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The Impact of R&D Expenditures on Regional Energy Intensity in Turkey

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ABSTRACT

Energy efficiency measures are effective solutions for addressing environmental and economic issues, including global warming, energy supply security, and trade deficits from imported energy sources. Turkey through an ambitious policy scheme in the last decades, have reduced energy intensity level significantly, though, still higher than developed countries. In this regard, this study investigates the relationship between R&D expenditures and energy intensity in Turkey through NUTS-I regional data ranging from 2010 to 2021. According to both FMOLS and DOLS technique findings increasing R&D expenditures may significantly decrease energy intensity. Furthermore, economic growth appears to correlate with reduced energy intensity. Additionally, FMOLS findings suggest that industrialization may increase energy intensity, while DOLS results indicate that population growth can also significantly increase energy intensity. Therefore, a customized research and development (R&D) incentivization support system could offer various benefits to Turkey and other developing nations facing similar challenges.

Keywords: Energy Efficiency, Energy Intensity, Research and Development, Global Warming, Turkey
JEL Classifications: O55, Q43

1. INTRODUCTION

Energy intensity, or conversely, energy efficiency, has garnered increasing attention from both academic circles and the general public due to its multifaceted significance. Primarily, the significance of energy intensity, which refers to the amount of energy consumed to produce a unit of output, stems from mounting concerns regarding environmental degradation and its adverse effects on terrestrial life, including climate change. Enhancing energy efficiency holds promise in supporting sustainable development endeavors. Secondly, energy efficiency holds economic importance, particularly in terms of potential cost reductions within production processes. For nations reliant on imported fossil fuels, enhancing energy efficiency offers the prospect of reducing current account and trade deficits. Additionally, energy supply security emerges as a critical consideration in geopolitical discourse. The issue of energy efficiency gains prominence in this context amid global political tensions, exemplified by recent events such as the Russia-Ukraine conflict and tensions between Israel and Iran. Moreover, the COVID-19 pandemic has underscored the importance of energy efficiency amidst broader geopolitical uncertainties.

One of the notable benefits associated with advancements in energy efficiency and reductions in energy intensity is their potential to mitigate environmental impacts. The rapid expansion of global population and economy over the past century has exerted considerable strain on the environment. Among the nations experiencing significant population and economic growth is Turkey. The country's Gross Domestic Product (GDP) has surged by more than 17-fold since 1960, escalating from approximately 69 billion USD (constant, 2015 dollars) to 1.2 trillion USD (constant, 2015 dollars) by 2022, representing one of the highest growth rates globally (World Bank). Consequently, the demand for energy, a vital input across various sectors of production, has surged in Turkey. Per capita energy consumption has witnessed a substantial rise from 388 kg equivalent of oil in 1960–1658 kg in 2015, indicating more than a fourfold increase in per capita energy utilization (World Bank).

The remarkable economic and energy consumption growth observed in Turkey has inevitably led to various environmental challenges, as anticipated. Over the span of 30 years, from 1990 to 2020, Turkey's total greenhouse gas emissions (kt of CO_2 equivalent) more than doubled, escalating from 205,436 kt to 504,956 kt (World Bank). This surge in emissions underscores Turkey's susceptibility to climate change and natural disasters, rendering it one of the most vulnerable countries globally, according to the Climate Vulnerability Index, where a higher rank indicates greater vulnerability (UNDP as cited in Somoye, 2024). Consequently, the substantial growth trajectory poses a significant threat to Turkey's sustainable development endeavors. Recognizing this, policymakers in Turkey have identified the reduction of energy intensity as one of the key policy objectives.

Another significant concern related to energy consumption, particularly in the context of Turkey, is its high dependency on energy imports. This dependency has surged notably over recent decades. According to the World Bank, in 1960, only 12% of Turkey's total energy consumption was sourced from imports. However, due to rapid economic expansion, this proportion escalated to 75% by 2015. Furthermore, aside from this energy import reliance, energy imports constitute a substantial portion of Turkey's total imports, comprising 70%, thereby constituting a significant portion of Turkey's import bill (Ervural et al., 2016).

Turkey's economic growth trajectory has not followed a straightforward and stable path, partly due to its dependency on energy imports. Instead, the Turkish economy has experienced significant fluctuations characterized by fluctuating growth rates, with many growth periods being short-lived and followed by downturns. This pattern is largely attributed to the unique structure of the Turkish economy, where a substantial portion of export sectors relies on imported capital goods, intermediate goods, and energy. Consequently, periods of growth driven by increasing exports are accompanied by rising trade deficits and current account deficits, placing pressure on exchange rates and exacerbating financial risks. This phenomenon is a primary contributor to the aforementioned financial fragility and crises. Therefore, reducing energy intensity in Turkey could yield positive effects on foreign debt, as well as mitigate current account deficits and associated financial vulnerabilities.

In recent decades, policymakers have implemented a range of new regulations, rules, and support initiatives to address the challenges posed by high import dependency and its adverse impacts on both the economy and the environment. Among these measures, the renewable energy sector stands out as particularly significant, given Turkey's abundant renewable energy resources, such as solar energy, owing to its geographical location. In light of this, Turkey's installed power capacity in renewable energy expanded to 54% by 2022, positioning Turkey as the 5th largest in Europe and the 12th globally (MFA).

Policy makers in Turkey also prioritize reducing energy dependency by focusing on energy efficiency and decreasing energy intensity. According to the International Energy Agency (IEA), while renewable energy plays a crucial role in sustainable development and energy transition, energy efficiency is equally significant. It is considered one of the quickest and most cost-effective methods for mitigating greenhouse gas emissions, lowering energy expenses, and enhancing energy supply security for countries and for this reason energy efficiency is often referred to as the "first fuel" in the literature (IEA).

The Turkish government has implemented various policy measures to reduce energy intensity in the country. Many of these measures align with European Union (EU) regulations, as Turkey is a candidate country for EU accession, and these regulations are primarily overseen by the MENR. One of the key steps in Turkish energy efficiency regulations was the enactment of the Energy Efficiency Law in 2007. Prior to this law, there were some scattered and disorganized regulations in place. Examples include the Energy Efficiency Regulation in Industry in 1995, Electrical Appliances Energy Efficiency Labels in 2000, and the Regulation on Informing Consumers on Fuel Economy and CO_2 Emissions of Passenger Cars in 2003 (Koçaslan, 2014).

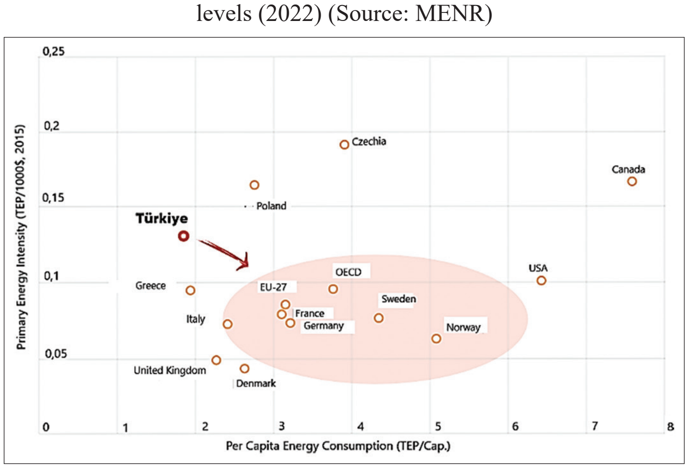
The Energy Efficiency Law, enacted in 2007 to establish a foundation for energy efficiency regulations, aimed to enhance the efficient use of energy. In line with this objective, various secondary subsidy programs, regulations, and rules were implemented. The law encompassed provisions aimed at promoting energy efficiency, providing incentives in this regard, imposing administrative sanctions for violations, and conducting educational and awareness-raising activities (Koçaslan, 2014). Subsequent to the enactment of the law, several regulations were issued to operationalize these practices, including the Regulation on Increasing Efficiency in the Use of Energy Resources and Energy, the Energy Performance Regulation in Buildings, the Energy Efficiency Control Regulation, and the Regulation on Procedures and Principles for Increasing Energy Efficiency in Transportation (MENR).

