Variables

Dependent Variables	**Symbols**	**Measure**	**Sources**
Total primary energy consumption in agriculture.	*AGREC*	Per capita tons of oil equivalent	Authors' calculations based on the 'environment' database of OECD (2023)
Total primary energy consumption in industry.	*INDEC*		
Total primary energy consumption in services.	*SEREC*		
Total primary energy consumption in transport.	*TREC*		
Independent variables			
Domestic production in agriculture.	*AGRP*	Per capita thousand US dollars at constant (2015) prices	Authors' calculations based on the 'output and income' database of UNCTAD (2023)
Domestic production in industry.	*INDP*		
Domestic production in services.	*SERP*		
Control Variables			
Annual change in multifactor (capital and labor) productivity.	*MFP*	%	'Productivity' database of OECD (2023)
Annual change (energy inflation) in energy consumer price index (energy-CPI).	*ENINF*		'Prices and purchasing power parities' database of OECD (2023)
Annual change in total population.	*POP*		'Demography and population' database of OECD (2023)

At the macro-level, energy intensity with the inverse meaning of energy efficiency and energy productivity is measured traditionally by the ratio of total primary energy use to either GDP or population. When the ratios increase, it indicates the exacerbated energy intensity (Karakaya et al. 2020; Demiral & Demiral, 2023; Ahmad et al., 2022). While the OECD (2023) database proposes both measures, like Csereklyei et al. (2016), Flores-Chamba et al. (2019), Bogmans et al. (2020), and Dokas et al. (2022), we have measured sectoral production and energy consumption in per capita terms to prevent the biases caused by significant population variations across countries. Technically, the per capita measure of energy consumption was a necessity for statistical convenience as sectoral production is also measured in per capita terms. The alternative GDP share measure would cause strong multicollinearity between sectoral production regressors, especially among the industrial and service production, as increasing service share means decreasing industry share, or vice versa, in our sample. As population change may distort the per capita measures, we also include the population change in the models to refine the pure associations. Energy prices and MFP are also expressed in change terms with negative values for some years of several countries. Thus, we have not converted the variables into logarithms. Yet, the per capita energy consumption and sectoral production indicators are expressed in tons and thousand US dollars, respectively, to eliminate large numbers of non-logarithmic variables.

Differently, we have represented technological progress by MFP to reflect the overall productivity mechanism of technological progress. In a production function, value-added increase (economic growth) can be achieved by either increasing the amount or quality of the inputs or by improving MFP. As a synonym for total factor productivity, MFP reflects the overall efficiency with which labor and capital inputs are used together in the production process. Changes in MFP also cover the effects of changes in management practices, industrial organization, firm values, knowledge spillovers, economies of scale, competition, and other factors contributing to economic growth. Growth in MFP is simply measured as a residual, i.e., the fraction of GDP growth that cannot be explained by changes in labor and capital inputs. Therefore, if the amounts of labor and capital inputs are constant between two periods, any variation in output gives changes in MFP (OECD, 2023). In a Cobb-Douglas form, when using a set of inputs (*X*) including capital (*K*) and labor (*L*) to produce an amount of output (*Q*), the technical change (*A*) affects these production factors proportionately: *Q=A.f(X); X=K,L*. Differentiating this expression with respect to time (*t*) and using a logarithmic (*ln*) change rate, MFP change (the change rate of *A*) is computed as in equation (2) (OECD, 2021; OECD, 2023).

$$\ln\left(\frac{MFP_t}{MFP_{t-1}}\right)=\ln\left(\frac{Q_t}{Q_{t-1}}\right)-\ln\left(\frac{X_t}{X_{t-1}}\right) \qquad (2)$$

In equation (2), *Q* is output measured as GDP at constant market prices, while *X* denotes the change rates of total *K* and *L* inputs calculated as a cost-share-weighted average of the change rate in the inputs' amounts. These are then aggregated through chained calculations of costs and quantities. As formulated in equation (3), the MFP change consists of the changes in contributions of *K* and *L* inputs to GDP growth.

$$\ln\left(\frac{X_t}{X_{t-1}}\right)=\frac{1}{2}\left(K_t+K_{t-1}\right)\ln\left(\frac{K_t}{K_{t-1}}\right)+\frac{1}{2}\left(L_t+L_{t-1}\right)\ln\left(\frac{L_t}{L_{t-1}}\right) \qquad (3)$$

As the use of *K* and *L* also requires energy, the growth of MFP is expected to be related to energy use. However, as the growth of MFP may either increase energy productivity or come at a cost of increasing energy use or both for different sectors, the net energy use effects of MFP growth are not that clear inherently.

4. Methodology

The analysis starts with the computation of descriptive statistics and pairwise correlations of variables. Then, the CD (cross-sectional dependence) of variables is inspected. CD stems from the presence of unobserved common shocks that affect the levels of the modeled variables in the sampled countries. CD concern is highly likely in our case since the sampled countries are strongly interdependent due to the ever-increasing economic integration and global policies such as unified climate coalitions. Neglecting CD can give misleading test statistics. To hinder this, in the case of CD, the second-generation methods that consider CD should be applied. Therefore, the variables' series and models' residuals are controlled for CD. Regarding the model in equation (1), CD arises if e_{it} is correlated across countries. The efficacy of the available CD tests depends on the size and structure of the panel data. When the number of countries (N) is smaller than that of years (T), the traditional LM (Lagrange multiplier) test of Breusch & Pagan (1980) is efficient. The Breusch-Pagan LM statistic is given by equation (4), where r_{it} is the sample estimate of the pairwise correlation of the residuals, and u_{it} is the OLS (ordinary least squares) estimate of e_{it}.

$$LM_{B-P} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} r_{ij}^2 \; ; \quad r_{ij} = r_{ji} = \frac{\sum_{t=1}^{T} u_{it}u_{jt}}{\left(\sum_{t=1}^{T} u_{it}^2\right)^{1/2}\left(\sum_{t=1}^{T} u_{jt}^2\right)^{1/2}} \qquad (4)$$

We also apply the Pesaran (2015) weak CD test. This test points to the limiting behavior of the wideness (from 0 to 1) in the range of statistical significance (α) for CD inference and, thus, builds on the ranking of CD (Chudik et al., 2011; Ditzen, 2021): weak (α is 0), semi-weak (α ranges between 0 and 0.5), semi-strong (α ranges between 0.5 and 1), and strong (α is 1) CD. By arguing that in the case of large N panels (e.g., N>10), the null of weak CD is more appropriate than the null of no CD, Pesaran's (2015) approach tests the null hypothesis of the weak CD against the alternative of strong CD.

When CD is evidenced for variables, the second-generation panel unit root tests should be conducted as they take CD into account while examining stationarity. The CADF (cross-sectionally augmented Dickey-Fuller) test (Pesaran, 2007) is one of these tests. The CADF procedure handles CD by augmenting standard Dickey-Fuller regressions with country averages of the lagged levels and the first differences of countries consecutively. The CADF method tests the null hypothesis of unit root for individual countries. The CIPS (cross-sectional Im, Pesaran, and Shin) statistic is computed by taking a simple average of individual CADF statistics to test the null hypothesis suggesting the presence of homogeneous unit root (non-stationarity) in the whole panel. Equation (5) gives formulations of the CADF and CIPS tests.

$$CADF: \Delta y_{it} = \alpha_i + r_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{p} \beta_{ij} \Delta \bar{y}_{it-j} + \sum_{j=0}^{p} \Delta y_{it-j} + u_{it} \; ;$$

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \qquad (5)$$

In equation (5) *y* is the variables tested for stationarity, *Δ* is the difference operator, *ybar* denotes the cross-sectional mean, *p* indicates the lags, and *N* denotes the number of countries in the panel, while $CADF_i$ is the estimated t-statistic of individual cross-sections (i) from the CADF regression.

