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EXPLORING THE IMPACT OF ECONOMIC GROWTH AND ENERGY CONSUMPTION ON ENVIRONMENTAL POLLUTION IN THE TR90 REGION: AN INSIGHT FROM THE MMQR APPROACH

TR90 Bölgesinde Ekonomik Büyüme ve Enerji Tüketiminin Çevre Kirliliğine Etkisinin Araştırılması: MMQR Yaklaşımından Bir Bakış

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Keywords: Sustainable Development, Environmental Pollution, Energy Consumption, Environmental Kuznets Curve, TR90 Region.

JEL Codes: O44, Q00, O13.

Abstract

Governments primarily face the basic conundrums that arise from balancing environmental concerns with economic growth. In this content, since most research focuses on the cases of countries or groups of countries, a significant gap exists in how economic growth and energy consumption influence environmental pollution processes at the regional or provincial level. This study is the first to investigate the effects of energy consumption and economic growth on environmental pollution in the TR90 region of Türkiye (including the provinces of Artvin, Giresun, Gümüşhane, Ordu, Rize, and Trabzon) for the years 2007–2021 in the framework of the Environmental Kuznets Curve (EKC) hypothesis. This study utilizes the innovative Method of Moments Quantile Regression (MMQR) approach to investigate these effects. The MMQR results support the EKC hypothesis, which contends that environmental pollution rises in the early stages of economic growth but then declines as growth levels reach a turning point. Furthermore, the results demonstrate that increasing energy consumption exacerbates environmental pollution in the TR90 region.

Anahtar Kelimeler: Sürdürülebilir Kalkınma, Çevre Kirliliği, Enerji Tüketimi, Çevresel Kuznets Eğrisi, TR90 Bölgesi.

JEL Kodları: O44, Q00, O13.

Öz

Hükümetler öncelikli olarak çevresel kaygıları ekonomik büyümeyle dengelemekten kaynaklanan temel açmazlarla karşı karşıyadır. Bu konuda çoğu araştırma ülke veya ülke grupları vakalarına odaklandığından, ekonomik büyümenin ve enerji tüketiminin bölgesel veya il düzeyinde çevre kirliliği süreçlerini nasıl etkilediği konusunda önemli bir bilimsel boşluk vardır. Bu çalışma, 2007-2021 yılları arasında Türkiye'nin TR90 bölgesinde (Artvin, Giresun, Gümüşhane, Ordu, Rize ve Trabzon illerini kapsayan) enerji tüketimi ve ekonomik büyümenin çevre kirliliği üzerindeki etkilerini Çevresel Kuznets Eğrisi (EKC) hipotezi çerçevesinde araştıran ilk çalışmadır. Bu çalışma, bu minvalde yeni Momentler Kantil Regresyonu Yöntemi (MMQR) yaklaşımı kullanmaktadır. MMQR sonuçları, çevre kirliliğinin ekonomik büyümenin erken evrelerinde arttığını ancak büyüme seviyeleri bir dönüm noktasına ulaştığında azalmaya başladığını ileri süren EKC hipotezini desteklemektedir. Ayrıca, sonuçlar artan enerji tüketiminin TR90 bölgesinde çevre kirliliğini olumsuz şekilde etkilediğini göstermektedir.

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1. Introduction

In the 21st century, the impacts of human activities on nature have reached a point where they pose serious threats to all living organisms (IPCC, 2021). However, even today, some believe that global environmental concerns are excessively exaggerated and that some of them such as the climate change crisis are utilized as an instrument to impose political, economic, and social changes for the benefit of certain groups. They also argue that data on changes to the global environmental regime are limited to worst-case scientific possibilities. However, as the Global Resource Outlook report's succinct and unambiguous message makes clear, "It should have already been understood that the issue is not whether a transformation towards sustainable resource consumption and production on a global scale is necessary, but how this can be achieved urgently." (UNEP, 2024). Further, the main point to comprehend is that the main forces straining biocapacity are population growth and, particularly, economic growth (EGr). To determine the extent of this pressure, changes in global environmental and economic conditions throughout the last 50 years are enough to be observed (see UN Environment, 2019). The scientific evidence on the severity and urgency of global environmental issues also necessitates rapid actions towards building a sustainable future. Therefore, the pressures created by EGr and population increases require the immediate implementation of sustainable resource management and environmental protection strategies.

EGr, energy consumption (ECon), and population increase are considered key catalysts in the transformation of the global environmental regime (UN Environment, 2019: 6). For instance, as stated in the United Nations reports, the world population, which was 2.5 billion in 1950, reached 8 billion in 2022 and is estimated to be 8.5 billion in 2030, 9.7 billion in 2050, and approximately 10.4 billion in 2100 (UNDESA–PD, 2022). Similarly, EGr is a fundamental dilemma that leads to higher levels of use of natural resources and damage to ecological systems. Indeed, considering global EGr, the fact that GDP per capita worldwide increased by 2.4 times from 1970 to 2024, surpassing $11,600, which indicates that significant inequalities continue at the regional and national level (see UNEP, 2024: 22). In this context, household consumption is responsible for approximately 60% of the overall environmental effect, and about 30% of total carbon dioxide (CO_2) emissions are attributed to the production of globally traded goods (UNEP, 2010). All these findings reveal the extent of the adverse changes that EGr has caused in the global environmental regime. At this point, governments and other actors are trying to overcome the "paradoxical" situation between EGr and ecological constraints with a "sustainability" prescription.