The Energy Efficiency Strategy Document, published in 2012 with a duration spanning 2012-2023 and involving a 10.9 billion US dollar investment, targeted achieving 23.9 million tons of energy savings, a reduction of 66.6 million tons of CO_2 equivalent emissions, and a 20% decrease in energy intensity, leading to the implementation of the 1st National Energy Efficiency Action Plan for the period of 2017-2023 by the MENR. Furthermore, according to the MENR, the 2nd Energy Efficiency Action Plan reports that during the 1st Energy Efficiency Action Plan period, an investment of 8.47 billion US dollars in energy efficiency measures resulted in 24.6 MTEP energy savings, a reduction of 68.62 million tons of CO_2 equivalent emissions, and an energy intensity reduction of 20.4%, surpassing the target set by the MENR. Additionally, as stated by the (MENR) in the 2nd Energy Efficiency Action Plan, the objective is to invest 20.2 billion US dollars in energy efficiency measures, aiming to achieve 46 billion USD in energy savings, a reduction of 100 million tons of CO_2 equivalent emissions, and a 15% reduction in energy intensity by 2030.

Despite achieving rigorous targets through ambitious performance in recent decades, as illustrated in Figure 1 depicting energy intensity and per capita energy consumption of various countries for the year 2022, Turkey's energy intensity level remains higher than that of developed countries. Additionally, given that per capita energy consumption in Turkey lags behind that of developed countries, it is anticipated that Turkey's rapid growth may lead to further increases in both per capita energy consumption and energy intensity levels. Consequently, while Turkey has made significant progress in renewable energy adoption, greater efforts are needed, particularly in reducing energy intensity, given Turkey's prolonged growth trajectory, which could exacerbate energy intensity levels.

From this perspective, while all policy efforts by the Turkish government are crucial, one significant avenue that could accelerate Turkey's energy transition is through research and development (R&D) investments aimed at reducing energy intensity. R&D investments are commonly regarded as a primary driver of enhancing growth capacity. However, a less-discussed potential impact of R&D investments could be realized through the promotion of energy efficiency. The potential contributions of investment in innovation activities may manifest directly through R&D investments in the energy sector, which has become increasingly important in recent decades as climate change concerns gain prominence in the public sphere. Moreover, various types of R&D investments across all sectors can lead to economic externalities that reduce energy intensity. For instance, the recent surge in R&D investment and growth in electric vehicle technology exemplifies this phenomenon, where intense competition in the sector aims to increase vehicle range by reducing weight, improving aerodynamics, and enhancing energy efficiency, thereby lowering energy consumption and intensity. Similarly, advancements in microprocessor technology have led to reduced energy consumption while increasing computing power. Analogous examples can be found across almost all sectors.

Figure 1: Energy intensity and per capita energy consumption levels (2022) (Source: MENR)



However, it is important to note that R&D investments may potentially lead to increased energy consumption and energy intensity. For instance, the recent emergence of cryptocurrencies in the finance sector has been scrutinized in various studies (Krause and Tolaymat, 2018; Li et al., 2019; Gallersdörfer et al., 2020) to assess their potential impact on rising energy consumption. Another example is the rapid growth of the artificial intelligence sector and the corresponding surge in R&D investments. The substantial computing power required for artificial intelligence applications may contribute to increased energy consumption. In summary, R&D investment has the potential to elevate energy consumption and intensity by introducing new tools, equipment, and applications into daily human life, thereby potentially increasing energy usage.

Hence, R&D investments could potentially either increase or decrease the energy intensity of countries, necessitating comprehensive analyses of the relationship between these two indicators. Recognizing this significance, the number of studies addressing this issue has been steadily increasing over the years. A considerable portion of these studies has been conducted in the context of China, with some also utilizing panel data analysis. However, despite Turkey's status as a rapidly growing and energy import-dependent country similar to China, there exist a notable gap in the literature, as there is currently no research investigating the relationship between R&D and energy intensity specific to Turkey. Consequently, scientific findings pertaining to Turkey could contribute novel insights and perspectives to the existing body of literature.

This study examines the relationship between R&D expenditures and energy intensity using Turkey's NUTS-I 12 regions data from 2010 to 2021. In addition to energy intensity and R&D expenditures, commonly used control variables in the literature such as industrialization, economic growth, and population are included. Two econometric techniques, Panel FMOLS and DOLS, are employed to ensure the robustness of the results. The methodology and findings are presented and discussed in Section 3 following this introduction. Section 2 reviews relevant literature, while Section 4 provides conclusions and policy implications.

2. LITERATURE REVIEW

Recently, there has been considerable research interest in reducing energy intensity globally. The existing literature has extensively explored the factors influencing energy intensity. This section conducts a literature review focusing on the key determinants of energy intensity, with particular attention to research R&D. The review is organized into two main categories: Studies examining the relationship between R&D and energy intensity, and studies investigating the determinants of energy intensity.

2.1. Studies on R&D and Energy Intensity

Technological progress is generally seen as a driver factor in limiting energy intensity. In the endogenous growth literature, R&D is considered as a factor that accelerates technological activities and increases production efficiency and limiting energy intensity (Lin and Wang, 2014; Dong et al., 2018; Huang and Chen, 2020).

Most studies in the literature have predominantly focused on data from China, revealing significant evidence that energy intensity can be limited with R&D investments. For instance, Fisher-Vanden et al. (2004), based on their analysis, affirm that R&D has a notable effect in reducing energy intensity in China. Similarly, Zhu et al. (2021b) suggest that public energy R&D leads to a decrease in energy intensity across 18-member countries of the IEA. Huang and Yu (2016) argue that R&D investment serves as a potent tool for decreasing energy intensity across China's 27 regions. Such regional studies shed light on the literature, for example, Wang and Han (2017) assert a negative relationship between R&D and energy intensity in nationwide, eastern, and central samples. Additionally, (Huang et al., 2017; Huang et al., 2018; Dong et al., 2018; Chen et al., 2019a; and Huang et al., 2020) scrutinize China's 30 regions and consistently demonstrate that R&D plays a crucial and dominant role in reducing energy intensity.

The relationship between R&D and energy intensity is also commonly examined at the sectoral level. For example, Teng (2012) finds that R&D significantly contributes to limit energy intensity in 31 industrial sectors in China. According to Luan et al. (2020), R&D is an important way to reduce energy intensity in China's 34 industry sectors. Lin and Zhang (2013) investigate the factors influencing energy intensity in China's nonferrous metal industry, and accordingly R&D investment has a significant declining effect on energy intensity. Similar findings across various sectors are reported in (Lin and Wang, 2014; Lin and Xie, 2015; Shen and Lin, 2020; and Sahu et al., 2022). Conversely, studies that find an insignificant relationship between the two variables, such as Lin and Du (2017) who argue that R&D investment does not significantly affect energy intensity in China's metallurgy industry due to low R&D levels and limited impacts. In a similar way, Karimu et al. (2017) suggest that the relationship between R&D and energy intensity is not significant across 14 Swedish industrial sectors. Consequently, it is suggested that R&D activities require time to yield new and applicable technologies and processes, and not all R&D activities result in valuable outcomes.

2.2. Studies on Determinants of Energy Intensity

Recently, many studies on energy intensity and its determinants are investigated for different country groups. This section provides a review of studies examining the impact of industrialization, economic growth, and population, which are utilized as control variables to assess their influence on energy intensity. Studies examining other control variables added to the energy intensity function were also reviewed.

The nexus between energy intensity and industrialization has been a focal point in the literature. Sadorsky (2013) identifies incentive effect of industrialization on energy intensity for 76 developing countries. According to Aboagye and Nketiah-Amponsah (2016), industrialization tends to elevate energy intensity in 36 selected Sub-Saharan African countries. Similarly, Liu et al. (2022a) emphasize the similar effect of industrialization on energy intensity for the BRICS countries, while Rahman et al. (2023) reach the same conclusion for the 12 Newly Industrializing Countries (NICs). This relationship is also explored in China, where Lv et al. (2019) examine 224 cities and Guo et al. (2022) analyze 30 regions, both finding that industrialization promotes to an increase in energy intensity. Additionally, Pan et al. (2019c) put forward a direct positive impact of industrialization on energy intensity in the case of Bangladesh.