The stationary properties of the modeled variables are decisive in selecting estimation procedures. If all variables do not have a unit root at their level, they are stationary, i.e., I(0).

In this case, the traditional least squares estimation procedures are efficient. When all variables have a unit root at level but not in the first-difference, they are integrated of order one, i.e., I(1). In this case, long-run estimations of the cointegration equations, if exist, are favorable. However, when the variables are mixed of level stationary, I(0), and first-difference stationary, I(1), processes, the ARDL (autoregressive distributed lag) approach should be adopted. Again, the efficacy of the ARDL procedure depends on their consideration of heterogeneity in data, which results in the heterogenous slope coefficients. The *Δ* (delta) test of Pesaran & Yamagata (2008) proposes *Δtilde* and adjusted *Δtilde* statistics used to test the null hypothesis of slope homogeneity. As shown in equation (6), the *Δtilde* test considers the weighted difference between the country-specific and the pooled estimates (*ditilde*), while the adjusted *Δtilde* statistic adjusts the mean-variances (Bersvendsen & Ditzen, 2021).

$$\tilde{\Delta} = \frac{1}{\sqrt{N}}\left(\frac{\sum_{i=1}^{N}\tilde{d}_i - k_2}{\sqrt{2k_2}}\right); \tilde{\Delta}_{adj.} = \sqrt{N}\left(\frac{N^{-1}\sum_{i=1}^{N}\tilde{d}_i - k_2}{\sqrt{Var(\tilde{z}_i T_i)}}\right); Var(\tilde{z}_i T_i) = \frac{2k_2(T_i - k - 1)}{T_i - k_1 + 1} \tag{6}$$

To check the stability of models, we also control for multicollinearity problems. Multicollinearity occurs when independent variables are correlated considerably. Multicollinearity can be checked through the VIF (variance inflation factor) values. The VIF for an *X* independent variable is calculated as $VIF_X=1/(1–R^2_X)$, where R^2_X is obtained by regressing *X* on the remaining explanatory variables. The VIF value varies between 1 (no multicollinearity) to infinity (certain multicollinearity). The general rule-of-thumb claims that VIF values should not exceed 5 (Pablo-Romero, 2017; Gregorich, 2021).

The final step of the analysis is model estimations. Considering the confirmed heterogeneity, CD, and mixed order of integration features in data, we apply the CS-ARDL (cross-sectional ARDL) approach of Chudik et al. (2016). This method has advantages as it estimates both the long-run and short-run coefficients in unified modeling by also considering lagged dependent variables as weakly exogenous regressors under the error correction framework and by controlling for unobservable factors (Ditzen, 2021). Based on the CS-ARDL approach, the models for sectoral energy consumption (*SEC*) are given in a unified form by equation (7).

$$\begin{aligned}\Delta SEC_{it} &= \mu_i + \phi_i(SEC_{it-1} - \beta_i X_{it-1} - \varphi_{1i}\overline{SEC}_{t-1} - \varphi_{2i}\overline{X}_{t-1}) \\ &+ \sum_{j-1}^{p-1}\lambda_{ij}\Delta LSEC_{it-j} + \sum_{j-0}^{q-1}\psi_{ij}\Delta X_{it-j} + \eta_{1i}\Delta\overline{LSEC}_t + \eta_{2i}\Delta\overline{X}_t + e_{it}\end{aligned} \tag{7}$$

In equation (7), β_i indicates the coefficients of regressors, λ_{it} is the short-run coefficient of the dependent variables, ψ_{ij} shows the short-run coefficients of regressors, η_{1i} is the expected values of regressors, η_{2i} denotes the mean of regressors in the short run, and *L* is the lag operator, while e_{it} represents the estimation error. X_{it} is the vector of regressors including sectoral production (*AGRP*, *INDP*, and *SERP*), *MFP, ENINF*, and *POP*. The term $SECbar_{t-1}$ denotes the value of the *SEC* estimated for the long run and $Xbar_{t-1}$ denotes the expected values of all regressors for the long run. ΔSEC_{it-j} specifies the dependent variable and ΔX_{it-j} represents regressors in the short run. $\Delta SECbar_t$ denotes the expected value of the regressed variable and $\Delta Xbar_t$ consists of the expected values of regressors in the short run. In this approach, the number of lags for dependent variables (*p*) and independent variables (*q*) needs to be known. The suggested rule to determine the lags is $T^{1/3}$ (Ditzen, 2021), which results in 3 in our case. In the CS-ARDL method, coefficients can be directly estimated by applying the mean-group variance estimator when the mean-group estimator is used (Chudik et al., 2016). As it handles efficiently the endogeneity, CD, heterogeneous slope coefficients, non-stationarity, as well as unobserved components concerns, the CS-ARDL method is increasingly used in the relevant literature (Ahmad et al., 2022; Wang et al., 2022).

More specifically, one of the criticisms of the traditional approach to testing the EKC hypothesis is the technical limitation due to the multicollinearity problem caused by the inclusion of both the production (income) and its square in the same model. Addressing this model misspecification, Narayan & Narayan (2010) alternatively suggest the comparison of the short-run and long-run coefficients to infer the validity of the EKC hypothesis. In this argument, when the significant environmentally-detrimental effect (energy consumption in our case) of a regressor is smaller in the long-run than that in the short-run, it is attributed to the support of the EKC hypothesis. Therefore, the CS-ARDL approach also enables us to control for the EKC hypothesis without the multicollinearity problem.

5. Results and Discussions

Table 2 displays panel descriptive statistics and Pearson correlation coefficients over the period. For sectoral energy consumption, the mean values of *AGREC*, *INDEC*, *SEREC*, and *TREC* are respectively 0.124, 1.203, 0.496, and 1.224 tons of oil equivalent per capita. Their maximum values are 0.406 (1996 value of Netherlands), 3.305 (2004 value of Finland), 1.127 (2019 value of Canada), and 3.126 (2005 value of the US), respectively. Their minimum values are 0.003 (2003 value of Germany), 0.333 (2019 value of Greece), 0.075 (1990 value of Portugal), and 0.407 (1990 value of Portugal), respectively.

Regarding sectoral production, the panel average of *AGRP* is 0.836 thousand US dollars per capita, which is maximum at 2.790 (New Zealand's 2013 value) and minimum at 0.261 (UK's 2005 value). Most of the sampled countries have been experiencing a deindustrialization process, which has resulted in low and decreasing industrial production in favor of high and increasing service production per capita, despite temporal and country heterogeneities. The mean of *INDP* is 9.377 ranging between 16.119 (Finland's 2007 value) and 2.929 (Greece's 2014 value). The mean of *SERP* is 25.079 thousand US dollars. It is highest at 48.556 (2019 value of the US), and lowest at 4.810 (1990 value of South Korea). *MFP* and *ENINF* are observed to be varying considerably over countries and time. The average population growth (*POP*) is 0.569%. Germany, Greece, Italy, Japan, Portugal, and Spain had a decline in population for several years in the period.