Similarly, among the factors influencing environmental pollution (EPol) and EGr, patterns of energy production and consumption are particularly noteworthy. Energy is the cornerstone of EGr, and electricity consumption emerges as a critical infrastructure element for socioeconomic development (Ghosh, 2002: 125). Electricity, which is a secondary and most commonly used energy source, is seen as a solution for countries to cope with economic and social challenges and is regarded as a necessity for development (Wolde–Rufael, 2006: 1106). With industrialization processes, electricity has become a fundamental factor in production through technological advancements. EGr has caused production to change over time in favor of the service industry, and therefore, electrical energy has become a necessary consumption good for both direct and indirect production as well as for maintaining service quality.

Regarding all of these matters, in 2015, the 193 UN member countries unanimously accepted the 2030 Agenda for Sustainable Development, which mandates collaborative efforts to protect existing natural resources, prevent EPol, and secure that the needs of both current and future generations are met (UN, 2015). The "United Nations Sustainable Development Goals" (SDGs) include a set of objectives that are closely linked to both EGr and environmental sustainability, such as 1. (no poverty), 2. (no hunger), 7. (affordable and clean energy), 11. (sustainable cities and communities), 12. (Responsible consumption and production), and 13. (climate action). In this context, governments, businesses, civil society organizations, individuals, and all other stakeholders must cooperate to deal with poverty and hunger effectively, promote economic development, reduce inequalities, address EPol and climate change issues, and ensure peace and justice in all their initiatives (Sánchez Gassen et al., 2018: 8). At the same time, as with this regulation and other global initiatives formally adopted by national governments, an adaptation or localization process is necessary for the implementation (see Valencia et al., 2019). So, SDGs can be successfully achieved through the capacity of regional and local actors to adapt the established targets to their specific conditions (Bardal et al., 2021).

The main motivation of this research can be explained as follows: When examining the relationship between variables in the studies, it is assumed that conclusions valid at the national level will also be valid for each region. However, the assumption that "what is good for the whole must be good for each part" often may not hold true (Žiković et al., 2020: 1). Each region has unique geographical and climatic conditions, agricultural characteristics, natural resources, and economic structures. Therefore, the effect of ECon and EGr on EPol may vary from region to region, depending on local dynamics. For instance, one region may be rich in energy resources, while another may be scarce. For this reason, rather than generalizing, it is more realistic to consider the specific dynamics of each region in the environment–economy–energy relationship. However, previous studies generally examined the effect of economic factors and ECon on EPol through policies, strategies, and plans at the national level or for specific country groups. However, research on actions at the regional and local scales is still insufficiently developed, whereas how global goals will be implemented at the local level is an important question. In this context, in Türkiye, over the past 20 years, it has been observed that EGr and ECon have increased along with EPol, and regional disparities have become more significant and visible. Therefore, investigating the connection between EGr, ECon, and EPol in the TR90 region is also expected to help determine appropriate environmental and energy policies, as well as economic strategies specific to this region.

Türkiye is divided into 12 sub-regions at Level–1, 26 sub-regions at Level–2, and 81 provinces at Level–3 based on the Turkish Statistical Institute's (TURKSTAT) Nomenclature of Territorial Units for Statistics (NUTS) classification system. TR90 region is one of 26 Level-2 subregions and involves the provinces of Trabzon, Ordu, Giresun, Rize, Artvin, and Gümüşhane. In the Socio-Economic Development Ranking Surveys (SEGE) (2017), the socio-economic development ranking of the TR90 region provinces is as follows: Trabzon is ranked 26th with an index value of 0.389, Rize is ranked 36th with an index value of 0.174, Artvin is ranked 49th with an index value of –0.235, Giresun is ranked 53rd with an index value of –0.323, Ordu is ranked 60th with an index value of –0.486, and Gümüşhane is ranked 64th with an index value of –0.623 (Ministry of Industry and Technology, 2017).

In light of the Environmental Kuznets Curve (EKC) hypothesis, the study investigates the effect of ECon and EGr on EPol in the TR90 region. In this regard, the reasons for choosing the

TR90 region as the sample for the present study can be explained as follows: The TR90 region, due to its ecological richness with diverse flora and fauna, has recently seen a rapid increase in investments, particularly in hydroelectric power plants (HPPs). The region is rich in ecological diversity and abundant water resources. This region, known for its rivers and streams, contributes to regional and national clean energy supply through the construction of dams and HPPs. However, Planning and inspection deficiencies have caused significant challenges for environmental sustainability in the region. Among the primary causes of environmental issues in rural regions are irregular building and conventional solid waste management. Another important concern in the region is the absence of adequate infrastructure facilities (DOKA, 2014; Yıldırım and Ayna, 2016). Furthermore, given the region's hydroelectric potential, the Eastern Black Sea Basin harnesses almost 20% of Turkey's energy potential (see Kankal and Akçay, 2019: 896). Nonetheless, the region garners attention for its ecological significance, including land composition, water resources, soil quality, and biodiversity of forests and flora, alongside the ecological issues arising from the proposed hydropower plant in the basin and increasing the local communities concerns (Atabey and Gürdoğan, 2015: 58–59). Moreover, the TR90 region possesses significant ecotourism potential owing to its diverse flora and fauna, topographical features, and cultural values (Kaya and Yıldırım, 2020). We must also consider the potential future ramifications of this circumstance. The region attracts attention due to changes in climatic factors such as temperature and precipitation. As the area with the highest annual precipitation rate in the country, it frequently experiences disasters like erosion and flooding (Yılmaz et al., 2021). All of these findings highlight how critical it is to implement the required measures for the medium– and long–term EGr of the TR90 region. Examining how EGr and energy use have affected EPol over the past 15 years is anticipated to yield important policy recommendations in this regard.