The nexus between energy intensity and economic growth is generally an object at issue in existing literature. Studies mostly suggest a negative association between the two variables. For instance, Sadorsky (2013) finds that income growth leads to a long-term reduction in energy intensity across 76 developing countries. Similarly, in the context of China's 30 regions, both Chen et al. (2022) and Zhang et al. (2022) assert that economic growth plays a significant role in decreasing energy intensity. Deichmann et al. (2019), analyzing data from 137 countries, argue that as the economies of poorer nations expand, a relatively rapid decline in energy intensity can be expected. Díaz et al. (2019) observe, based on their analysis of economic growth and energy intensity in 134 countries, that reductions in energy intensity are linked to higher GDP growth rates. Moreover, Mahmood and Ahmad (2018) report a significant decrease in energy intensity in response to economic growth, even after controlling for economic growth trends in European countries.

Studies examining the linkage between energy intensity and population generally find that population growth tends to increase energy intensity. For instance, Moshiri and Duah (2016) note a positive correlation between energy intensity and population size in Canadian provinces with larger populations. Oseni (2009) observes that population growth leads to increase on energy intensity in 16 OECD countries. Rafiq et al. (2016) argue that population growth contributes to higher energy intensity in increasingly urbanized emerging economies, while Mahmood and Ahmad (2018) find that the relationship between energy intensity and population is relatively insignificant in European countries. In the context of Chinese regions and cities, (Yang et al., 2016; Wu et al., 2018; and He et al., 2023) arrive at similar conclusions, suggesting that population size is an important factor driving up energy intensity. Similarly, Otsuka and Goto (2018), analyzing the issue at regional and sectoral levels in Japan, find that population growth leads to increases in energy intensity.

In addition to previously discussed variables like population and economic growth, other factors such as urbanization, financial development, foreign direct investment, trade openness, and renewable energy are also examined concerning their influence on energy intensity. There exists no consensus regarding the relationship between urbanization and energy intensity. While the majority of studies (Jones, 1989; Jones, 1991; Yan, 2015; Belloumi and Alshehry, 2016; Rafiq et al., 2016; Elliott et al., 2017; Chen and Zhou, 2021) suggest a positive impact of urbanization on energy intensity, alternative studies (Sadorsky, 2013; Bilgili et al., 2017; Lin and Zhu, 2021; Zhu et al., 2021a) argue that urbanization may have negative or mixed effects on energy intensity.

A similar debate surrounds the relationship between financial development and energy intensity. Some studies (Pan et al., 2019a; Pan et al., 2019b; Canh et al., 2020; Hussain et al., 2020) assert the stimulating impact of financial development on energy intensity, while others (Chen et al., 2019b; Adom et al., 2020; Ma et al., 2022; Uddin et al., 2022; Rahman et al., 2023) highlight its constraining effect. This discourse within the literature is similarly addressed concerning foreign direct investment (FDI) and energy intensity. While a few studies (Adom, 2015b; Kasimov et al., 2023) suggest that FDI tends to elevate energy intensity, numerous others (Ting et al., 2011; Elliott et al., 2013; Jiang et al., 2014; Bu et al., 2019; Petrović and Lobanov, 2022; Wang, 2022; Soto, 2024) propose the contrary view.

However, there is general agreement regarding the influence of trade openness and renewable energy on energy intensity. Trade openness is consistently identified as a significant factor exacerbating energy intensity (Adom and Kwakwa, 2014; Adom, 2015a; Rafiq et al., 2016; Pan et al., 2019c; Samargandi, 2019; Chen et al., 2022; Wang et al., 2023), while renewable energy is claimed to have a similar effect (Samargandi, 2019; Liu et al., 2022b; Yu et al., 2022; Ge et al., 2023; Gyamfi et al., 2023; Jiao et al., 2024).

In conclusion, prior research emphasizes the significance of these variables in mitigating energy intensity, albeit with considerable ambiguity in the literature. This study aims to explore the impacts of R&D and other specific variables within Turkey's NUTS-I panel, which has not been addressed previously. A conspicuous gap exists in the literature, as there is currently no investigation into the relationship between R&D and energy intensity tailored to Turkey. Thus, the primary objective of this study is to address this gap in the existing literature.

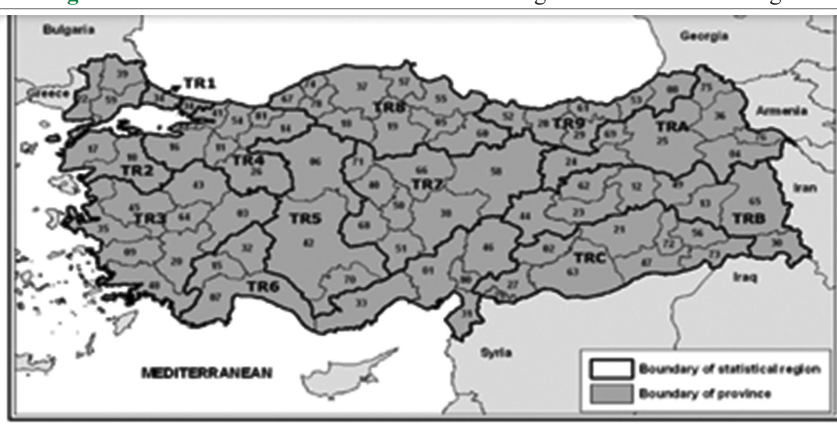
3. METHODOLOGY

3.1. Model Information and Construction

This study examines the influence of R&D expenditures on energy intensity, utilizing Turkey's Nomenclature of Territorial Units for Statistics 1 (NUTS-I) regional data spanning the years 2010-2021. The NUTS classification is a hierarchical system used to categorize the economic regions of the EU, with NUTS-I representing major socio-economic territories, NUTS-II covering basic territories for regional policy applications, and NUTS-III consisting of smaller regions for specific diagnoses (Eurostat). The classification of Turkish regions according to the NUTS-I and NUTS-III hierarchy is illustrated in Figure 2 below. In this study, NUTS-I regions were selected to maximize the dataset's size.

According to existing literature, R&D expenditures (Huang and Chen, 2020), industrialization (Sadorsky, 2013), economic growth (Mahmood and Ahmad, 2018) and population (Rafiq et al., 2016) influence the energy intensity. In this context, the relevant equation is defined in Equation (1):

Figure 2: NUTS-I and NUTS-III Hierarchical categorization of Turkish Regions



TR1	Name of province	TR5	Name of province	TR8	Name of province	TRB	Name of province
34	Istanbul	06	Ankara	67	Zonguldak	44	Malatya
TR2		42	Konya	78	Karabuk	23	Elazig
59	Tekirdag	70	Karaman	74	Bartin	12	Bingol
22	Edirne	TR6		37	Kastamonu	62	Tunceli
39	Kırklareli	07	Antalya	18	Cankiri	65	Van
10	Balikesir	32	Isparta	57	Sinop	49	Mus
17	Canakkale	15	Burdur	55	Samsun	13	Bitlis
TR3		01	Adana	60	Tokat	30	Hakkari
35	Izmir	33	Mersin	19	Corum	TRC	
09	Aydin	31	Hatay	05	Amasya	27	Gaziantep
20	Denizli	46	Kahramanmaras	TR9		02	Adiyaman
48	Mugla	80	Osmaniye	61	Trabzon	79	Kilis
45	Manisa	TR7		52	Ordu	63	Sanliurfa
03	Afyon	71	Kirikkale	28	Giresun	21	Diyarbakir
43	Kutahya	68	Aksaray	53	Rize	47	Mardin
64	Usak	51	Nigde	08	Artvin	72	Batman
TR4		50	Nevsehir	29	Gumushane	73	Sirnak
16	Bursa	40	Kirsehir	TRA		56	Siirt
26	Eskisehir	38	Kayseri	25	Erzurum		
11	Bilecik	58	Sivas	24	Erzincan		
41	Kocaeli	66	Yozgat	69	Bayburt		
54	Sakarya			04	Agri		
17	Duzce			36	Kars		
14	Bolu			76	Igdir		
77	Yalova			75	Ardahan		