Table 2: Panel Descriptive Statistics and Correlations (Observations: 570)

		Descriptive Statistics			
Variables↓	Mean	Median	Max.	Min.	Std. dev.
AGREC	0.124	0.104	0.406	0.003	0.078
INDEC	1.203	1.059	3.305	0.333	0.586
SEREC	0.496	0.480	1.127	0.075	0.224
TREC	1.224	1.039	3.126	0.407	0.581
AGRP	0.836	0.755	2.790	0.261	0.439
INDP	9.377	9.617	16.119	2.929	2.734
SERP	25.079	24.538	48.556	4.810	8.263
MFP	0.661	0.657	7.309	–8.190	1.517
ENINF	3.615	3.162	35.706	–18.397	6.360
POP	0.569	0.489	3.098	–1.837	0.512
		Matrix of Correlations			
Variables↓→	*AGREC*	*INDEC*	*SEREC*	*TREC*	*AGRP*
INDEC	0.376***	1			
SEREC	0.199***	0.582***	1		
TREC	0.166***	0.446***	0.698***	1	
AGRP	0.590***	0.286***	–0.207***	0.089**	1
INDP	0.223***	0.556***	0.546***	0.397***	–0.008
SERP	0.230***	0.208***	0.512***	0.492***	–0.082**
MFP	–0.009	0.122***	0.077*	–0.006	0.026
ENINF	0.020	0.010	–0.062	–0.013	0.084**
POP	0.295***	0.291***	0.220***	0.526***	0.396***
Variables↓→	*INDP*	*SERP*	*MFP*	*ENINF*	*POP*
SERP	0.721***	1			
MFP	0.052	–0.136***	1		
ENINF	–0.067	–0.099**	0.023	1	
POP	0.226***	0.227***	0.002	0.054	1

Note: Triple, double, and single asterisks show the statistical significance of correlations at the 99%, 95%, and 90% confidence levels, respectively.

The significant pairwise correlations in Table 2 show that *AGREC* is positively correlated with production and energy consumption in other sectors. This is true for *INDEC*, as well. However, *SEREC* is negatively correlated with *AGRP*, while *TREC* is positively associated with production in all three sectors. Notably, *AGRP* is negatively but weakly correlated with *SERP*. *MFP* is positively correlated with *INDEC* and *SEREC*, whereas its correlation with *SERP* is negative. Despite the weakness, *ENINF* is positively and negatively correlated with *AGRP* and *SERP*, respectively. Lastly, *POP* is positively correlated with all sectoral production and energy consumption variables. In general, the correlations reveal the interconnectivity of sectoral production and energy consumption, which needs to be explored through regression analysis.

Table 3 provides the CD test results, which confirm that all variables' series have CD. Furthermore, the CD exists strongly for the variables except for *POP*. The CD findings indicate that the sampled countries are widely affected by some unmeasured common factors. The sum of these factors' effects becomes stronger gradually with the inclusion of the members of the sample for the variables except for *POP*.

For the stationarity control, the CIPS panel unit root test is applied and results are reported in Table 4. The results infer that sectoral production and energy consumption variables exhibit a unit root process at their levels but not in their first differences, I(1), implying that any shocks to sectoral production and energy consumption will have permanent effects on the indicators of these variables. In this case, policies may be efficiently implemented to change the amount of sectoral production and energy consumption in the long-run. The possible effects of the policies are explored through the long-run estimation of the cointegration equations. However, MFP does not have a unit root at level, I(0), and the decision between I(0) and I(1) depends on the consideration of the contingent trend for *ENINF* and *POP*. The level-stationary process indicates that any shocks will have a transitory effect and indicators will return to their trend. Thus, the inclusion of both I(0) and I(1) variables in a model prompts us to use the ARDL modeling.

Table 3: Results from Cross-Sectional Dependence (CD) Tests

Null→	No CD		Weak CD	CD inference
Tests→ Variables↓	Breusch-Pagan (1980) LM (detrended)	Breusch-Pagan (1980) LM (trended)	Pesaran (2015) weak CD	
AGREC	209.416** (0.024)	214.257** (0.014)	5.469*** (0.000)	Strong
INDEC	206.779** (0.032)	234.187*** (0.001)	29.902*** (0.000)	Strong
SEREC	240.596*** (0.000)	276.627*** (0.000)	23.625*** (0.000)	Strong
TREC	224.966*** (0.005)	256.481*** (0.000)	30.153*** (0.000)	Strong
AGRP	249.967*** (0.000)	245.650*** (0.000)	32.753*** (0.000)	Strong
INDP	238.364*** (0.001)	253.031*** (0.000)	26.574*** (0.000)	Strong
SERP	356.634*** (0.000)	369.437*** (0.000)	68.160*** (0.000)	Strong
MFP	199.136* (0.069)	249.105*** (0.000)	21.205*** (0.000)	Strong
ENINF	369.718*** (0.000)	274.150*** (0.000)	49.477*** (0.000)	Strong
POP	216.323** (0.011)	225.399*** (0.003)	2.046 (0.410)	Weak

Note: Probability values are in (). Triple, double, and single asterisks show the rejection of the null hypothesis at the 99%, 95%, and 90% confidence levels, respectively.

Table 4: Results from the CIPS Unit Root Test

Null→	Non-stationarity (unit root)				Order of integration inference↓
Specification→	Level (max. lags: 7)		First-difference (max. lags: 6)		
Trend→	Detrended	Trended	Detrended	Trended	
Variables↓					
AGREC	–1.400	–1.476	–3.646***	–3.538***	I(1)
INDEC	–1.536	–2.592	–3.955***	–3.692***	I(1)
SEREC	–1.544	–1.622	–3.513***	–3.196***	I(1)
TREC	–1.213	–1.556	–3.903***	–3.245***	I(1)
AGRP	–1.457	–1.456	–3.134***	–3.516***	I(1)
INDP	–1.373	–1.827	–3.561***	–3.675***	I(1)
SERP	–1.399	–1.673	–3.356***	–3.028***	I(1)
MFP	–2.547***	–3.034***	——	——	I(0)
ENINF	–2.454***	–2.438	–4.408***	–3.835***	Not I(2)
POP	–2.155*	–2.265	–3.095***	–3.701***	Not I(2)

Note: Optimal lag lengths are selected based on the Akaike criterion. CIPS critical values for detrended (trended) specifications are –2.40, –2.21, and –2.12 (–2.90, –2.73, and –2.64), at the 1%, 5%, and 10% significance levels, respectively. Triple, double, and single asterisks show the rejection of the null hypothesis at the 99%, 95%, and 90% confidence levels, respectively.

Afterward, in order to specify the ARDL approach, the models are controlled for slope heterogeneity and CD. The results reported in Table 5 show that the coefficients to be estimated are heterogeneous and the cross-country regression residuals are strongly interrelated, which fits the CS-ARDL estimate.

Table 5: Results from Heterogeneity and CD Tests for Models

Dependent variable		*AGREC*	*INDEC*	*SEREC*	*TREC*
Null↓	Tests↓	Model 1	Model 2	Model 3	Model 4
Slope homogeneity	Δtilde	14.600*** (0.000)	22.876*** (0.000)	9.101*** (0.000)	19.562*** (0.000)
	Adjusted Δtilde	15.390*** (0.000)	24.114*** (0.000)	9.593*** (0.000)	20.620*** (0.000)
Cross-sectional dependence	Breusch-Pagan (1980) LM	816.093*** (0.000)	1596.627*** (0.000)	786.659*** (0.000)	1408.066*** (0.000)
	Pesaran (2015)	1.758* (0.080)	3.724*** (0.000)	7.351*** (0.000)	2.288** 0.023

Note: Probability values are in (). Triple, double, and single asterisks show the rejection of the null hypothesis at the 99%, 95%, and 90% confidence levels, respectively.

In addition, the calculated VIF values for the *AGRP* (1.213), *INDP* (1.603), *SERP* (1.823), *MFP* (1.086), *ENINF* (1.016), and *POP* (1.034) regressors do not move away severely from 1, corroborating the absence of multicollinearity problem. Consequently, the coefficients are estimated through the CS-ARDL method and the results are given in Table 6.

