SEEFOR SOUTH-EAST EUROPEAN FORESTRY
OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.25-14

An Econometric Perspective on the Effects of Renewable Energy Production and Carbon Emission on Forest Areas: The Case of Türkiye

Mehmet Akif Peçe[1], Mesut Kayaer[2], Ramazan Arslan[1], Ali Konak[3,*]

(1) University of Bartin, Faculty of Economics and Administrative Sciences, Department of Economics, Agdaci Village Road, TR-74110, Bartin, Türkiye; **(2)** University of Bartin, Faculty of Economics and Administrative Sciences, Department of Political Science and Public Administration, Agdaci Village Road, TR-74110, Bartin, Türkiye; **(3)** University of Karabuk, Faculty of Economics and Administrative Sciences, Department of Economics, Kılavuzlar Mahallesi 413, TR-78100 Karabuk, Türkiye

*** Correspondence:** e-mail: alikonak@karabuk.edu.tr

Citation: Peçe MA, Kayaer M, Arslan R, Konak A, 2025. An Econometric Perspective on the Effects of Renewable Energy Production and Carbon Emission on Forest Areas: The Case of Türkiye. *South-east Eur for* 16(2): 179-193. https://doi.org/10.15177/seefor.25-14.
Received: 22 Nov 2024; **Revised:** 13 Jun 2025; **Accepted:** 23 Jun 2025; **Published online:** 17 Nov 2025

ABSTRACT

This study analyses the impacts of carbon emissions and renewable energy production on forest areas in Türkiye. Fossil fuel usage has negative effects on forest ecosystems. Empirical analyses reveal that carbon emissions negatively impact forest resources (H1 hypothesis), while renewable energy production positively affects them (H2 hypothesis). Carbon emissions contribute to environmental threats like climate change and forest fires, leading to deforestation. In contrast, renewable energy sources play a crucial role in reducing carbon emissions and preserving forests. Particularly, wind, solar, geothermal, and biomass energy sources not only ensure energy security but also mitigate environmental damage. However, environmental impacts must be carefully considered during the planning of renewable energy projects, as large land usage for solar and wind power plants may cause short-term negative effects. Under Türkiye's Climate Change Mitigation Strategy and Action Plan (2024-2030), renewable energy investments are critical for forest preservation and environmental sustainability. This study provides valuable insights into the development of sustainable energy policies.

Keywords: carbon emissions; renewable energy; forest areas; environmental sustainability; energy policy

INTRODUCTION

It is now evident that fossil-based energy production processes lead to global warming and climate change. The effects of these negative developments on biodiversity, forest fires and water resources have reached serious dimensions. In order to prevent these processes that put pressure on the ecological balance, the transition to renewable energy is of great importance. In particular, the assumption that carbon emissions negatively affect forest areas, as suggested in hypothesis H1, is one of the main examination points of this study. The negative impact of carbon emissions in the atmosphere causes the intensification of the problems of climate change, resources, and the destruction of forests.

On the other hand, the fact that renewable energy sources have the potential to protect forest ecosystems is increasingly supported in the literature. The H2 hypothesis tested in the study is based on the proposition that renewable energy generation has a positive effect on forest areas. Renewable energy investments both reduce carbon emissions and contribute to the protection of forest areas. In this context, the aim of the study is to understand how sustainable energy policies contribute to environmental and economic sustainability.

In the short term, especially for developing countries, there is an inverse relationship between economic growth and environmental sustainability. The reason for this can be said to be that renewable energy systems installation processes may increase carbon emissions as a result of the negative impact on forest areas (Yıldırım and Akın 2023). In the long run, renewable energy and forest presence have negative effects on carbon emissions directly and indirectly. This shows that the main reasons underlying the reduction of emissions are related to the presence of renewable energy and forest areas. When the proposition is evaluated from the reverse, renewable energy production and consumption processes positively affect the presence of forests due to their contribution to the reduction of carbon emissions (Waheed et al. 2018, Özbek and Oğul 2023).