This study makes substantial theoretical and practical contributions to the literature. First, regarding the EKC, this study is the first to consider how EGr and ECon affect EPol in the TR90 region. Second, it was discovered that national or group of countries' assessments of the links between EGr, ECon, and EPol were made in general, whereas regional or provincial–level analyses are inadequate. Yet, regarding resource consumption, environmental effects, and economic structure, subnational regions may differ greatly from one another. For instance, some of the regional economies are heavily reliant on industry, whereas those of others are centered on services or agriculture in Türkiye. Third, this study adopts the novel Method of Moments Quantile Regression (MMQR) approach as a modern and robust method addressing issues of heteroscedasticity, endogeneity, and conditional distribution rather than traditional estimation methods. On the other hand, traditional test techniques may lead to untrustworthy and biased inferences.

The study's subsequent sections have the following structure: Section 2 reviews the literature in the context of the conceptual and theoretical effects of electricity consumption and EGr on environmental degradation. Section 3 presents the data and methodology, while Section 4 addresses the findings and discussions. Section 5 also presents the conclusion and policy recommendations.

2. Literature Review

The nexus between EGr, Econ, and EPol has become a critical area of research due to the growing of environmental concerns and the commitment to SDGs. These linkages are explored from a variety of theoretical and empirical perspectives, characteristically under the following headings.

2.1. Theoretical and Conceptual Basis of the Study

The political and administrative initiatives or strategies taken to promote quicker EGr are the main reason for changes in the global environmental regime in the 21st century. In fact, there has been a notable and concerning increase in population and EGr in recent years, which has raised demand for global resources and intensified environmental strain (Nasrollahi et al., 2020: 1105). The rapid continuation of EGr on a global scale has exacerbated environmental problems. Thus, it is crucial to coordinate EGr with environmental quality, as this is a pressing strategic problem (Rao and Yan, 2020: 39442).

Previous studies addressing the relationship between ECon and environmental degradation address energy use as a factor that increases EPol. Indeed, the level of ECon is almost considered an indicator of the level of EPol (see Ibekilo et al., 2023; Sumaira and Siddique, 2023). Furthermore, previous studies generally agree that EPol originates from human activities (Fatima et al., 2021). Activities such as energy production and consumption are particularly prominent examples of anthropogenic effects on nature. While energy is considered the fundamental driving force of societal and economic development, the types of energy used, especially in terms of carbon emissions, can be primary determinants of environmental degradation (Armeanu et al., 2019). In this regard, governments are diligently implementing a range of innovative initiatives and practices to lessen environmental damage such as using renewable energy sources (Xiong and Xu, 2021).

Alongside steady economic growth, the global energy supply and consumption have lately increased. Rising ECon has also been influenced by emerging economies' attempts at EGr. The world's ECon has been rising noticeably due to rapid population growth, urbanization, and increased economic activity. On the other hand, this increase, particularly with the widespread use of non–renewable energy sources such as coal, natural gas, and oil, has had serious negative impacts on the environment. Even though economic and social development are desired by governments to be sustainable, a large-scale ecological disaster threat has emerged in many countries (Zhang et al., 2017: 365). However, to prevent any negative impacts on industrial production due to the scarcity of electricity, it is very important for policymakers to ensure the security of electricity supply and to plan sufficient production capacity to meet industrial electricity demand, which necessitates more investment in the energy sector (Shiu and Lam, 2004: 47). Energy efficiency may boost economic gains and the economy's overall competitiveness in addition to new investments. In general, the pattern of EGr is depended on a nation's energy structure, which in a sense might represent the degree of economic development of that nation. Thus, without a shift in the energy system, there will be no incentive for sustained transformation in the social and economic spheres, and the foundation for development would no longer be viable. In sum, today's world, constrained by resources and the environment, is engaged in a tough struggle to transition from high–carbon to low–carbon ECon (Zhang et al., 2017: 354).

In light of these elucidations, the theoretical framework of this study is based on the EKC hypothesis developed by Grossman and Krueger (1991, 1995). This hypothesis follows a similar analogy to the Kuznets curve, which assumes an inverted U–shaped relationship between income and income inequality, as proposed by Kuznets (1955) (Andreoni and Levinson, 2001: 269; Dinda, 2004: 431; Sulemana et al., 2017: 134). In this regard, studies examining the environmental effects of energy use and EGr at global and national levels generally rely on the EKC hypothesis. It assumes an inverted U–shaped relationship between income and EPol. A theoretical overview of this study is also seen in Figure 1, which denotes the relationship between EPol, ECon, and EGr.

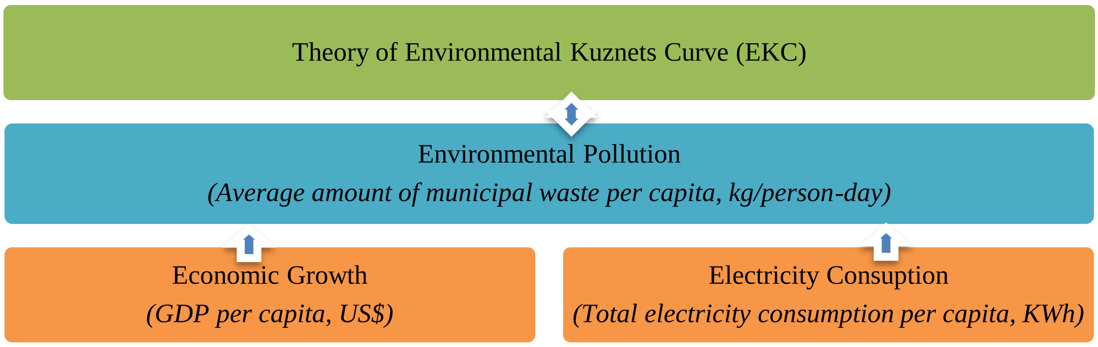

Figure 1. Theoretical Summary

The relationship between environmental deterioration, economic conditions, and economic growth is a significant study focus for several scholars and policymakers. So, analyzing the environment–economy–energy nexus accurately is essential for the research fields of sustainable development pathway.