Table 6: Results from CS-ARDL Estimates

Dependent variable→	*AGREC:* Model 1	*INDEC:* Model 2	*SEREC:* Model 3	*TREC:* Model 4
Regressor↓	Short-run estimates			
ECT	–0.498*** (0.000)	–0.400*** (0.000)	–0.579*** (0.000)	–0.587*** (0.000)
AGRP	0.005 (0.620)	0.004 (0.955)	–0.038 (0.331)	0.087* (0.051)
INDP	–0.001 (0.585)	0.032*** (0.001)	0.013* (0.062)	0.008 (0.321)
SERP	–0.001 (0.714)	–0.005 (0.124)	0.001 (0.765)	0.005* (0.087)
MFP	0.001** (0.012)	0.009*** (0.000)	0.002 (0.427)	0.003* (0.010)
ENINF	0.0001 (0.501)	0.001* (0.010)	0.001** (0.011)	–0.0005* (0.074)
POP	–0.003 (0.394)	0.056 (0.129)	–0.009 (0.489)	0.039*** (0.001)
	Long-run estimates			
AGRP	0.005 (0.564)	0.016 (0.737)	–0.013 (0.583)	0.058* (0.067)
INDP	–0.001 (0.552)	0.020*** (0.001)	0.007* (0.096)	0.005 (0.274)
SERP	–0.001 (0.535)	–0.004* (0.056)	0.001 (0.745)	0.003* (0.096)
MFP	0.001** (0.012)	0.006*** (0.000)	0.002 (0.280)	0.002** (0.012)
ENINF	0.00004 (0.457)	0.001** (0.016)	0.0005** (0.012)	–0.0003* (0.092)
POP	–0.002 (0.374)	0.037 (0.105)	–0.004 (0.681)	0.025*** (0.002)
F-stat.	1.240** (0.040)	2.420** (0.000)	1.420*** (0.000)	2.300*** (0.000)
R^2	0.590	0.380	0.480	0.440
RMSE	0.010	0.040	0.030	0.030

Note: Probability values are in (). Triple, double, and single asterisks show statistical significance at 99%, 95%, and 90% confidence levels, respectively.

According to statistically significant results, the growth of *AGRP* leads to an increase in only *TREC* in both the short-run and the long-run. The estimated coefficients indicate that when per capita agricultural production increases by one thousand US dollars, per capita transport energy consumption also increases by about 0.087 tons (87 kg) in the short-run and 0.058 tons (58 kg) in the long-run. The reason behind the positive impact is that the increasing agricultural activities, from production to consumption, need extra transport. Moreover, growing *AGRP* increases new agricultural investment which again vitalizes the energy use in the transport sector. In addition, the sampled countries may be using some agricultural content as bioenergy consumed in the transport sector. The insignificant impacts of agricultural production on agricultural energy consumption reveal the energy-coupling feature in agricultural sectors.

A premised, rising *INDP* scales up not only its own energy consumption but also that of service in both the short-run and the long-run. Quantitatively, the estimated coefficients reveal that an extra one thousand US dollars per capita production in the industry sector causes 0.032 tons (32 kg) and 0.013 tons (13 kg) increases in per capita energy consumption of the industry and service sectors in the short-run. These effects decrease to about 0.020 (20 kg) and 0.007 (7 kg) tons in the long-run.

The expanding service sector is highly using transport services in developed countries. *SERP* is found positively associated with *TREC* in both the short-run and the long-run. More specifically, about 0.005 tons (5 kg) (in the short run) and 0.003 tons (3 kg) (in the long-run) increases are expected in per capita energy consumed in the transport sector, when one-thousand-valued new production per capita is created in the service sector. However, this extra service production reduces industrial energy consumption per capita by about 0.004 (4 kg) in the long run. This link indicates the possible structural shift within the industry. Developed countries tend to outsource energy-intensive industrial production (from other countries) and specialize in less-energy-intensive components, which are strongly related to the service sector. This service-led specialization in light industries supports the energy reduction contribution of deindustrialization and tertiarization when they are defined separately as outsourcing of energy-intensive industries and growing service sector, respectively (Moreau & Vuille, 2018; Chang et al., 2022). The energy reduction contribution of tertiarization (–0.004) to the industry remains higher than its energy-intensifying effects (0.003) on the transport sector in the long run. This means that further tertiarization will help in reducing the overall energy intensity in developed countries. Even though our intersectoral energy coefficients are not directly comparable with that of the earlier studies with an aggregated approach, the net energy reduction contribution of service production is in line with the outcomes of Atalla & Bean (2017), Wu et al. (2018), and Chang et al. (2022).

Additionally, as the production-energy consumption linkage weakens in magnitude from the short-run (0.032) to the long-run (0.020) for the industry sector, the industrial energy Kuznets curve pattern is supported from the perspective of Narayan & Narayan (2010). This indicates that the initial (in the short-run) strong positive link between industrial production and industrial energy consumption later (in the long-run) starts weakening. Given the decreasing trend of industrial production in our case, this pattern is likely driven by developed countries' leaving the low-valued but high-energy-intensive industrial activities and concentrating on the high-valued but less-energy-intensive light industrial activities. Moreover, this pattern is also evidenced in the cross-sectoral impacts, such that agricultural production's energy intensity impacts on the transport sector declined from the short-run to the long-run. Similarly, the energy Kuznets curve pattern is observed in the impacts of industrial production on service energy consumption and in the impacts of service production on transport energy consumption. These findings imply the increasing structural shift to energy-efficient activities both within and between sectors, enhancing overall environmental awareness, improving energy-saving technologies, and strengthening energy standards in the long-run. Yet, as the long-run coefficients remain positive, these energy efficiency improvements remain relative and need more ambitious efforts to improve energy efficiency for a certain decline in energy intensity. Unfortunately, there is no evidence provided by the earlier research to compare directly with our findings of cross-sectoral energy linkages.

The positive association between *MFP* and energy consumption in all sectors, particularly in agriculture, industry, and transport, indicates that the reduction in energy intensity does not occur in the normal course of technological development spontaneously. This clearly indicates the need for targeted efforts to shift toward less energy-intensive production technologies and activities even in developed countries with high technological capacities. While labor and capital resources produce goods and services productively as desired economically, they also simultaneously use extra energy undesired both economically and environmentally. This win-lose structure emerges a new concept of the energy-adjusted MFP. This evidence contradicts that of studies showing that technological progress reduces energy consumption and improves energy efficiency (e.g., Hasanov & Mikayilov, 2021; Uddin et al., 2022). One explanation for the energy intensity impacts of *MFP* is that firms with large positive labor and capital productivity may respond using more energy inputs. Another explanation is the energy rebound effect which states that energy efficiency improvement realized by *MFP* growth does not reduce but rather increases the energy demand. This occurs because the additional financial gains enabled by energy efficiency encourage economic agents to consume more energy. Our findings are consistent with the rebound effects channels highlighted and evidenced by Vélez-Henao et al. (2019), Freire-González (2020), Demiral & Demiral (2023), and Amjadi et al. (2022).