Another undesirable short-term consequence is the damage to forest areas, biodiversity and ecosystems during and after the construction of renewable energy plants. Examples of this situation include the need for large forest areas for solar power plants, the installation of power transmission lines in wind energy, the use of huge areas for the reservoir of hydroelectric power plants and the thermal pollution that occurs after energy production, the pressure of raw material supply on flora in the biomass energy production process, and some changes caused by the geothermal energy production process on air, vegetation and forest existence. It is also a handicap that these power plants and electricity transmission lines are potential forest fire initiators and spreaders (Turgut 2009, Doğan 2011, Waheed et al. 2018, Yıldırım and Akın 2023, Taghiyev 2023, NCCMSAP 2024).

In the road map determined within the framework of the Climate Change Mitigation Strategy and Action Plan (2024-2030), Türkiye has based its carbon intensity reduction strategy on renewable energy sources such as solar, wind, hydroelectric, geothermal and biomass. Although this strategy has some negative consequences in terms of forest assets in the short term, it can be expected to yield positive results in the long term when sustainable practices and especially climate change-related problems are taken into consideration (NCCMSAP 2024). Water resources, which have a key role in the protection of ecosystems and the sustainability of ecological balance, especially forest assets, are also vulnerable to risks arising from carbon emissions. Therefore, not only humanity but also freshwater resources, which are the lifeblood for all living beings, can be directly or indirectly affected by energy production processes. In this framework, the Water Efficiency Strategy Document and Action Plan (2024-2030) within the Framework of Adaptation to a Changing Climate aims to mitigate the impact of climate change-induced problems and policies developed against these problems on water areas through the management of water basins and efficiency practices (NCCMSAP 2024). In the long term, the carbon emission reducing effect of renewable energy production and consumption processes positively reflects on freshwater resources.

Aim of the Study

This study aims to thoroughly examine the impacts of carbon emissions and renewable energy production on forest areas in Türkiye. The detrimental effects of fossil fuel-based energy production linked to carbon emissions, as well as the potential positive effects of renewable energy sources (RES) on forest ecosystems, will be revealed through econometric analyses. In this context, the hypotheses developed regarding carbon emissions, renewable energy production, and the per capita availability of freshwater form the foundation of this study, with the goal of uncovering both the short-term and long-term effects of these factors on forest areas.

Significance of the Study

Critical environmental problems such as global warming and climate change reveal the importance of environmental sustainability today more than ever. Understanding the impacts of renewable energy production and carbon emissions on forest areas is of great importance for shaping environmental policies and sustainable energy strategies. This study can provide important data for policymakers, environmental scientists and economists to guide decision-making processes. Assessing the impacts of renewable energy investments on forest areas can contribute to drawing a strategic roadmap for achieving sustainable development goals.

Original Value of the Study

The unique value of this study stems from the fact that it analyses the effects of renewable energy generation and carbon emissions on forest areas in detail using econometric analysis methods. Although there are various studies on the environmental impacts of renewable energy generation in the existing literature, the originality of this study is provided by the focus on forest ecosystems and the econometric testing of hypotheses. The main hypotheses of the study are as follows:

Long-Term Hypotheses

H1: CO_2 emissions have a negative long-term effect on forest areas.

H2: Renewable energy production has a positive long-term effect on forest areas.

Short-Term Hypotheses

H3: CO_2 emissions have a positive short-term effect on forest areas.

H4: Renewable energy production has a positive short-term effect on forest areas.

This study provides important implications for the development of sustainable energy and environmental policies by analysing the long-term effects of renewable energy policies on forest cover within the framework of Türkiye's Climate Change Mitigation Strategy and Action Plan (2024-2030).

Historical Development of Environmental Problems

People have exerted pressure on natural resources to meet their basic needs. This pressure has led to an increasing demand for resources in agriculture, industry, transportation, and energy sectors. As a result, the rising demand for raw materials and energy has contributed to an increase in emissions. Consequently, while the depletion of natural resources has accelerated, the impact of emissions on environmental values has been devastating. One of the major negative outcomes of this is deforestation. Thus, population growth and urbanisation have caused a reduction in forested areas—one of the prominent environmental problems—while deforestation, by directly hindering the absorption of CO_2 through photosynthesis, reduces carbon sequestration and increases emission rates. Accordingly, it can be said that population growth, deforestation, and rising emissions show a parallel tendency (Yiğit 2021). This vicious cycle has historically evolved into a phenomenon that humanity has had to confront in the form of various environmental issues. In truth, what we call an environmental issue is, in essence, a human problem—our inability to coexist harmoniously with nature.