Source: Özgür and Aydin (2012)

$$EI = f(RD, IND, EG, POP) \quad (1)$$

Where EI, RD, IND, EG and POP refer to energy intensity, R&D expenditures, industrialization, economic growth and population, respectively. IND, EG and POP are included as control variables to avoid data biasness. All variables are logarithmically transformed as it provide more consistent and reliable empirical results and solve problems related to the characteristics of the data set (Bhattacharya et al., 2016). Accordingly, the model used in this study is determined in Equation (2):

$$EI_{it} = \beta_1 RD_{it} + \beta 2\, IND_{it} + \beta_3 EG_{it} + \beta_4 POP_{it} + \varepsilon_{it} \quad (2)$$

Where i and t denote the region and year. Detailed information on the variables is presented in Table 1. Table 2 states the variables' descriptive statistics and pairwise correlation. The pairwise correlation analysis indicates that R&D expenditures and GDP exhibit a negative and statistically significant relationship with energy intensity, whereas industrialization shows a positive and statistically significant correlation with energy intensity. However, there is no observed correlation between population and energy intensity.

Energy intensity is typically determined by comparing the total energy consumption to GDP. However, this study focuses on electricity energy intensity due to the availability of regional data. Figure 3 illustrates that the average electricity energy intensity for the NUTS-I 12 regions was 0.157 in 2010, decreasing to 0.044 in 2021, representing a decline of 71%. On average, electricity energy intensity exhibited a downward trend across the NUTS-I 12 regions, including both maximum and minimum values.

Further analysis in Figure 4 reveals a declining pattern in electrical energy intensity across the NUTS-I 12 regions, with some regions experiencing interruptions, notably Central Anatolia (TR7), Northeastern Anatolia (TRA), and Southeastern Anatolia (TRC). Nonetheless, the overall trend indicates enhanced energy efficiency and decreased energy intensity across the regions during the specified timeframe.

3.2. Cross-sectional Dependence and Homogeneity Tests

Baltagi et al. (2016) emphasize the importance of cross-sectional dependence to detect social network interaction, geographical effects and uncertain mutual shocks. Pesaran (2021) propose the CD test statistic to test the cross-sectional dependence. The following empirical Equation (3) is estimated in computing the CD test:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right) \quad (3)$$

In this context, where the unit dimension is denoted by N, the time dimension by T, and the prediction of cross-sectional correlation between regions i and j is represented by ρ_{ij} (Bashir et al., 2021). The hypothesis stating the absence of cross-sectional dependence should be assessed against an alternative hypothesis, and if cross-sectional dependence is detected, the second-generation panel unit root test can be utilized (Ali et al., 2020). To examine the homogeneity of parameters, the delta tilde (Δ) and adjusted delta tilde (Δ_{adj}) tests proposed by Pesaran and Yamagata (2008) are utilized as an alternative to the Swamy (1970) slope homogeneity test. The delta tilde test is computed using Equation (4):

$$\Delta = \sqrt{N}\left(\frac{N^{-1}\breve{S}-k}{\sqrt{2k}}\right) \quad (4)$$

Where the unit dimension is denoted by N, the number of independent variables by k, and the Swamy statistic by Š (Bilgili et al., 2017). The Adjusted delta tilde test statistics can be expressed using Equation (5):

$$\Delta_{adj} = \sqrt{N}\left(\frac{N^{-1}\breve{S}-E(\tilde{z}_{it})}{\sqrt{var(\tilde{z}_{it})}}\right) \quad (5)$$

Where $E(\tilde{z}_{it}) = k$ and $var(\tilde{z}_{it}) = 2k(T - k - 1)/T+1$ (Bektur, 2023). In these tests, the null hypothesis assumes homogeneity, while

Table 1: Information on data variables

Variables	Code	Definitions	Data source
Energy intensity	EI	Total electricity consumption divided by GDP (MWh/2009, 1000 TL)	TurkStat
Research and development	RD	R&D expenditures (1000 TL)	
Industrialization	IND	Industry divided by GDP (2009, 1000 TL)	
Economic growth	EG	Gross Domestic Production (2009, 1000 TL)	
Population	POP	Number of Total Population in Regions	

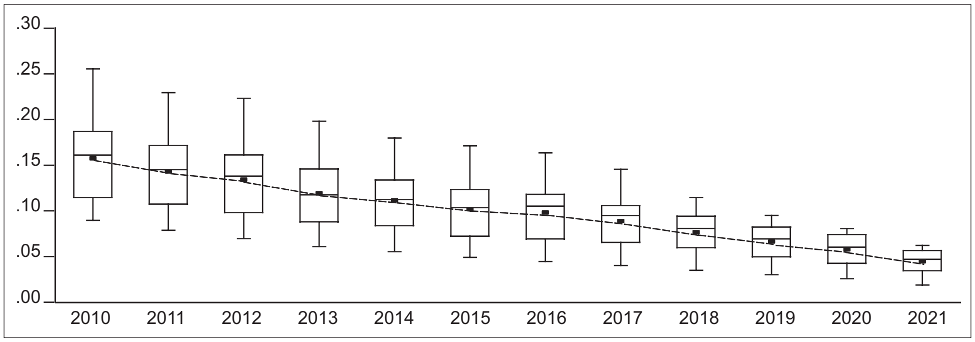
TurkStat Turkish Statistical Institute, TL: Turkish Lira

Table 2: Descriptive statistics and pairwise correlation

	Descriptive statistics						Pairwise Cor.
Variable	Obs.	Unit	Mean	Min	Max	Std. Dev.	EI
EI	144	%	0.1000	0.0188	0.2554	0.0468	1.0000
RD	144	Number	2516442	126068	2.73e+07	4277974	-0.4203*
IND	144	%	0.2629	0.1307	0.4827	0.0753	0.1969*
EG	144	Number	2.54e+08	1.97e+07	2.20e+09	3.08e+08	-0.4526*
POP	144	Number	6605961	2183098	1.58e+07	3680529	-0.1365

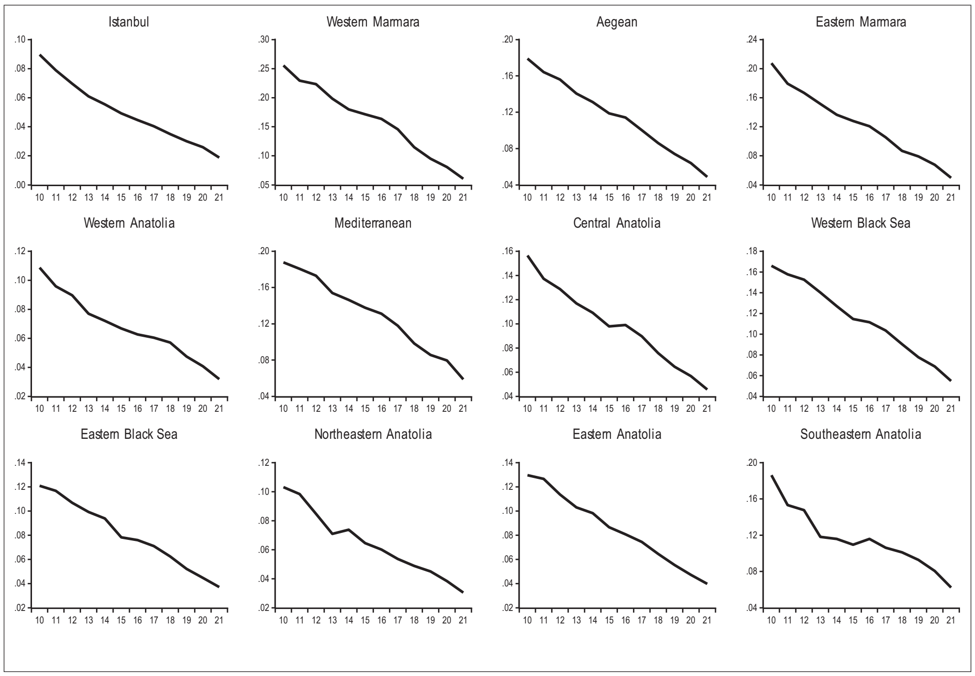
* imply the significance level at the 1%