The results reveal that *ENINF* is positively associated with *INDEC* and *SEREC* but the nexus is negative for *TREC* in both the short-run and the long-run. The evidence that energy prices do not affect all sectors in the same way, highlights the importance of the sectoral perspective. The negative association between *ENINF* and *TREC* is consistent with the theoretical expectations and some previous evidence (e.g., Atalla & Bean, 2017; Flores-Chamba et al., 2019; Shahbaz et al., 2019; Hasanov & Mikayilov, 2021; Liu, 2022). This link validates the energy price adjustment as an important policy instrument for transport, but not for other sectors. Filipović et al. (2015) supported the usefulness of energy taxation to reduce energy intensity by showing that some EU countries with higher energy taxes also had lower energy intensity during the period 1990-2012. Like us, Pablo-Romero et al. (2017) found that energy inflation helped reduce energy consumption in the transport sector. This indicates the expected energy-saving technical change is occurring only in the transport sector. This can be also the outcome of the avoidance of individuals and logistics operators from the excessive use of transport as a response to increasing energy costs. One reason for the challenging positive *ENINF-INDEC* and *ENINF-SEREC* nexuses is our sectoral consideration. Yet, there are some economic rationales for these positive associations that industry also covers energy-related activities, in which energy inflation increases productivity and encourages industrial producers to use more energy inputs. The positive association in the service sector may be explained by the structural change in developed countries. Service sectors in these countries are expanding against the industry sectors. The value-added in the services sector is created with high productivity and profits. It seems that the marginal cost of the used energy remains lower than its marginal profit. The possible increasing return of energy use may be encouraging firms in service sectors to expand their production, even if the energy inflation increases. Moreover, as the industry and service sectors provide many crucial inputs to other sectors' production, the producers in these sectors may be reflecting the cost of energy inflation to consumers (the pass-through effect), which also lead to an increase in per capita energy consumption.

POP is significantly (positively) associated with only *TREC* in both the short-run and the long-run, despite a decline in the magnitude of the long-run effect. Again, some research confirmed the energy consumption impact of the growing population and urbanization (e.g., Sheng et al., 2017; Liddle & Sadorsky, 2021; Bogmans et al., 2020).

The error correction term (*ECT*) explains the speed of adjustment to return to equilibrium in the long-run. The *ECT* coefficients of the estimated models are statistically significant with consistent negative signs. Quantitatively, they reveal that any variation from the equilibriums of *AGREC* (Model 1), *INDEC* (Model 2), *SEREC* (Model 3), and *TREC* (Model 4) in the short run will be adjusted in the long-run by 0.498, 0.400, 0.579, and 0.587, respectively.

6. Conclusions and Implications

The explored cross-sectoral energy consumption responses to intersectoral production provide some insights into potentials, challenges, and policy implications. As agricultural energy consumption is independent of other sectors' production, energy-reduction policies in agriculture should be sector-specific and intended to facilitate the energy-efficient transformation in all agricultural machinery and agricultural powering and heating activities. The improvement of agricultural productive innovation to boost energy efficiency is also important. However, agricultural energy consumption is not affected by its own production, either. Even though this neutral effect supports the energy-decoupling, some significant reduction in per capita agricultural energy consumption can be achieved by further lessening per capita food losses and wastes, which also fits the zero-hunger aims of developed countries. Most of the sampled countries are EU members. These countries may further lower agricultural energy consumption by better allocating the agricultural production within the Union, considering the members' advantages in terms of climate, weather, soil, temperature, etc. For other countries, increasing bilateral agricultural trade agreements will bring about similar benefits.

Since industrial energy consumption is positively associated with its own production, energy-saving technologies in this sector should be promoted. The development and adoption of energy-saving technologies in the industrial sector may be difficult and expensive as these efforts are related to the replacement of the present energy-intensive industrial systems with more energy-efficient ones. Thus, the adjustment cost of low-energy transition may be financed by the governments based on energy efficiency assessment. Again, binding energy standards enforced by energy taxes (for high-energy-intensive manufacturing) or grants/rewards (for low-energy-intensive manufacturing) may also discourage the excessive use of energy in industrial activities. These actions will help reduce per capita industrial energy consumption, especially in the long-run.

Given the ongoing tertiarization trend of developed countries, the overall industrial energy intensity in these countries may be further reduced by enhancing structural change toward service sectors. This argument is supported by the evidenced negative impact of increasing service production on industrial energy consumption in the long-run. The energy-saving contribution of tertiarization seems to have some untapped potential as services sector energy intensity is increased by only industrial production, rather than service production, which again underlines the importance of the structural shift from industrial to service activities. It can be inferred that structural transformation in developed countries is occurring from more energy-intensive industrial production to less energy-intensive service production. Therefore, promoting this transition will help in improving total energy efficiency. However, deindustrialization and tertiarization exert an important challenge such that increasing service production leads to significant increases in the energy intensity of the transport sector, which is also closely linked to service sectors. These perplexing intersectoral linkages highlight once again the importance of low-energy green transport modes, which will also ease the evidenced energy consumption effect of agricultural production on transport energy consumption. Alternatively, and/or inclusively, firms in transport sectors may be intervened by internal energy price adjustment when global shocks reduce energy prices. Moreover, the users of transportation need to be well-educated about the economic and environmental costs of energy consumption and well-provided with alternative energy-efficient and cheap transportation services. More specifically, the buying and using of energy-intensive transports and personal cars should be made more expensive depending on their energy consumption compared to energy-efficient alternatives, which should be available cheaply in the markets.

Nonetheless, the policies that hold the energy prices high should be transport-specific as energy inflation increases the energy intensity of industry and service sectors. Thus, the possible markup pricing of the firms in these sectors should be controlled and they are encouraged to decrease the amount of energy use not to pass the energy costs through their customers easily. Unless this is achieved, the strong correlation between energy prices and overall inflation cannot be weakened and the harmful impacts of external energy shocks cannot be recovered. From the environmental pollution perspective, as green logistics and energy-saving transport modes initiatives have more potential in the mitigation undertakings, developed countries should focus on the renewable energy transition in the transport sector.

In addition to its distinctive intersectoral framework, another important contribution of this study is its consideration of *MFP* rather than oversimplified measures of technology. The evidenced positive associations between *MFP* and sectoral energy consumption highlight the importance of distinguishing *MFP* growth between energy-intensifying and energy-easing components. From the technological perspective, our findings indicate that *MFP* is not high enough to lower the level of energy consumption in the sectors. Therefore, developed countries have a risk of *MFP*-driven energy intensity since the growing productivity of the used labor and capital tends to raise the energy intensity of sectors, particularly that of agriculture, industry, and transport. This evidence indicates the energy rebound effects and calls for more attention from energy practitioners to the energy-adjusted green *MFP*. For the labor component of *MFP*, because the productivity gains seem to be gained by extra energy use, the employees need to be trained in energy-efficiency behaviors and energy-efficient management practices. For the capital productivity contribution to energy use, investment should be centered on the energy-efficiency merit. From the technology perspective, the technologies used by labor and capital again should be modernized to more energy-efficient content. The *MFP* growth increases the earnings of capital (investors) and employees. Since this income growth may also increase their agricultural, industrial, service, and transport consumption (the rebound effect), the economic agents' extra energy demand responses may be counterbalanced by extra taxation. The tax revenues should be allocated to support the energy efficiency projects of producers to reduce the economy-wide rebound effects embodied in intersectoral energy linkages.

Besides, the energy use impacts of economic agents and broadly the total population should be eased by increasing societal awareness of the economic and environmental harms of energy consumption. This can be conveyed by environmental education which will improve the environmental human capital. The increasing environmental human capital will also enhance the embracement and efficacy of energy efficiency campaigns and policy actions from both the demand and supply sides. All these practices will support the increase of energy efficiency on the production side and reduce energy inefficiencies on the consumption side, which together pave the path to the greener economy of developed countries.

The study also provides some research notes for academics. As the consideration of country heterogeneity is not alone competent, scholars should also consider sectoral heterogeneity and intersectoral energy linkages. More importantly, the potential rebound effects leaking in the intersectoral energy linkages should be a concern. For our aims, we did not distinguish total primary energy between those supplied by renewable or non-renewable resources. We also grouped industries from a broad perspective. Again, we did not compute *MFP* and energy inflation at the sectoral level due to the highly likely productivity and inflation spillovers across all sectors. Finally, because we purposed to explore the common relationships in developed economies, we did not test the associations at the country level. These points may be addressed by future research.