Population growth and the human drive to satisfy needs have led to environmental problems, which have intensified especially after the Industrial Revolution. The 2018 report by the IPCC (Intergovernmental Panel on Climate Change) revealed that human activities have raised global warming by approximately 1.0°C compared to pre-industrial levels (Hoegh-Guldberg et al. 2019). Although international initiatives aimed at finding solutions since the 1970s have increased awareness, they have not achieved the desired success. These issues have transformed into a complex threat with global repercussions. This process has negatively impacted human lives, economic relations, and urban and social structures. Extraordinary meteorological events and natural disasters have become more frequent and severe. The increasing frequency of disasters such as forest fires, floods, storms, heatwaves, and droughts—which directly affect human life—clearly demonstrates this. Projections of 1.5°C and 2.0°C increases in global temperatures indicate that such disasters will become more widespread. This process is also expected to trigger migration waves (Hoegh-Guldberg et al. 2019). Indeed, the IPCC's 2021 report strongly warned, based on scientific data, that natural disasters will rapidly increase (IPCC 2021).

As highlighted in IPCC reports, increasing and intensifying economic activities exert pressure on the environment. The energy sector, in particular, plays a dominant role in the climate crisis. However, environmental regulations should not be developed solely for the sake of protectionist policies, but should also support economic development—an approach that is vital for sustainability (Guler and Kumar 2022). After all, emission increases lie at the heart of many environmental problems, especially the climate crisis. The historical process has shown that as economic activities intensify, environmental degradation also increases. Empirical studies support this assertion. Economic growth is directly aligned with increasing environmental degradation. Consequently, environmental deterioration has a negative impact on economic growth. Findings from a study covering 140 countries between 1980 and 2021 show that environmental degradation generally has a delaying effect on economic growth (Acheampong and Opoku 2023).

The dilemma between environmental issues and economic activities, which has turned into a story of historical deadlock, manifests within the framework of sustainability as the breaking of circularity in forest ecosystems, which are key to maintaining ecological balance. Today, as human activities, driven by ambition and empowered by science and technology, increasingly turn toward renewable energy sources to meet energy demands, they will provide hope and contribute to the future of all environmental values, especially forested areas.

Economic Activities, Greenhouse Gases and Atmospheric Balance

While economic activities have driven environmental problems into an impasse, the energy demand stemming from economic growth has also disrupted the sustainability of ecological balance. All environmental values—especially forests, wetlands, and biodiversity—have borne the brunt of these adverse consequences. Particularly during the Industrial Revolution, rapid transformations took place, and after the World Wars, newly restructured states and societies entered a race to adapt to a new world. The global environmental issues that emerged during and after this period have intensified in direct relation to human activities (Warburton 2021).

Indeed, the European Union's new Forest Strategy (2030) aims to counteract these challenges by enhancing both the quantity and quality of forests. Within the framework of sustainability, supporting the bioeconomy—through forest-based bioenergy and ecotourism, for example—will strengthen the socio-economic functions of forests. Furthermore, wood-based bioenergy, the primary source of renewable energy, accounts for 60% of the EU's renewable energy consumption. To meet the 55% emission reduction target by 2030, the share of renewable resources must be significantly increased. In this context, since 2000, the use of woody biomass for energy production in the EU has grown by approximately 20% (European Commission 2024). Given that forests host 80% of global biodiversity and that 25% of the world's population depend on forests for their livelihoods, it becomes evident how critical sensitivity is in balancing economic activities with the preservation of forest ecosystems (European Commission 2024).