Figure 3: NUTS-I regions's average electricity energy intensity in Turkey during 2010-2021



Electricity energy intensity values (MWh/2009, 1000 TL) on the vertical axis and the years on the horizontal axis

Figure 4: NUTS-I regions's electricity energy intensity trends in Turkey during 2010-2021



Electricity energy intensity values (MWh/2009, 1000 TL) on the vertical axis and the years on the horizontal axis

the alternative hypothesis posits heterogeneity. Subsequently, the second-generation LLC and IPS panel unit root tests are employed to ascertain the stationarity of variables. The Levin, Lin, and Chu (LLC) test assume uniform autoregressive parameters across all units, whereas the Im, Pesaran, and Shin (IPS) test suggests variability in autoregressive parameters for all units (Levin et al., 2002; Im et al., 2003).

The fact that all variables become stationary at the first difference level enables the use of cointegration tests to identify the presence of a long-term relationship.

3.3. Estimation Techniques

Pedroni (2004) and Westerlund (2005) techniques are choosen to designate the long-term equilibrium. Pedroni (2004) is explained by the following Equation (6):

$$Y_{it} = \alpha_i + \delta_i t + \beta_i X_{it} + u_{it} \quad (6)$$

Where member-specific fixed effects is represented by and deterministic trends by δ_i. Slope coefficient β_i is permitted to evaluate by units (Bashir et al., 2021). Therefore cointegration model may be heterogeneous across the panels (Pesaran, 2004). Westerlund (2005) tests cointegration by deciding whether each unit has its own error correction.

3.4. Panel FMOLS and DOLS Techniques

Pedroni (2001) proposed a more reliable and consistent test than single equation techniques that directly investigate the condition on the cointegrating vector needed to maintain a strong relationship (Ozturk et al., 2010). Moreover, these techniques allow to express the null hypothesis in a more natural way, testing the consistency of the strong linkage between variables across all regions. The fully modified ordinary least squares (FMOLS) technique addresses autocorrelation and endogeneity issues (Pedroni, 2001), whereas the dynamic ordinary least squares (DOLS) technique mitigates endogeneity, sampling bias, and serial correlation lag problems

(Stock and Watson, 1993). Moreover, the DOLS technique accommodates cross-sectional dependence (CD) and heterogeneity in the data. Both techniques exhibit improved performance in small samples and yield unbiased estimates (Danish et al., 2019; Shekhawat et al., 2021). FMOLS is described by Equation (7):

$$\beta_{FMOLS} = N^{-1/2}\sum_{i=1}^{N} t_{\beta_{FMOLS,i}} \quad (7)$$

And DOLS estimation is calculated in Equation (8):

$$\beta_{DOLS} = N^{-1/2}\sum_{i=1}^{N} t_{\beta_{DOLS,i}} \quad (8)$$

Where $\beta_{FMOLS,i}$ and $\beta_{DOLS,i}$ are the estimators FMOLS and DOLS calculated for the unit i^{th} (Danish et al., 2019).

4. ESTIMATION RESULTS

This section provides analyses on cross-sectional dependence, homogeneity, unit root, short-run cointegration, and long-run cointegration tests for the NUTS-I 12 regions. Table 3 proposes that each variable exhibits cross-sectional dependence and heterogeneity. Subsequently, this requires checking the unit root of the variables in the presence of cross-sectional dependence and heterogeneity.

Table 4 asserts the each variable stationary in the first difference according to LLC and IPS unit root tests. The null hypothesis of the unit root is stationary at I(0) is rejected at 1% significance level. Accordingly, the results allow testing cointegration for the variables at the I(1) level.

4.1. Panel Cointegration

Pedroni (2004) and Westerlund (2005) cointegration tests result are indicated in Table 5. The following results state the presence of cointegration between the variables at the 1% significance level. After identifying the short-run relationship, the next step is to apply the long-run FMOLS and DOLS techniques.

Table 6 reports the long-run empirical results from panel FMOLS and DOLS techniques. The coefficient for R&D expenditures is negative and significant in both techniques. The negative impact of R&D expenditures stand for R&D expenditures helps to restrain an effect on energy intensity across the Turkey's regions. Accordingly, incentivising the R&D by governments can help to bring energy intensity under control. Fisher-Vanden et al. (2004) state that R&D as a driving force reduces the energy intensity. Especially, implementing R&D in energy-saving technologies can support to recede production costs, circumvent green trade barriers and increase energy efficiency (Zheng et al., 2011).

Technological progress with R&D leads to the usage of substitute materials in reducing energy-intensive (Sadorsky, 2013). Moreover, the adoption of highly advanced technologies reduces energy intensity and produces more output simultaneously (Pan et al., 2019b). Consistent with our findings, previous regional-level studies have highlighted the comparable significance of R&D (Huang and Yu, 2016; Wang and Han, 2017; Huang et al., 2017; Huang et al., 2018; Dong et al., 2018; Chen et al., 2019a; Huang et al., 2020).

The negative and significant relationship between economic growth and energy intensity, observed in both techniques, indicates that economic growth leads to a decrease in energy intensity. Furthermore, economic growth can enhance energy intensity by promoting the utilization of efficient energy practices, which may involve the installation of more energy-efficient machinery (Oseni, 2009).

In the regions of Turkey, the adoption of more efficient methods, along with a rise in the service sector and a shift in GDP

Table 3: Tests for cross-sectional dependence and homogeneity

Variable	CD-test	P-value	Corr	Abs (corr)
Panel	27.55	0.000*	0.979	0.979
Slope homogeneity test Pesaran and Yamagata (2008)				
Delta tilde (Δ)	3.609	0.000*		
Adjusted delta tilde (Δadj)	5.104	0.000*		

* indicate 1% significance level

Table 4: Panel unit root analysis

Variable	Test	Level		First difference	
		Statistic	P-value	Statistic	P-value
EI	LLC	−1.0489	0.1471	−5.0997	0.0000*
	IPS	−0.0301	0.4880	−4.2397	0.0000*
RD	LLC	−1.1453	0.1261	−5.7367	0.0000*
	IPS	0.8481	0.8018	−4.7550	0.0000*
IND	LLC	−0.8427	0.1047	−10.2128	0.0000*
	IPS	1.8368	0.9669	−3.9699	0.0000*
EG	LLC	−1.6790	0.0466**	−6.0675	0.0000*
	IPS	0.1442	0.5573	−4.4763	0.0000*
POP	LLC	−1.6414	0.0504**	−5.0204	0.0000*
	IPS	1.6369	0.9492	−5.6034	0.0000*

*Indicate 1% significance level

Table 5: Pedroni and Westerlund cointegration tests

Cointegration tests		
Pedroni cointregration	Statistic	P-value
Modified Phillips-Perron t	3.9830	0.0000*
Phillips-Perron t	−6.6856	0.0000*
Augmented Dickey-Fuller t	−5.5110	0.0000*
Westerlund cointregration		
Variance ratio	3.5321	0.0002*

*Indicate 1% significance level

Table 6: FMOLS and DOLS regressions

Dependent Variable: EI	FMOLS		PDOLS	
	Coefficient	P-value	Coefficient	P-value
RD	−0.0814	0.001*	−0.1296	0.014**
IND	0.1804	0.000*	0.1749	0.100
EG	−0.8189	0.000*	−0.8399	0.000*
POP	0.2867	0.264	0.6939	0.079***
Constant	0.0101	0.000*	0.0136	0.014**
R^2	0.504	-	0.691	-
Bandwidth (neweywest)	49.05	-	62.16	-

*,**,***Indicate 1%, 5%, and 10% significance levels, respectively

composition towards less energy-intensive products, can contribute to a decrease in energy intensity.