References

Aden, N. (2018). Necessary but Not Sufficient: The Role of Energy Efficiency in Industrial Sector Low-Carbon Transformation. *Energy Efficiency*, *11,* 1083-1101. https://doi.org/10.1007/s12053-017-9570-z

Ahmad, M., Shabir, M., Naheed, R. & Shehzad, K. (2022). How Do Environmental Innovations and Energy Productivity Affect the Environment? Analyzing the Role of Economic Globalization. *International Journal of Environmental Science and Technology, 19,* 7527-7538. https://doi.org/10.1007/s13762-021-03620-8

Amjadi, G., Lundgren, T. & Zhou, W. (2022). A Dynamic Analysis of Industrial Energy Efficiency and the Rebound Effect: Implications for Carbon Emissions and Sustainability. *Energy Efficiency, 15(*54). https://doi.org/10.1007/s12053-022-10059-4

Atalla, T. & Bean, P. (2017). Determinants of Energy Productivity in 39 Countries: An Empirical Investigation. *Energy Economics, 62,* 217-229. https://doi.org/10.1016/j.eneco.2016.12.003

Balogh, J.M. (2022). The Impacts of Agricultural Development and Trade on CO_2 Emissions? Evidence from the Non-European Union Countries. *Environmental Science & Policy, 137,* 99-108. https://doi.org/10.1016/j.envsci.2022.08.012

Bergquist, A. K. & Söderholm, K. (2016). Sustainable Energy Transition: The Case of the Swedish Pulp and Paper Industry 1973-1990. *Energy Efficiency, 9,* 1179-1192. https://doi.org/10.1007/s12053-015-9416-5

Bersvendsen, T. & Ditzen, J. (2021). Testing for Slope Heterogeneity in Stata. *The Stata Journal, 21*(1), 51-80. https://doi.org/10.1177/1536867X211000004

Blanchard, O. J. & Riggi, M. (2013). Why are the 2000s so Different from the 1970s? A Structural Interpretation of Changes in The Macroeconomic Effects of Oil Prices. *Journal of the European Economic Association, 11,* 1032-1052. https://doi.org/10.1111/jeea.12029

Bogmans, C., Kiyasseh, L., Matsumoto, A. & Pescatori, A. (2020). Energy, Efficiency Gains and Economic Development: When will Global Energy Demand Saturate?. *IMF Working Papers, 20*(253). https://doi.org/10.5089/9781513561240.001

Bowden, N. & Payne, J. E. (2010). Sectoral Analysis of the Causal Relationship Between Renewable and Non-Renewable Energy Consumption and Real Output in the US. *Energy Sources, Part B: Economics, Planning, and Policy, 5*(4), 400-408. https://doi.org/10.1080/15567240802534250

Breusch, T. S. & Pagan, A. R. (1980). The Lagrange Multiplier Test and Its Applications to Model Specification in Econometrics. *The Review of Economic Studies, 47*(1), 239-253. https://doi.org/10.2307/2297111

Brinkerink, J., Chegut, A. & Letterie, W. (2019). Energy Performance and Capital Expenditures in Manufacturing Industries. *Energy Efficiency, 12,* 2011-2038. https://doi.org/10.1007/s12053-019-09779-x

Cagno, E., Trianni, A., Spallina, G. & Marchesani, F. (2017). Drivers for Energy Efficiency and Their Effect on Barriers: Empirical Evidence from Italian Manufacturing Enterprises. *Energy Efficiency, 10,* 855-869. https://doi.org/10.1007/s12053-016-9488-x

Canh, N. P., Schinckus, C., Thanh, S. D. & Chong, F. H. L. (2021). The Determinants of the Energy Consumption: A Shadow Economy-Based Perspective. *Energy, 225.* https://doi.org/10.1016/j.energy.2021.120210

Chang, T.-H., Ma, K.-M. & Chang, S.-L. (2022). Towards Green Growth: Industry Structure and Energy Transition in OECD Countries. *Energy & Environment,* https://doi.org/10.1177/0958305X221135978

Chikezie Ekwueme, D., Lasisi, T. T. & Eluwole, K. K. (2022). Environmental Sustainability in Asian Countries: Understanding the Criticality of Economic Growth, Industrialization, Tourism Import, and Energy Use. *Energy & Environment*. https://doi.org/10.1177/0958305X221091543

Chudik, A., Pesaran, M. H. & Tosetti, E. (2011). Weak and Strong Cross-Section Dependence and Estimation of Large Panels. *The Econometrics Journal, 14*(1), C45-C90. https://doi.org/10.1111/j.1368-423X.2010.00330.x

Chudik, A., Mohaddes, K., Pesaran, M. H. & Raissi, M. (2016). Long-Run Effects in Large Heterogeneous Panel Data Models with Cross-Sectionally Correlated Errors. *Essays in Honor of Aman Ullah (Advances in Econometrics, 36).* Bingley: Emerald. https://doi.org/10.1108/S0731-905320160000036013

Csereklyei, Z., Varas, M. R. & Stern, D. I. (2016). Energy and Economic Growth: The Stylized Facts. *The Energy Journal, 37*(2), 223-255. http://dx.doi.org/10.5547/01956574.37.2.zcse

Deichmann, U., Reuter, A., Vollmer, S. & Zhang, F. (2019). The Relationship between Energy Intensity and Economic Growth: New Evidence from a Multi-Country Multi-Sectorial Dataset. *World Development, 124.* https://doi.org/10.1016/j.worlddev.2019.104664

Demiral, M. & Akça, E. E. (2022). Economic Complexity-Carbonization Nexus in the European Union: A Heterogeneous Panel Data Analysis. *Energy Sources, Part B: Economics, Planning, and Policy, 17*(1). https://doi.org/10.1080/15567249.2022.2046210

Demiral, M. & Demiral, Ö. (2023). Socio-Economic Productive Capacities and Energy Efficiency: Global Evidence by Income Level and Resource Dependence. *Environmental Science and Pollution Research*, *30*(15), 42766-42790 https://doi.org/10.1007/s11356-021-17266-z

Dietz, T. & Rosa, E. A. (1994). Rethinking the Environmental Impacts of Population, Affluence and Technology. *Human Ecology Review, 1*(2), 277-300.

Dietz, T. & Rosa, E. A. (1997). Effects of Population and Affluence on CO_2 Emissions. *Proceedings of the National Academy of Sciences, 94*(1), 175-179. https://doi.org/10.1073/pnas.94.1.175

Ditzen, J. (2021). Estimating Long-Run Effects and the Exponent of Cross-Sectional Dependence: An Update to xtdcce2. *The Stata Journal, 21*(3), 687-707. https://doi.org/10.1177/1536867X211045560

Dokas, I., Panagiotidis, M., Papadamou, S. & Spyromitros, E. (2022). The Determinants of Energy and Electricity Consumption in Developed and Developing Countries: International Evidence. *Energies, 15*, 2558. https://doi.org/10.3390/en15072558

Dunlop, T. (2019). Mind the Gap: A Social Sciences Review of Energy Efficiency. *Energy Research & Social Science, 56.* https://doi.org/10.1016/j.erss.2019.05.026

Eder, L. & Provornaya, I. (2018). Analysis of Energy Intensity Trend as a Tool for Long-Term Forecasting of Energy Consumption. *Energy Efficiency, 11,* 1971-1997. https://doi.org/10.1007/s12053-018-9656-2

Ferreira, A., Pinheiro, M. D., de Brito, J. & Mateus, R. (2020). Relating Carbon and Energy Intensity of Best-Performing Retailers with Policy, Strategy and Building Practice. *Energy Efficiency, 13,* 597-619. https://doi.org/10.1007/s12053-020-09840-0