2.2. Economic Growth and Environmental Pollution Nexus

Studies examining the impact of EGr on environmental quality were carried out using various country samples, datasets, and analytical methods. A simple search using the keywords "EGr" and "EPol" in the Web of Science database reveals that 210 academic publications have addressed this topic. Notably, 75% of these studies were published between 2014 and 2024, indicating a growing concern over the environmental constraints associated with economic developments in recent years. 80% of those of which are research articles, with 57% categorized under "environmental science or environmental studies" and 27% under "economics". This trend reflects increasing global and academic concerns about the risks and threats posed by changes in environmental systems, especially those related to climate change.

Previous research has analyzed and evaluated various groups of countries such as New Industrialized Countries (NICs), Group of Seven (G7), BRICS (Brazil, Russia, India, China, South Africa), and OECD (The Organization for Economic Co-operation and Development). Considering that these divisions are usually predicated on political and economic standards, it is ignored that there are notable variations across the nations that comprise each group. Due to the varying methods of defining and reporting environmental variables, concerns about the reliability and validity of the findings have emerged, particularly in developing countries where data collection and methodological issues can lead to inconsistent results. However, this study uses the term "region" to refer to sub–regions that share similar geographic and economic conditions in a single country, rather than a generalized definition referring to groups of countries. This approach allows for the analysis of comparable data collected under similar political and administrative structures, which is crucial for getting reliable and consistently results.

Studies inquiring at how EGr affects ecological constraints frequently employ a variety of datasets and methodologies in their empirical evaluations at the national level. In this regard, Nasir et al. (2019) reported a direct correlation between EGr, financial development, foreign direct investment (FDI), and environmental degradation among ASEAN–5 countries (Association of Southeast Asian Nations). Similarly, Bakirtas and Cetin (2017) used a panel vector autoregressive (PVAR) model to investigate the validity of the EKC hypothesis in MIKTA countries (Mexico, Indonesia, South Korea, Türkiye, and Australia) between the years 1982 and 2011. Their empirical results, however, did not support the EKC hypothesis. Ali et al. (2023) also addressed the connection between EGr, globalization, renewable energy, and non–renewable energy in South American countries between 1995 and 2020. Given their results, while EGr increases EPol, using renewable energy reduces EPol in both the short and long run. Ali et al. (2020) also studied the relationship between environmental degradation, EGr, and energy innovation in 33 European countries for the period between 1996 and 2017. These authors also reported a significant inverse U–shaped relationship between GDP and environmental degradation, supporting the EKC hypothesis. Alike Yilanci and Ozgur (2019) analyzed the relationship between income and pollution in G7 countries (Canada, France, Germany, Italy, Japan, the UK, and the USA) using data for the years between 1970 and 2014. Their results also support the EKC hypothesis in Japan and the USA but do not indicate a U–shaped relationship between ecological footprint and GDP in other countries. Sulemana et al. (2017) tested the validity of the EKC hypothesis for CO_2 and particulate matter (PM10) emissions in African countries and high–income OECD countries as well. The results supported the EKC hypothesis for both CO_2 and PM10 emissions in these regions.

On the other hand, national–level studies generally align with the results reported by country–group studies regarding the impacts of EGr on environmental quality. For example, Cai et al. (2020) explored the relationship between China's water pollution discharges, including wastewater, chemical oxygen demand, and ammonia nitrogen, and GDP per capita from the aspect of the EKC hypothesis. Their results demonstrate that the EKC types may be distinguished from one another based on characteristics or distinct tipping points. However, it is noticed that studies on the relationship between EPol and EGr often yield different results depending on the type of analysis and model used. For instance, Giovanis (2013) aimed to provide empirical evidence of a correlation between air pollution and income by analyzing social data from the "British Household Panel Survey" covering the years 1991 to 2009. While the results achieved from the Arellano–Bond GMM and logit models, which include fixed effects and all types of family income, strongly support the EKC hypothesis for the air pollutants, the fixed effects results of the research do not support the EKC hypothesis.

Studies exploring the associations between environmental degradation and EGr at the regional and urban levels have also increased recently, much like those conducted on a global and national scale. For instance, Song et al. (2008) examined the relationship between EPol and EGr by making use of city-scale data from China between 1985 and 2005. The results revealed that all three pollutants, contaminated water, gas, and solid waste, exhibited an inverted U–shape with respect to per capita income levels. Similarly, Liu et al. (2019) investigated the impact of EGr and foreign direct investments on CO_2 emissions using provincial-scale data from China spanning from 1996 to 2015, integrating these factors into a unified framework. The results indicate a curvilinear relationship characterized by an inverted U–shape between EGr and CO_2 emissions. Moreover, Zhang et al. (2020) analyzed the association between EGr, energy usage, and the spatial distribution of environmental pollutants in 31 cities in China from 2008 to 2018 within the context of the EKC hypothesis. Their results similarly indicated a spatial relationship in China between industrial pollution, energy structure, and EGr, and that this relationship is distributed over several agglomeration regions. Stern and Zha (2016) also scrutinized the effects of income, convergence, and time–related factors on recent fluctuations in PM2.5 and PM10 particulate pollution levels in 50 Chinese cities. Their results reveal that EGr, convergence, and time collectively contribute to reducing pollution.