The link between industrialization and energy intensity is positive and statistically significant only in FMOLS estimation. Sadorsky (2013) argues that industrialization leads to increased industrial activities, which typically require more energy compared to traditional agriculture or manufacturing processes. The industrial sector serves as the primary energy consumer in countries, and consequently, the production demands of industries are directly linked to energy consumption (Pan et al., 2019c). To reduce regional energy intensity in Turkey, it is important to curtail outdated, energy-intensive industrial activities while increasing the share of the service sector and other more efficient industrial sectors.

Lastly, the relationship between population and energy intensity is positive and statistically significant only in PDOLS estimation. A growing population can generate additional energy demand, resulting in environmental challenges.

Additionally, if infrastructure development fails to match population growth, rapidly growing regions may exhibit higher energy intensity due to increased reliance on outdated and inefficient infrastructure, as well as traffic congestion (Moshiri and Duah, 2016). The influence of population concentration in regions is significant, underscoring the importance of considering the population's impact when formulating national energy policies (Otsuka and Goto, 2018).

5. CONCLUSION AND POLICY IMPLICATIONS

Energy efficiency, also known as the "first fuel," can serve as a powerful tool in addressing a range of issues, including environmental concerns like climate change and global warming, as well as economic and geopolitical challenges such as energy supply security, trade deficits, and current account deficits. Unfortunately, Turkey, a dynamic country with significant growth potential, experiences these problems due to a lack of energy resources, despite being surrounded by energy-rich neighboring countries.

Over the past two decades, Turkey has introduced several policy schemes and tools, aiming to harness the potential benefits of energy efficiency. While these initiatives have achieved success in meeting short and medium-term goals, achieving long-term targets remains a considerable challenge, particularly given Turkey's position midway through its growth trajectory. Despite recent advancements in energy efficiency, Turkey remains one of the more energy-intensive economies compared to developed nations. Therefore, R&D investment has garnered attention in the literature due to its potential social, economic, and environmental benefits, including its positive impact on reducing energy intensity.

This study examines the nexus between R&D expenditure and energy intensity using Turkey's NUTS-I regional data from 2010 to 2021. Control variables such as industrialization, economic growth, and population, commonly utilized in relevant literature, are incorporated. The datasets are analyzed using two different methodologies: Panel FMOLS and DOLS techniques, to ensure the robustness of the results.

Both estimation results indicate that R&D expenditure significantly and negatively affects energy intensity, implying that an increase in R&D expenditures may lead to a decrease in energy intensity. Additionally, while industrialization may increase energy intensity according to the FMOLS technique findings, both FMOLS and DOLS results suggest that economic growth can decrease energy intensity. However, population growth is found to potentially increase energy intensity according to the DOLS technique.

These findings hold significant and meaningful implications for Turkey. While industrialization appears to have an increasing impact on energy intensity, overall economic growth is found to reduce energy intensity. This suggests that although industrial sectors in Turkey are highly energy-intensive, the agriculture and service sectors are relatively less energy-intensive, thus lowering the average energy intensity of the Turkish economy. Turkey is a major international player in some energy-intensive traditional industrial sectors, such as cement, iron, steel, and construction, which face intense competition and offer relatively low value added. Therefore, the current energy-intensive structure of industrialization in Turkey may exacerbate energy intensity. However, prioritizing R&D investments in Turkish industry, as suggested by the econometric findings, could potentially reduce energy intensity in the Turkish industry and possibly transform its energy-intensive structure. Furthermore, R&D investments could foster growth in other sectors with higher value-added and lower energy intensity, offering the dual benefit of enhancing energy efficiency and promoting economic growth simultaneously.

In Turkey and other nations, current subsidies and supports primarily target bolstering the export activities of established large corporations to meet their specific requirements. However, within the current Turkish industrial landscape, these incentives predominantly benefit energy-intensive enterprises like iron and steel, cement, and construction industries, hindering efforts to decrease overall energy consumption. Instead of perpetuating this paradigm, there is a need for a deliberate shift towards identifying sectors with lower energy intensity and greater economic value. It is recommended to allocate customized R&D support and incentives to these sectors. This strategic realignment has the potential to stimulate increased economic growth, promote value-added production, and simultaneously reduce energy intensity. Consequently, it could significantly improve energy supply security, address trade imbalances, and mitigate environmental vulnerabilities.

To illustrate, Turkey's notable presence in the automotive industry underscores the potential benefits of investing in research and development (R&D) within this sector. The recent surge in electric vehicle (EV) adoption has revolutionized both the energy and transportation sectors. Turkey, equipped with a well-defined R&D incentive framework tailored to this sector, stands to contribute significantly to reducing energy consumption and enhancing growth potential, exemplified by the recent advancements in Turkish electric vehicle production, such as TOGG. Another instance pertains to the insulation and retrofit sector aimed at bolstering the energy efficiency of buildings. Given that a substantial portion of energy usage emanates from buildings, particularly for space heating purposes, targeted support for R&D endeavors focused on developing new materials and methodologies for insulation holds promise. Lastly, directing R&D support towards the renewable energy sector, given the dominance of major players like China, could offer numerous advantages for Turkey, particularly in areas such as solar panel manufacturing.

REFERENCES

Aboagye, S., Nketiah-Amponsah, E. (2016), The implication of economic growth, industrialization and urbanization on energy intensity in Sub-Saharan Africa. Journal of Applied Economics and Business Research, 6(4), 297-311.

Adom, P.K. (2015a), Asymmetric impacts of the determinants of energy intensity in Nigeria. Energy Economics, 49, 570-580.

Adom, P.K. (2015b), Determinants of energy intensity in South Africa: Testing for structural effects in parameters. Energy, 89, 334-346.

Adom, P.K., Appiah, M.O., Agradi, M.P. (2020), Does financial development lower energy intensity? Frontiers in Energy, 14, 620-634.

Adom, P.K., Kwakwa, P.A. (2014), Effects of changing trade structure and technical characteristics of the manufacturing sector on energy intensity in Ghana. Renewable and Sustainable Energy Reviews, 35, 475-483.

Ali, S., Yusop, Z., Kaliappan, S.R., Chin, L. (2020), Dynamic common correlated effects of trade openness, FDI, and institutional performance on environmental quality: Evidence from OIC countries. Environmental Science and Pollution Research, 27(11), 11671-11682.

Baltagi, B.H., Kao, C., Peng, B. (2016), Testing cross-sectional correlation in large panel data models with serial correlation. Econometrics, 4(4), 1-24.

Bashir, M.F., Benjiang, M.A., Shahbaz, M., Shahzad, U., Vo, X.V. (2021), Unveiling the heterogeneous impacts of environmental taxes on energy consumption and energy intensity: Empirical evidence from OECD countries. Energy, 226, 1-15.

Bektur, Ç. (2023), The role of economic freedom in achieving the environmental sustainability for the highest economic freedom countries: Testing the environmental Kuznets curve hypothesis. Environmental Science and Pollution Research, 1-10.

Belloumi, M., Alshehry, A.S. (2016), The impact of urbanization on energy intensity in Saudi Arabia. Sustainability, 8(4), 1-17.

Bhattacharya, M., Paramati, S.R., Ozturk, I., Bhattacharya, S. (2016), The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. Applied Energy, 162, 733-741.

Bilgili, F., Koçak, E., Bulut, Ü., Kuloğlu, A. (2017), The impact of urbanization on energy intensity: Panel data evidence considering cross-sectional dependence and heterogeneity. Energy, 133, 242-256.

Bu, M., Li, S., Jiang, L. (2019), Foreign direct investment and energy intensity in China: Firm-level evidence. Energy Economics, 80, 366-376.

Canh, N.P., Thanh, S.D., Nasir, M.A. (2020), Nexus between financial development & energy intensity: Two sides of a coin? Journal of Environmental Management, 270, 1-14.

Chen, C., Huang, J., Chang, H., Lei, H. (2019a), The effects of indigenous R&D activities on China's energy intensity: A regional perspective. Science of the Total Environment, 689, 1066-1078.