Filipović, S., Verbič, M. & Radovanović, M. (2015). Determinants of Energy Intensity in the European Union: A Panel Data Analysis. *Energy, 92*(Part 3), 547-555. https://doi.org/10.1016/j.energy.2015.07.011

Flores-Chamba, J., López-Sánchez, M., Ponce, P., Guerrero-Riofrío, P. & Álvarez-García, J. (2019). Economic and Spatial Determinants of Energy Consumption in the European Union. *Energies, 12,* 4118. https://doi.org/10.3390/en12214118

Freire-González, J. (2020). Energy Taxation Policies Can Counteract the Rebound Effect: Analysis within a General Equilibrium Framework. *Energy Efficiency, 13,* 69-78. https://doi.org/10.1007/s12053-019-09830-x

Goh, T. & Ang, B. W. (2020). Four Reasons Why There is so much Confusion about Energy Efficiency. *Energy Policy, 146.* https://doi.org/10.1016/j.enpol.2020.111832

Gokmenoglu, K. K. & Taspinar, N. (2018). Testing the Agriculture-Induced EKC Hypothesis: The Case of Pakistan. *Environmental Science and Pollution Research, 25,* 22829-22841. https://doi.org/10.1007/s11356-018-2330-6

Gota, S., Huizenga, C., Peet, K., Medimorec, N. & Bakker, S. (2019). Decarbonising Transport to Achieve Paris Agreement Targets. *Energy Efficiency, 12,* 363-386. https://doi.org/10.1007/s12053-018-9671-3

Gregorich, M., Strohmaier, S., Dunkler, D. & Heinze, G. (2021). Regression with Highly Correlated Predictors: Variable Omission is not the Solution. *International Journal of Environmental Research and Public Health, 18*(8). https://doi.org/10.3390/ijerph18084259

Habiba, U., Xinbang, C. & Anwar, A. (2022). Do Green Technology Innovations, Financial Development, and Renewable Energy Use Help to Curb Carbon Emissions?. *Renewable Energy, 193,* 1082-1093. https://doi.org/10.1016/j.renene.2022.05.084

Hasanov, F. J. & Mikayilov, J. I. (2021). The Impact of Total Factor Productivity on Energy Consumption: Theoretical Framework and Empirical Validation. *Energy Strategy Reviews, 38,* 100777. https://doi.org/10.1016/j.esr.2021.100777

Htike, M. M., Shrestha, A. & Kakinaka, M. (2022). Investigating Whether the Environmental Kuznets Curve Hypothesis Holds for Sectoral CO_2 Emissions: Evidence from Developed and Developing Countries. *Environment, Development and Sustainability, 24,* 12712-12739. https://doi.org/10.1007/s10668-021-01961-5

IEA-International Energy Agency. (2022). *World Energy Outlook 2022.* https://www.iea.org/reports/world-energy-outlook-2022

Karakaya, E., Alataş, S. & Yılmaz, B. (2020). Sectoral Convergence in Energy Consumption from Developing Country Perspective: The Case of Turkey. *Energy Efficiency, 13,* 1457-1472. https://doi.org/10.1007/s12053-020-09891-3

Kim, M. J. (2020). Understanding the Determinants on Household Electricity Consumption in Korea: OLS Regression and Quantile Regression. *The Electricity Journal, 33*(7). https://doi.org/10.1016/j.tej.2020.106802

Komarova, A. V., Filimonova, I. V. & Kartashevich, A. A. (2022). Energy Consumption of the Countries in the Context of Economic Development and Energy Transition. *Energy Reports, 8*(Supplement 9), 683-690. https://doi.org/10.1016/j.egyr.2022.07.072

Li, T. (2022). Energy Productivity and Financial Inclusion: Evidence from Non-Parametric Novel Panel Methods. *Energy Efficiency, 15(*51). https://doi.org/10.1007/s12053-022-10057-6

Liddle, B. & Sadorsky, P. (2021). Energy Efficiency in OECD and Non-OECD countries: Estimates and Convergence. *Energy Efficiency, 14*(72). https://doi.org/10.1007/s12053-021-09992-7

Liu, J., Wang, H., Rahman, S. & Sriboonchitta, S. (2021). Energy Efficiency, Energy Conservation and Determinants in the Agricultural Sector in Emerging Economies. *Agriculture, 11*, 773. https://doi.org/10.3390/agriculture11080773

Liu, Y. (2022). Energy Efficiency, Cleaner Energy and Energy Related Prices: Evidence from Dynamic Generalised Method of Moments. *Economic Research-Ekonomska Istraživanja*. https://doi.org/10.1080/1331677X.2022.2106280

Lorente, D. B. & Álvarez-Herranz, A. (2016). Economic Growth and Energy Regulation in the Environmental Kuznets Curve. *Environmental Science and Pollution Research, 23,* 16478-16494. https://doi.org/10.1007/s11356-016-6773-3

Mahmood, H., Alkhateeb, T. T. Y., Tanveer, M. & Mahmoud, D. H. I. (2021). Testing the Energy-Environmental Kuznets Curve Hypothesis in the Renewable and Nonrenewable Energy Consumption Models in Egypt. *International Journal of Environmental Research and Public Health, 18,* 7334. https://doi.org/10.3390/ijerph18147334

McAndrew, R., Mulcahy, R., Gordon, R. & Russell-Bennett, R. (2021). Household Energy Efficiency Interventions: A Systematic Literature Review. *Energy Policy, 150,* 112136. https://doi.org/10.1016/j.enpol.2021.112136

Mendiluce, M., Pérez-Arriaga, I. & Ocaña, C. (2010). Comparison of the Evolution of Energy Intensity in Spain and in the EU15. Why is Spain Different?. *Energy Policy, 38*(1), 639-645. https://doi.org/10.1016/j.enpol.2009.07.069

Metcalf, G. E. (2008). An Empirical Analysis of Energy Intensity and Its Determinants at the State Level. *The Energy Journal, 29*(3), 1-26.

Moreau, V. & Vuille, F. (2018). Decoupling Energy Use and Economic Growth: Counter Evidence from Structural Effects and Embodied Energy in Trade. *Applied Energy, 215,* 54-62. https://doi.org/10.1016/j.apenergy.2018.01.044

Narayan, P. K. & Narayan, S. (2010). Carbon Dioxide Emissions and Economic Growth: Panel Data Evidence from Developing Countries. *Energy Policy, 38*(1), 661-666. https://doi.org/10.1016/j.enpol.2009.09.005

Nassani, A. A., Aldakhil, A. M., Abro, M. M. Q. & Zaman, K. (2017). Environmental Kuznets Curve Among BRICS Countries: Spot Lightening Finance, Transport, Energy and Growth Factors. *Journal of Cleaner Production, 154,* 474-487. https://doi.org/10.1016/j.jclepro.2017.04.025

OECD. (2017). *Green Growth Indicators 2017.* Paris: OECD Publishing. http://dx.doi.org/10.1787/9789264268586-en

OECD. (2021). *OECD Productivity Statistics Database Methodological Notes.* https://www.oecd.org/sdd/productivity-stats/OECD-Productivity-Statistics-Methodological-note.pdf

OECD. (2023). *OECD Stat.* https://stats.oecd.org/

Omri, A. (2014). An International Literature Survey on Energy-Economic Growth Nexus: Evidence from Country-Specific Studies. *Renewable and Sustainable Energy Reviews, 38,* 951-959. https://doi.org/10.1016/j.rser.2014.07.084

Pablo-Romero, M. P., Cruz, L. & Barata, E. (2017). Testing the Transport Energy-Environmental Kuznets Curve Hypothesis in the EU27 Countries. *Energy Economics, 62,* 257-269. https://doi.org/10.1016/j.eneco.2017.01.003