All in all, it is observed that at the regional level, the effects of EGr on EPol are determined by the complex interactions of various factors which may vary depending on the characteristics of the regional economic structure, industrial activities, and environmental regulations. The initial hypothesis of the research has been formulated based on these evaluations as follows:

H1: For the case of the TR90, the EKC hypothesis is valid.

2.3. Energy Consumption and Environmental Pollution Nexus

Many studies empirically examined the relationship between ECon and EPol. Particularly, the study carried out by Bekun et al. (2019) analyzed the relationship between consumption of renewable and non–renewable energy sources, carbon emissions, and EGr over the period from 1996 to 2014 for a specific group of EU–16 countries. Their study clearly demonstrated that using renewable energy helps lower CO_2 emissions, while EGr and using non–renewable energy increase carbon emissions. Analyzing the usage of renewable and non–renewable energy sources, Anwar et al. (2021) also scrutinized the relationship between ECon, income, and the environment in ASEAN countries. Their findings clearly support the EKC hypothesis, which states that rising non–renewable ECon causes rising CO_2 emissions, whereas rising renewable ECon causes falling CO_2 emissions in ASEAN countries. In addition, as for the political recommendations of the studies, Sarkodie and Adams (2018) emphasized the need for fossil fuel-rich countries to diversify their energy portfolios by incorporating renewable energy sources to reduce sensitivity to price fluctuations, promote environmental sustainability, and improve air quality. Similarly, Destek and Aslan (2020) highlighted the effectiveness of hydroelectric, biomass, and wind ECon in reducing carbon emissions in G7 countries by focusing on different types of renewable energy sources.

Governments and all other public and non–public actors aim to improve environmental quality by utilizing regulatory environmental policy tools. For instance, Yuan (2024) investigated the restrictive influence of EPol taxes on the level of energy usage, suggesting that technological advancements, optimization of industrial structure, and tax collection further enhance the restrictive impact of EPol taxes on ECon. Similarly, improvements in environmental regulations lead to positive outcomes in clean ECon and a long–term reduction in environmental degradation, such as CO_2 emissions (Zhang et al., 2022). Furthermore, Jiatong et al. (2023) used new econometric techniques to scrutinize the impacts of geopolitical risk, economic uncertainty, and renewable source usage on the ecological footprint from 2000 to 2021, finding that only renewable energy use positively affects environmental quality.

Research on how ECon affects environmental deterioration has produced some notable results, particularly for developing and low–income countries. For instance, increased usage of fossil fuels like coal in these countries' ECon portfolios results in increased industrial carbon emissions (Chen et al., 2024). Some studies similarly showed that an increase in the proportional use of renewable energy in total energy sources expectedly results in a reduction in EPol (see Wang, 2019; Azam et al., 2021; Wang et al., 2022). Likely, Assi et al. (2021) examined the effects of five primary factors on renewable ECon in ASEAN+3 (Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam + China, Japan, and Korea) economies between 1998 and 2018. These factors included financial development, EPol, innovation, economic freedom, and GDP per capita. They found that while environmental degradation and economic freedom have a negative relationship with the use of renewable energy, financial progress has no discernible impact on renewable ECon. Additionally, Nawaz et al. (2021) addressed the role of ECon in environmental degradation for South Asian economies as part of their political advice, arguing that these countries should concentrate on luring clean foreign investment and that the production of renewable energy is essential to halting climate change. So, based on the latest literature, the following research hypothesis was developed.

H2: Energy consumption increases environmental pollution and hampers the environmental quality in the case of the TR90 region.

There are still many remarkable gaps in the literature regarding the analysis of the relationships between environmental degradation, ECon, and EGr, in particular at the regional level. Within this scope, it is observed that the results vary depending on factors such as the period analyzed, the selected country or regional groups, and the preferred methodology. Furthermore, studies that commonly use traditional tests often tend to produce weak or biased results. To the best of our knowledge, no empirical study examining how ECon and EGr relate to EPol in any region of Türkiye by making use of the EKC hypothesis could be found. This study aims to bridge the gaps in the literature on regional studies by analyzing the relationships between EGr, ECon, and EPol in the TR90 region of Türkiye between 2007 and 2021 within the context of the EKC hypothesis, which is the inaugural research on that point.

3. Data and Methodology

3.1. Data and Model Specification

This study examines the effects of energy consumption and economic growth on environmental pollution in the TR90 region from 2007 to 2021 in the framework of the EKC. In this direct, environmental pollution (POL) is represented by the average amount of municipal waste per capita. The gross domestic product per capita represents economic growth (GDP), and the total electricity consumption per capita indicates energy consumption (ELC). GDPSQ refers to the square of GDP. Data for POL, GDP, GDPSQ, and ELC are obtained from the Turkish Statistical Institute (TURKSTAT, 2024). The logarithmic transformations of all the variables are computed in the analysis. Table 1 presents the definitions and essential information about the variables.