Chen, S., Zhang, H., Wang, S. (2022), Trade openness, economic growth, and energy intensity in China. Technological Forecasting and Social Change, 179, 121608.

Chen, Z., Huang, W., Zheng, X. (2019b), The decline in energy intensity: Does financial development matter? Energy Policy, 134, 1-9.

Chen, Z., Zhou, M. (2021), Urbanization and energy intensity: Evidence from the institutional threshold effect. Environmental Science and Pollution Research, 28, 11142-11157.

Danish, Zhang, J., Wang, B., Latif, Z. (2019), Towards cross-regional sustainable development: The nexus between information and communication technology, energy consumption, and CO_2 emissions. Sustainable Development, 27(5), 990-1000.

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, 1-11.

Díaz, A., Marrero, G.A., Puch, L.A., Rodríguez, J. (2019), Economic growth, energy intensity and the energy mix. Energy Economics, 81, 1056-1077.

Dong, K., Sun, R., Hochman, G., Li, H. (2018), Energy intensity and energy conservation potential in China: A regional comparison perspective. Energy, 155, 782-795.

Elliott, R.J., Sun, P., Chen, S. (2013), Energy intensity and foreign direct investment: A Chinese city-level study. Energy Economics, 40, 484-494.

Elliott, R.J., Sun, P., Zhu, T. (2017), The direct and indirect effect of urbanization on energy intensity: A province-level study for China. Energy, 123, 677-692.

Ervural, B.C., Ervural, B., Zaim, S. (2016), Energy efficiency evaluation of provinces in Turkey using data envelopment analysis. Procedia-Social and Behavioral Sciences, 235, 139-148.

Eurostat. NUTS, Nomenclature of Territorial Units for Statistics. Available from: https://ec.europa.eu/eurostat/web/nuts [Last accessed on 2024 Mar 06].

Fisher-Vanden, K., Jefferson, G.H., Liu, H., Tao, Q. (2004), What is driving China's decline in energy intensity? Resource and Energy Economics, 26(1), 77-97.

Gallersdörfer, U., Klaaßen, L., Stoll, C. (2020), Energy consumption of cryptocurrencies beyond bitcoin. Joule, 4(9), 1843-1846.

Ge, T., Ge, Y., Lin, S., Ji, J. (2023), Do energy intensity reduction targets promote renewable energy development? Evidence from partially linear functional-coefficient models. Energy Strategy Reviews, 49, 1-10.

Guo, Q., Ding, C., Guo, T., Liu, S. (2022), Dynamic effects and regional differences of industrialization and urbanization on China's energy intensity under the background of "dual carbon". Sustainability, 14(16), 1-20.

Gyamfi, B.A., Kwakwa, P.A., Adebayo, T.S. (2023), Energy intensity among European Union countries: The role of renewable energy, income and trade. International Journal of Energy Sector Management, 17(4), 801-819.

He, X., Yu, Y., Jiang, S. (2023), City centrality, population density and energy efficiency. Energy Economics, 117, 1-12.

Huang, J., Chen, X. (2020), Domestic R&D activities, technology absorption ability, and energy intensity in China. Energy Policy, 138, 1-11.

Huang, J., Du, D., Tao, Q. (2017), An analysis of technological factors and energy intensity in China. Energy Policy, 109, 1-9.

Huang, J., Hao, Y., Lei, H. (2018), Indigenous versus foreign innovation and energy intensity in China. Renewable and Sustainable Energy Reviews, 81, 1721-1729.

Huang, J., Lai, Y., Hu, H. (2020), The effect of technological factors and structural change on China's energy intensity: Evidence from dynamic panel models. China Economic Review, 64, 1-14.

Huang, J., Yu, S. (2016), Effects of investment on energy intensity:

Evidence from China. Chinese Journal of Population Resources and Environment, 14(3), 197-207.
Hussain, H.I., Slusarczyk, B., Kamarudin, F., Thaker, H.M.T., Szczepańska-Woszczyna, K. (2020), An investigation of an adaptive neuro-fuzzy inference system to predict the relationship among energy intensity, globalization, and financial development in major ASEAN economies. Energies, 13(4), 850.
Im, K.S., Pesaran, M.H., Shin, Y. (2003), Testing for unit roots in heterogeneous panels. Journal of Econometrics, 115(1), 53-74.
Jiang, L., Folmer, H., Ji, M. (2014), The drivers of energy intensity in China: A spatial panel data approach. China Economic Review, 31, 351-360.
Jiao, J., Song, J., Ding, T. (2024), The impact of synergistic development of renewable energy and digital economy on energy intensity: Evidence from 33 countries. Energy, 295, 1-19.
Jones, D.W. (1989), Urbanization and energy use in economic development. The Energy Journal, 10(4), 29-45.
Jones, D.W. (1991), How urbanization affects energy-use in developing countries. Energy Policy, 19(7), 621-630.
Karimu, A., Brännlund, R., Lundgren, T., Söderholm, P. (2017), Energy intensity and convergence in Swedish industry: A combined econometric and decomposition analysis. Energy Economics, 62, 347-356.
Kasimov, I., Wencong, L., Saydaliev, H.B. (2023), Unlocking the potential of foreign direct investment to reduce energy intensity. Environmental Science and Pollution Research, 30(30), 75382-75400.
Koçaslan, G. (2014), Türkiye'nin enerji verimliliği mevzuati, avrupa birliği'ndeki düzenlemeler ve uluslararasi-ulusal öneriler. Cumhuriyet Üniversitesi İktisadi ve İdari Bilimler Dergisi, 15(2), 117-133.
Krause, M.J., Tolaymat, T. (2018), Quantification of energy and carbon costs for mining cryptocurrencies. Nature Sustainability, 1(11), 711-718.
Levin, A., Lin, C.F., Chu, C.S.J. (2002), Unit root tests in panel data: Asymptotic and finite-sample properties. Journal of Econometrics, 108(1), 1-24.
Li, J., Li, N., Peng, J., Cui, H., Wu, Z. (2019), Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. Energy, 168, 160-168.
Lin, B., Du, Z. (2017), Promoting energy conservation in China's metallurgy industry. Energy Policy, 104, 285-294.
Lin, B., Wang, X. (2014), Promoting energy conservation in China's iron & steel sector. Energy, 73, 465-474.
Lin, B., Xie, X. (2015), Energy conservation potential in China's petroleum refining industry: Evidence and policy implications. Energy Conversion and Management, 91, 377-386.
Lin, B., Zhang, G. (2013), Estimates of electricity saving potential in Chinese nonferrous metals industry. Energy Policy, 60, 558-568.
Lin, B., Zhang, G. (2017), Energy efficiency of Chinese service sector and its regional differences. Journal of Cleaner Production, 168, 614-625.
Lin, B., Zhu, J. (2021), Impact of China's new-type urbanization on energy intensity: A city-level analysis. Energy Economics, 99, 1-11.
Liu, F., Zhang, X., Adebayo, T.S., Awosusi, A.A. (2022a), Asymmetric and moderating role of industrialisation and technological innovation on energy intensity: Evidence from BRICS economies. Renewable Energy, 198, 1364-1372.
Liu, J., Caporin, M., Zheng, Y., Yu, S. (2022b), The effect of renewable energy development on China's energy intensity: Evidence from partially linear functional-coefficient panel data analyses. Journal of Cleaner Production, 350, 1-14.
Luan, B., Huang, J., Zou, H., Huang, C. (2020), Determining the factors driving China's industrial energy intensity: Evidence from technological innovation sources and structural change. Science of the Total Environment, 737, 1-10.
Lv, Y., Chen, W., Cheng, J. (2019), Direct and indirect effects of urbanization on energy intensity in Chinese cities: A regional heterogeneity analysis. Sustainability, 11(11), 1-20.
Ma, Y., Zhao, Y., Jia, R., Wang, W., Zhang, B. (2022), Impact of financial development on the energy intensity of developing countries. Heliyon, 8(8), 1-16.
Mahmood, T., Ahmad, E. (2018), The relationship of energy intensity with economic growth: Evidence for European economies. Energy Strategy Reviews, 20, 90-98.
MENR, Ministry of Energy and Natural Resources, Energy Efficiency 2030 Strategy and II. National Energy Efficiency Action Plan (2024-2030). Available from: https://enerji.gov.tr//media/dizin/evced/tr/enerjiverimlili%c4%9fi/ulusalenerjiverimlili%c4%9fieylemplan%c4%b1/belgeler/2ulusalenerjiverimlili%c4%9fieylemplan%C4%B1.pdf [Last accessed on 2024 Apr 03].
MFA. Available from: https://www.mfa.gov.tr/turkeys-energy-strategy.en.mfa [Last accessed on 2024 Apr 28].
Moshiri, S., Duah, N. (2016), Changes in energy intensity in Canada. The Energy Journal, 37(4), 315-342.
OECD. Environment at a Glance 2015, OECD Indicators. Available from: https://www.oecd-ilibrary.org/docserver/9789264235199-en.pdf?expires=1714561382&id=id&accname=guest&checksum=A8FB593836F145E05A4109BFD35133CE [Last accessed on 2024 Apr 01].
Oseni, M.O. (2009), Analysis of energy intensity and its determinants in 16 OECD countries. The Journal of Energy and Development, 35(1/2), 101-140.
Otsuka, A., Goto, M. (2018), Regional determinants of energy intensity in Japan: The impact of population density. Asia-Pacific Journal of Regional Science, 2, 257-278.
Özgür, E.M., Aydin, O. (2012), Spatial patterns of marriage migration in Turkey. Marriage and Family Review, 48(5), 418-442.
Ozturk, I. Aslan, A., Kalyoncu, H. (2010), Energy consumption and economic growth relationship: Evidence from panel data for low and middle income countries. Energy Policy, 38(8), 4422-4428.
Pan, X., Uddin, M.K., Han, C., Pan, X. (2019b), Dynamics of financial development, trade openness, technological innovation and energy intensity: Evidence from Bangladesh. Energy, 171, 456-464.
Pan, X., Uddin, M.K., Saima, U., Guo, S., Guo, R. (2019a), Regime switching effect of financial development on energy intensity: Evidence from Markov-switching vector error correction model. Energy Policy, 135, 1-9.
Pan, X., Uddin, M.K., Saima, U., Jiao, Z., Han, C. (2019c), How do industrialization and trade openness influence energy intensity? Evidence from a path model in case of Bangladesh. Energy Policy, 133, 1-9.
Pedroni, P. (2001), Fully modified OLS for heterogeneous cointegrated panels. In: Nonstationary Panels, Panel Cointegration, and Dynamic Panels. United Kingdom: Emerald Group Publishing Limited. p93-130.
Pedroni, P. (2004), Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric Theory, 20(3), 597-625.
Pesaran, M.H. (2021), General diagnostic tests for cross-sectional dependence in panels. Empirical Economics, 60(1), 13-50.
Pesaran, M.H., Yamagata, T. (2008), Testing slope homogeneity in large panels. Journal of Econometrics, 142(1), 50-93.
Petrović, P., Lobanov, M.M. (2022), Energy intensity and foreign direct investment nexus: Advanced panel data analysis. Applied Energy, 311, 1-10.
Rafiq, S., Salim, R., Nielsen, I. (2016), Urbanization, openness, emissions, and energy intensity: A study of increasingly urbanized emerging economies. Energy Economics, 56, 20-28.