Patt, A., Van Vliet, O., Lilliestam, J. & Pfenninger, S. (2019). Will Policies to Promote Energy Efficiency Help or Hinder Achieving a 1.5°C Climate Target?. *Energy Efficiency, 12*, 551-565. https://doi.org/10.1007/s12053-018-9715-8

Payne, J. E. (2010). Survey of the International Evidence on the Causal Relationship Between Energy Consumption and Growth. *Journal of Economic Studies, 37*(1), 53-95. https://doi.org/10.1108/01443581011012261

Perret, J. K., Udalov, V. & Fabisch, N. (2022). Motivations behind Individuals' Energy Efficiency Investments and Daily Energy-Saving Behavior: The Case of China. *International Economics and Economic Policy, 19,* 129-155. https://doi.org/10.1007/s10368-021-00521-6

Pesaran, M. H. (2007). A Simple Panel Unit Root Test in the Presence of Cross-Section Dependence. *Journal of Applied Econometrics*, *22,* 265-312. https://doi.org/10.1002/jae.951

Pesaran, M. H. & Yamagata, T. (2008). Testing Slope Homogeneity in Large Panels. *Journal of Econometrics, 142*(1), 50-93. https://doi.org/10.1016/j.jeconom.2007.05.010

Pesaran, M. H. (2015). Testing Weak Cross-Sectional Dependence in Large Panels. *Econometric Reviews, 34*(6-10), 1089-1117. https://doi.org/10.1080/07474938.2014.956623

Rehermann, F. & Pablo-Romero, M. (2018). Economic Growth and Transport Energy Consumption in the Latin American and Caribbean Countries. *Energy Policy, 122,* 518-527. https://doi.org/10.1016/j.enpol.2018.08.006

Renna, P. & Materi, S. (2021). A Literature Review of Energy Efficiency and Sustainability in Manufacturing Systems. *Applied Sciences, 11,* 7366. https://doi.org/10.3390/app11167366

Rosenblum, J., Horvath, A. & Hendrickson, C. (2000). Environmental Implications of Service Industries. *Environmental Science & Technology, 34*(22), 4669-4676. https://doi.org/10.1021/es9914083

Schneider, U. A. & Smith, P. (2009). Energy Intensities and Greenhouse Gas Emission Mitigation in Global Agriculture. *Energy Efficiency, 2,* 195-206. https://doi.org/10.1007/s12053-008-9035-5

Shahbaz, M. & Sinha, A. (2019). Environmental Kuznets Curve for CO_2 Emissions: A Literature Survey. *Journal of Economic Studies, 46*(1), 106-168. https://doi.org/10.1108/JES-09-2017-0249

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. https://doi.org/10.1016/j.eneco.2018.11.016

Sharma, K. (2022). An Analysis of Consumer Purchase Intention for Energy-Efficient Products. *Energy Efficiency, 15(*64). https://doi.org/10.1007/s12053-022-10072-7

Sheng, P., He, Y. & Guo, X. (2017). The Impact of Urbanization on Energy Consumption and Efficiency. *Energy & Environment, 28*(7), 673-686. https://doi.org/10.1177/0958305X17723893

Sineviciene, L., Sotnyk, I. & Kubatko, O. (2017). Determinants of Energy Efficiency and Energy Consumption of Eastern Europe Post-Communist Economies. *Energy Environment, 28*(8), 870-884. https://doi.org/10.1177/0958305X17734386

Singh, K. & Vashishtha, S. (2022). Relationship Trend of Energy Consumption and Economic Growth Studies: A Global Examination Based on Bibliometric and Visualization Analysis. *International Journal of Energy Sector Management.* https://doi.org/10.1108/IJESM-06-2021-0022

Sueyoshi, T., Yuan, Y. & Goto, M. (2017). A Literature Study for DEA Applied to Energy and Environment. *Energy Economics, 62,* 104-124. https://doi.org/10.1016/j.eneco.2016.11.006

Tajudeen, I. A. (2021). The Underlying Drivers of Economy-wide Energy Efficiency and Asymmetric Energy Price Responses. *Energy Economics, 98,* 105222. https://doi.org/10.1016/j.eneco.2021.105222

Tzeremes, P. (2020). The Impact of Total Factor Productivity on Energy Consumption and CO_2 Emissions in G20 Countries. *Economics Bulletin, 40*(3), 2179-2192.

Uddin, K., Pan, X., Saima, U. & Zhang, C. (2022). Influence of Financial Development on Energy Intensity Subject to Technological Innovation: Evidence from Panel Threshold Regression. *Energy, 239*(Part D). https://doi.org/10.1016/j.energy.2021.122337

UNCTAD. (2023). *UNCTAD Stat Data Center.* https://unctadstat.unctad.org/EN/

Vélez-Henao, J. A., Vivanco, D. F. & Hernández-Riveros, J. A. (2019). Technological Change and the Rebound Effect in the STIRPAT Model: A Critical View. *Energy Policy, 129,* 1372-1381. https://doi.org/10.1016/j.enpol.2019.03.044

Voigt, S., De Cian, E., Schymura, M. & Verdolini, E. (2014). Energy Intensity Developments in 40 Major Economies: Structural Change or Technology Improvement?. *Energy Economics, 41,* 47-62. https://doi.org/10.1016/j.eneco.2013.10.015

Wachsmuth, J. & Duscha, V. (2019). Achievability of the Paris Targets in the EU-The Role of Demand-Side-Driven Mitigation in Different Types of Scenarios. *Energy Efficiency, 12,* 403-421. https://doi.org/10.1007/s12053-018-9670-4

Wang, W., Rehman, M. A. & Fahad, S. (2022). The Dynamic Influence of Renewable Energy, Trade Openness, and Industrialization on the Sustainable Environment in G-7 Economies. *Renewable Energy, 198,* 484-491. https://doi.org/10.1016/j.renene.2022.08.067

Wu, Y., Zhu, Q. & Zhu, B. (2018). Comparisons of Decoupling Trends of Global Economic Growth and Energy Consumption between Developed and Developing Countries. *Energy Policy, 116,* 30-38. https://doi.org/10.1016/j.enpol.2018.01.047

Zeng, L., Ye, A. & Lin, W. (2022). Deepening Decoupling for Sustainable Development: Evidence from Threshold Model. *Energy Efficiency, 15(*33). https://doi.org/10.1007/s12053-022-10031-2

Çıkar Beyanı: Yazarlar arasında çıkar çatışması yoktur.

Etik Beyanı: Bu çalışmanın tüm hazırlanma süreçlerinde etik kurallara uyulduğunu yazarlar beyan eder. Aksi bir durumun tespiti halinde Fiscaoeconomia Dergisinin hiçbir sorumluluğu olmayıp, tüm sorumluluk çalışmanın yazarlarına aittir.

Yazar Katkısı: Yazarların katkısı aşağıdaki gibidir:

Giriş: 1. ve 4. yazar

Literatür: 1. ve 4. yazar

Metodoloji: 2. ve 3. yazar

Sonuç: 2. ve 3. yazar

1. yazarın katkı oranı: %30. 2. yazarın katkı oranı: %25. 3. yazarın katkı oranı: %25. 4. yazarın katkı oranı: %20.

Conflict of Interest: The authors declare that they have no competing interests.

Ethical Approval: The authors declare that ethical rules are followed in all preparation processes of this study. In the case of a contrary situation, Fiscaoeconomia has no responsibility, and all responsibility belongs to the study's authors.

Author Contributions: Author contributions are below:

Introduction: 1st and 4th authors

Literature: 1st and 4th authors

Methodology: 2nd and 3rd authors

Conclusion: 2nd and 3rd authors

1st author's contribution rate: 30%, 2nd author's contribution rate: 25%, 3rd author's contribution rate: 25%, 4th author's contribution rate: 20%.