Table 1. Descriptions of the Variables

Variable	Acronym	Definition (Units)	Source
Environmental pollution	POL	Average amount of municipal waste per capita (kg/person-day)	TURKSTAT
Economic growth	GDP	GDP per capita (constant 2009 US$)	TURKSTAT
Squared economic growth	GDPSQ	The square of GDP per capita (constant 2009 US$)	TURKSTAT
Energy consumption	ELC	Total electricity consumption per capita (KWh)	TURKSTAT

Following the study carried out by Lean and Smyth (2010), the basic model of this study is specified as:

$$POL = f\ (GDP, GDPSQ, ELC) \quad (1)$$

Econometrically,

$$POL_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDPSQ_{it} + \beta_3 ELC_{it} + \varepsilon_{it} \quad (2)$$

where, *i* and *t* refer to cross sections and time, respectively, while ε_{it} denotes error terms. Since economic activities trigger environmental damage, the efforts made to achieve a faster EGr cause an increase in EPol (Beckerman, 1995). Therefore, the GDP coefficient is expected to be positive $\left(\beta_1 = \frac{\partial POL}{\partial GDP} > 0\right)$. On the other hand, GDPSQ coefficient is expected to be negative $\left(\beta_2 = \frac{\partial POL}{\partial GDPSQ} < 0\right)$. In this context, the fact that β_1 coefficient is positive and significant, and β_2 coefficient was negative and significant confirms the validity of the EKC hypothesis (Dinda, 2004; Panayotou, 1997). In accordance with the aforementioned research, ECon is essential for sustainable development and environmental quality. However, fossil fuels account for approximately 82% of global ECon (British Petroleum, 2024). Therefore, electricity consumption relies mainly on fossil fuels on a global scale. This ECon pattern causes EPol to increase and threatens environmental sustainability (He et al., 2021). In this context, the ELC coefficient is expected to be positive $\left(\beta_3 = \frac{\partial POL}{\partial ELC} > 0\right)$.

3.2. Econometric Methodology

In panel data analysis, firstly, cross-sectional dependence (CSD) and slope heterogeneity (SH) should be addressed because, in panel data samples, the likelihood of countries/regions being significantly correlated or dependent might be high due to common shocks, unknown factors, and geographical interaction. For this purpose, ignoring CSD and SH tests could lead to biased and unreliable results, and it may cause ineffective and invalid inferences regarding the subject being analyzed. For these reasons, in the study, the CSD is tested using Pesaran's (2015) CD test, and the presence of SH is verified using Pesaran and Yamagata's (2008) Delta ($\tilde{\Delta}$ test) and Adjusted Delta ($\tilde{\Delta}_{adj.}$) tests.

Traditional unit root tests, such as IPS, LLC, and Hadri unit root tests, fail to address the issues of CSD and SH. Therefore, this study uses a second–generation unit root test capable of considering CSD and SH issues to determine the stationarity of the variables. In this context, this study utilizes the cross-sectionally augmented IPS (CIPS) unit root test proposed by Pesaran

(2007). The CIPS test also regards CSD and SH and performs robustly under both T (time dimension)>N (cross–unit) and N>T conditions. The CIPS test statistic assumes the null hypothesis (H_0) that the panel has a unit root, whereas the alternative hypothesis (H_A) states that the panel is stationary.

After checking the stationarity of the variables, the study conducted two different cointegration tests, considering CSD and SH. The first was the Durbin–Hausman (DH) cointegration test advanced by Westerlund (2008), and the second was the Lagrange multiplier (LM) cointegration test proposed by Westerlund and Edgerton (2007). As second–generation cointegration tests, both DH and LM address CSD issues using the bootstrap approach. The DH cointegration test provides the DH_{group} test statistic, which permits panel heterogeneity, and the DH_{panel} test statistic, which aligns with panel homogeneity. Similarly, the LM cointegration test provides a bootstrap test statistic that allows for CSD and an asymptotic test statistic that applies in the absence of CSD. The LM test examines the null hypothesis (H_0) that cointegration exists for all units against the alternative hypothesis (H_A) that cointegration exists for some units. In the DH test, DH_{group}, and DH_{panel} test statistics test the null hypothesis of no cointegration in all units, while DH_{group} test statistic's alternative hypothesis suggests cointegration for some units, and DH_{panel} test statistic's alternative hypothesis suggests cointegration for all units.

Traditional linear estimation methods such as OLS, FMOLS, and DOLS provide limited information as they focus on average relationships. In contrast, the quantile regression models developed by Koenker and Bassett (1978), and Koenker (2004) yield different estimation results for each quantile rather than average–based estimates. Among quantile-based approaches, the MMQR with fixed–effect method, newly established by Machado and Silva (2019), comes to the forefront as a modern and robust alternative. This study uses the MMQR approach to estimate long-run coefficients. MMQR offers advantages including addressing endogeneity issues, producing robust estimates, allowing for individual effects, and considering outliers. Moreover, MMQR is capable of providing efficient and consistent estimates in explaining nonlinear and asymmetric relationships. This approach accounts for covariance effects in conditional heterogeneity and measures multiple parameters at different quantiles.

We preferred the MMQR approach in this study due to its advantages and some of its main features. As a non–parametric method, MMQR effectively captures the impact of economic growth and energy consumption on distribution tails of environmental pollution at the regional level while also alleviating the issue of misspecification bias. Moreover, previous environment–growth–energy studies have widely used this approach, which is particularly suited to the significant macroeconomic and socio-economic structural changes in recent years and provide a more detailed insight than traditional methods.

In the study, the MMQR equation is formed as follows:

$$Q_Y(\tau/X_{it}) = \left(\alpha_i + \delta_i q(\tau)\right) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \tag{3}$$

In Equation (3), X_{it} is the vector of GDP, GDPSQ, and ELC, which are explanatory variables, while $Q_Y(\tau/X_{it})$ show the quantile distribution (Y_{it}) of the dependent variable of POL.

This study's small sample size necessitates the use of alternative and reliable methods, in addition to MMQR, to enhance the reliability of the analysis results. For this reason, the study employs fixed effects with Driscoll–Kraay standard errors (FE–DKSE) and the Augmented Mean Group (AMG) estimators to gauge the robustness of the MMQR results. FE–DKSE is a very reliable method against heteroskedasticity, autocorrelation, and CSD, while AMG is a powerful technique against SH and CSD.