Rahman, M.M., Khan, Z., Khan, S., Tariq, M. (2023), How is energy intensity affected by industrialisation, trade openness and financial development? A dynamic analysis for the panel of newly industrialized countries. Energy Strategy Reviews, 49, 1-11.

Sadorsky, P. (2013), Do urbanization and industrialization affect energy intensity in developing countries? Energy Economics, 37, 52-59.

Sahu, S.K., Bagchi, P., Kumar, A., Tan, K.H. (2022), Technology, price instruments and energy intensity: A study of firms in the manufacturing sector of the Indian economy. Annals of Operations Research, 313, 319-339.

Samargandi, N. (2019), Energy intensity and its determinants in OPEC countries. Energy, 186, 1-10.

Shekhawat, K.K., Yadav, A.K., Sanu, M.S., Kumar, P. (2022), Key drivers of consumption-based carbon emissions: Empirical evidence from SAARC countries. Environmental Science and Pollution Research, 29(16), 23206-23224.

Shen, X., Lin, B. (2020), Policy incentives, R&D investment, and the energy intensity of China's manufacturing sector. Journal of Cleaner Production, 255, 1-10.

Somoye, O.A. (2024), Assessing the link between energy intensity, renewable energy, economic growth, and carbon dioxide emissions: Evidence from Turkey. Environmental Quality Management, 34, 1-12.

Soto, G.H. (2024), The role of outward foreign direct investment as a filter for high energy intensity economies in the European Union. Applied Energy, 361, 1-11.

Stock, J.H., Watson, M.W. (1993), A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica: Journal of the Econometric Society, 61, 783-820.

Swamy, P.A.V.B. (1970), Efficient inference in a random coefficient regression model. Econometrica, 38, 311-323.

Teng, Y. (2012), Indigenous R&D, technology imports and energy consumption intensity: Evidence from industrial sectors in China. Energy Procedia, 16, 2019-2026.

The International Energy Agency (IEA). Available from: https://www.iea.org/energy-system/energy-efficiency-and-demand/energy-efficiency 29.04.2024

Ting, Y.U.E., Yin, L.R., Ying, Z.Y. (2011), Analysis of the FDI effect on energy consumption intensity in Jiangsu province. Energy Procedia, 5, 100-104.

Uddin, M.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, 1-12.

Wang, D., Han, B. (2017), Effects of indigenous R&D and foreign spillover on energy intensity in China. Journal of Renewable and Sustainable Energy, 9(3), 035901.

Wang, L. (2022), Role of FDI and energy intensity in mitigating the environmental pollution in the Chinese steel industry: Does technological innovation makes a difference? Environmental Science and Pollution Research, 29(19), 28127-28138.

Wang, R., Laila, U., Nazir, R., Hao, X. (2023), Unleashing the influence of industrialization and trade openness on renewable energy intensity using path model analysis: A roadmap towards sustainable development. Renewable Energy, 202, 280-288.

Westerlund, J. (2005), New simple tests for panel cointegration. Econometric Reviews, 24(3), 297-316.

World Bank. Available from: https://databank.worldbank.org/source/world-development-indicators [Last accessed on 2024 Apr 03].

World Bank2. Available from: https://data.worldbank.org/indicator/En.atm.ghgt.kt.ce?end=2020&locations=tr&start=1990&view=chart [Last accessed on 2024 Apr 27].

Wu, J., Wu, Y., Cheong, T.S., Yu, Y. (2018), Distribution dynamics of energy intensity in Chinese cities. Applied Energy, 211, 875-889.

Yan, H. (2015), Provincial energy intensity in China: The role of urbanization. Energy Policy, 86, 635-650.

Yang, G., Li, W., Wang, J., Zhang, D. (2016), A comparative study on the influential factors of China's provincial energy intensity. Energy Policy, 88, 74-85.

Yu, S., Liu, J., Hu, X., Tian, P. (2022), Does development of renewable energy reduce energy intensity? Evidence from 82 countries. Technological Forecasting and Social Change, 174, 1-13.

Zhang, H., Chen, S., Wang, S. (2022), Impact of economic growth and labor productivity dispersion on energy intensity in China. Energy, 242, 1-10.

Zheng, Y., Qi, J., Chen, X. (2011), The effect of increasing exports on industrial energy intensity in China. Energy Policy, 39(5), 2688-2698.

Zhu, J., Huang, Z., Li, Z., Albitar, K. (2021a), The impact of urbanization on energy intensity-an empirical study on OECD countries. Green Finance, 3(4), 508-526.

Zhu, Z., Liao, H., Liu, L. (2021b), The role of public energy R&D in energy conservation and transition: Experiences from IEA countries. Renewable and Sustainable Energy Reviews, 143, 1-14.