4. Findings and Discussion

This study first estimated descriptive statistics that provide a priori information about the variables in order to scrutinize the association between EPol and explanatory variables for the TR90 region. So, Table 2 displays the results of descriptive statistics. GDP (GDPSQ) data has the highest maximum value, whereas data with the lowest minimum value is POL. The POL data also has the lowest standard deviation value. Chen–Shapiro (1995) normality test statistics demonstrate that all variables, except for POL, do have a non–normal distribution. The non–normal distribution of the data renders the utilization of quantile-based techniques a superior and more efficacious methodology for the analysis process.

Table 2. Results of Descriptive Statistics

Variables	Mean	Median	Max.	Min.	Std. Dev.	Chen–Shapiro Normality Test
POL	–0.068	–0.072	0.418	–0.462	0.175	–0.073
GDP	8.893	8.886	9.351	8.450	0.223	0.993**
GDPSQ	79.152	78.964	87.458	71.405	3.976	0.994**
ELC	7.403	7.419	7.882	6.480	0.284	0.995**

Note: ** represents statistical significance at 5% level.

Subsequently, in the study, slope coefficients were scrutinized by means of Delta ($\tilde{\Delta}$ test) and Adjusted Delta ($\tilde{\Delta}_{adj.}$) tests. Table 3 shows the results of the slope heterogeneity test. Given the $\tilde{\Delta}$ and $\tilde{\Delta}_{adj.}$ test results, H_0 assuming the homogeneity of the panel was rejected. Accordingly, it is observed that the panel was determined to be heterogeneous.

Table 3. Results of the Heterogeneity Test

Test	Test Statistic	p–value
$\tilde{\Delta}$ test	3.977***	0.000
$\tilde{\Delta}_{adj.}$ test	4.871***	0.000

Note: *** represents statistical significance at the 1% level.

CSD and unit root test results are presented in Table 4. Considering the CSD test outcomes, the H_0 assuming no–CSD is rejected, and it suggests the presence of CSD in all variables. This finding reveals that disturbances or shocks occurring in any city in the TR90 region spread and affect other cities. The study used the CIPS unit root test to ascertain the degrees of integration of the variables. Considering the CIPS test results, the H_0 assuming that the panel has a unit root at the level cannot be rejected, which suggests that all variables have a unit root at the level. However, it was found that all variables become stationary at their first difference.

Table 4. Results of Cross-Section Dependence Test and Unit Root Test

Variables	CD Test	p–value	CIPS Test	
			Level	1st difference
POL	2.263**	0.024	–1.609	–2.263*
GDP	14.999***	0.000	–1.387	–3.584***
GDPSQ	14.997***	0.000	–1.393	–3.579***
ELC	14.995***	0.000	–1.897	–3.625***

Note: ***, **, and * represent statistical significance at 1%, 5%, and 10% levels, respectively.

After determining the integration degrees of the variables, the study analyzed whether the variables are cointegrated in the long–run. The cointegration relationship was estimated using LM and DH tests. The bootstrap p-value should be considered for the LM test when there is the existence of CSD, whereas the DH_{group} test statistic should be regarded for the DH test when there is the presence of slope heterogeneity. Table 5 presents the results of the panel cointegration test. Given the bootstrap p-value in the LM test, the H_0 indicating the validity of cointegration cannot be rejected for the constant and, constant and trend models, indicating the presence of cointegration. Similarly, considering the DH_{group} test statistic, the H_0 assuming no cointegration is rejected, proving the existence of cointegration for the constant and, constant and trend models. Thus, both cointegration tests confirm the long–run cointegration relationship among variables.

Table 5. Results of The Cointegration Test

LM Test	Test Statistic	Asymptotic p–value	Bootstrap p–value
Constant	4.061	0.000	0.962
Constant and trend	13.317	0.000	0.539
DH Test	**DH_{group} Test Statistic**		**DH_{panel} Test Statistic**
Constant	–2.006**		–1.660**
Constant and trend	–1.822**		–1.413*

Note: ** and * represent statistical significance at 5% and 10% levels, respectively.

In order to check the robustness of the MMQR results, this study utilizes various estimators such as AMG and FE–DKSE. Table 6 displays the AMG and FE–DKSE estimation findings. AMG and FE–DKSE results indicate that GDP has a positive and significant impact on EPol, while the GDPSQ coefficient is negative and significant. These findings confirm the validity of the EKC hypothesis. However, the AMG result shows that the impact of ELC on EPol is insignificant, whereas the FE–DKSE result demonstrates that the impact of the ELC on EPol is positive and significant.

Table 6. Results of AMG and FE–DKSE Estimation

	AMG			FE–DKSE		
Variables	Coeff.	Std. Err.	t–stats.	Coeff.	Std. Err.	t–stats.
GDP	7.579*	3.915	1.94	18.895***	6.150	3.07
GDPSQ	–0.430*	0.221	–1.94	–1.065***	0.344	–3.09
ELC	0.222	0.171	1.29	0.166***	0.052	3.16

Note: *** and * represent statistical significance at 1% and 10% levels, respectively.

The coefficient estimation was conducted after confirming the long–run cointegration relationship. Table 7 reports the MMQR results. Based on the MMQR findings, the GDP coefficient was found to be positive and significant for the POL across all quantiles, but the GDPSQ coefficient is negative and significant at all quantiles. These findings verify the validity of the EKC hypothesis in the TR90 region. Additionally, for all quantiles, the findings show that the ELC coefficient is positive and significant for EPol, which shows that the increase in ECon in the TR90 region increases EPol.

Table 7. Results of Quantile Regression Estimation (MMQR)

Variables	Location	Scale	Quantiles			
			$Q_{(0.25)}$	$Q_{(0.50)}$	$Q_{(0.75)}$	$Q_{(0.90)}$
GDP	5.956	7.246*	18.441**	18.977***	19.563***	19.993**
GDPSQ	–0.335	–0.407*	–1.038**	–1.070***	–1.106***	–1.132**
ELC	0.137*	0.123***	0.158*	0.167***	0.178**	0.185*

Note: ***, **, and * represent statistical significance at 1%, 5%, and 10% levels, respectively.

The findings achieved in the present study support the validity of the EKC hypothesis, which states that EPol increases initially, but following a turning point, starts to decrease with increasing in income in the TR90 region. These results align with those of sub–national research including Song et al. (2008), Andreoni and Levinson (2001), and Dinda (2004). More specifically, an inverted U–shaped relationship is observed between per capita income and EPol for the six cities in the study, while environmental pressure rises to a particular income level and then falls. Thus, the first hypothesis of the study, "*H_1: For the case of the TR90, the EKC hypothesis is valid,"* is accepted.

However, the results achieved in the present study do not align with those reported by Bakirtas and Cetin (2017) and Kijima et al. (2010), who did not support the validity of the EKC. This discrepancy highlights that evaluations of the EKC may yield different results when conducted at a subnational scale. The literature is anticipated to be greatly enhanced by regional and local–scale evaluations for various nations and country groupings such as this study. In this sense, comparing TR90 with Level-1 and Level-2 sub-regions offers valuable insights.

Moreover, this study clearly reveals a positive link between electricity use and EPol at the regional level. It indicates that increased ECon in the TR90 region contributes to higher EPol. The findings align with regional–scale studies confirming that higher ECon levels lead to increased EPol. These results are also consistent with the general findings of Sumaira and Siddique (2023) and Ibekilo et al. (2023). In other words, ECon in the TR90 region is identified as a factor that exacerbates EPol. Therefore, the second hypothesis of the study, "*H_2: Energy consumption increases the amount of municipal waste and hampers the environment in the case of the TR90 region,*" is acknowledged. However, recent development initiatives in the region are expected to yield positive outcomes for maintaining and improving environmental quality in the future. These results are consistent with the studies carried out by Armeanu et al. (2019) and Anwar et al. (2021). Nonetheless, due to limited urban data, it was not possible to evaluate the types of energy used in this study. Furthermore, examining factors influencing ECon levels on a subnational scale could contribute to regional sustainable development.

5. Conclusion and Policy Recommendations

This study addressed the effects of EGr and ECon on EPol in Türkiye's TR90 region for the period 2007–2021 within the framework of the EKC hypothesis using the MMQR approach. The results achieved in this study clearly confirmed the EKC hypothesis for the TR90 region. That is, improvements in environmental quality can be achieved in the later stages of EGr once income exceeds a certain threshold, even though EPol increases during the early stages of economic development when income is low. Moreover, the results of the study indicate that ECon also exacerbates EPol at the regional level. From this aspect, this study suggests that in the context of regional development, Türkiye should pursue policies tailored to the varying levels of regional development rather than applying a uniform policy across all regions, as this can lead to erroneous outcomes. Therefore, specific policy implementations based on the level of regional development should be enacted in Türkiye.

So, it would not be an accurate approach to restrict economic activities to control EPol in the TR90 region. Instead, focus should be placed on measures that enhance environmental quality, including improving production efficiency, promoting sustainable production and consumption patterns, afforestation activities, encouraging energy innovation, and adopting other eco–friendly production. Moreover, active policies to increase environmental awareness and implement stricter environmental regulations should be put into effect to achieve environmental sustainability in the region.

This study also highlighted that the increase in ECon in the TR90 region has led to EPol issues. Consequently, the growing energy demand poses threats to human health, nature, and biodiversity. Ensuring a sustainable environment in the TR90 region requires the adoption of clean energy sources, eco–friendly technology, and production methods. In this context, particularly in the region, the promotion of a variety of renewable energy sources such as hydropower plants, solar, and wind energy can play an important role in achieving a sustainable future. Thus, the consumption of renewable energy in this region will help mitigate environmental adversities and ensure energy security to the extent that it reduces dependency on fossil fuels. It underscores the necessity of policymakers developing region-specific policies regarding energy R&D and energy substitution to reduce EPol in the region.

However, the study has some restrictions. First, the study period is restricted to the years 2007–2021, owing to data limitations. Therefore, the small sample size of the study highlights the importance of caution in generalizing the results of the analysis. Second, this study only investigates the effects of EGr and ECon on EPol in the TR90 region, excluding other regions of Türkiye. Third, due to data limitations, no distinction could be made between renewable and non–renewable energy usage. As economic and ecological disparities between regions in Türkiye become increasingly apparent, it would be important to study the spatial–temporal characteristics of the growth–energy–pollution relationships more comprehensively. Finally, future studies could explore the effects of various factors such as EGr, ECon, education, exports, technology, and population on EPol for different regions of Türkiye. Despite the existing data and methodological limitations, this study can be considered a pioneering step in understanding the linkages between regional environment, energy, and economy. In this context, the study might inspire future research that can be supported by expanded datasets and comprehensive regional comparative analyses.

Declaration of Research and Publication Ethics
This study, which does not require ethics committee approval and/or legal/specific permission, complies with the research and publication ethics.

Researcher's Contribution Rate Statement
The authors declare that they have contributed equally to the article.

Declaration of Researcher's Conflict of Interest
There is no potential conflicts of interest in this study.

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