With the effect of greenhouse gases, the balance of the atmosphere has been dragged towards an irreversible deterioration. These gases cause global warming by retaining heat in the atmosphere. Atmospheric balance is of critical importance for the whole ecosystem in our world. The emission of carbon-based gases makes this balance dramatically fragile (WMO 2024). This problem appears as global warming and climate change. Today, global warming, climate change and the problems arising from them are among the most fundamental problem areas of humanity. Therefore, it is expected to reduce carbon emissions and increase the orientation towards sustainable and renewable energy sources instead of fossil energy sources. Thus, it is aimed to prevent the overheating of our world while minimising the carbon footprint. In this context, many international conferences with wide participation have been organised and agreements have been signed (Özer 2022).

Human-induced activities have significantly increased the atmospheric concentration of greenhouse gases—particularly carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs)—to levels well above their natural thresholds. This disproportionate accumulation has been a primary driver of global warming and climate change, posing a critical threat that requires urgent action (CO_2Earth 2024). In response to this environmental challenge, international agreements such as the Kyoto Protocol (1997) and the Paris Climate Agreement (2015) have emerged as pivotal frameworks aimed at mitigating greenhouse gas emissions and addressing climate change on a global scale. With the devastating effects of climate change, many countries have made commitments, especially in Paris. Accordingly, it is aimed to keep global warming below 2.0°C by reducing greenhouse gas emissions (IPCC 2022). Therefore, what is expected from these international initiatives towards the problem, which we are already seeing the negative effects of and which is likely to show more destructive effects in the future, is that it is a step towards a solution and a hope for the future. This is because, due to the increase in carbon emissions, especially wetlands have started to dry up, thus endangering the existence of local ecosystems (Republic of Türkiye Ministry of Foreign Affairs 2023). According to the findings, global warming has led to the breakdown of ecological balance and the destruction of closed systems.

Closed water basins and ecosystems, which are relatively larger, have started to shrink and lose their qualities. This situation has set a barrier to ecological and economic sustainability. Therefore, it is accepted that carbon emission causes heat retention in the atmosphere and global warming, which in turn causes drought and disruption of hydrological balance (UNEP 2023).

Türkiye's Renewable Energy Potential and the Role of Forest Areas in Combating Global Warming and Climate Change

Projections reveal that the magnitude of the problem, as well as its risks for the future, are so frightening that it is in an irreversible cycle. In such a dilemma, forest areas have the potential to offer an opportunity. Because forest areas, which constitute approximately 1/3 of the terrestrial ecosystem, store 3/4 of the carbon. In this respect, the existence of forests, which are both an ecological and economic value, is critical for the ecological cycle (Yılmaz et al. 2018). However, the core paradox lies in the fact that carbon emissions contribute to global warming, which in turn causes droughts. These droughts increase the risk of wildfires, leading to the destruction of forests, critical carbon sinks that help regulate atmospheric CO_2 levels. Today, a vicious circle has been entered in this way, and exit formulas are being sought. Finally, it has become inevitable to experience natural disasters, especially forest fires, where a spark is enough. According to IPCC reports, it has been stated that natural disasters will escalate rapidly if warming continues to increase, and the urgency of taking measures has been declared (IPCC 2021). In this context, evaluating the carbon sequestration potential of forests and implementing sustainability-centred carbon emission-reducing policies, especially turning to renewable energy instead of fossil-based energy, will provide the ability to manage the problem of global warming and climate change (GDF 2021).

Emission increases, which are among the most important factors leading to global warming and climate change, put pressure on forest areas and cause negative effects in terms of the amount. It is thought that there is a correlation between these emission increases and the decrease in forest areas. In recent years, investments in renewable energy sources have increased. As a result, the utilisation rate of such energy sources in energy supply has increased compared to previous periods, while fossil-based ones have decreased (Özbek and Oğul 2023).

In this framework, the orientation towards renewable energy sources such as hydraulic, solar, wind, geothermal, biofuel, which are expressed as energy sources that do not produce emissions, are environmentally compatible and sustainable, has a positive effect on forest existence and contributes to the protection and expansion of forest areas (Waheed et al. 2018 Yıldırım and Akın 2023). As can be seen in Figure 1 and Figure 2, Türkiye's forest cover has increased in terms of area, tree wealth, current increment, and eta, which refers to the annual and periodic allowable cut determined in line with the main principles of forestry and national forestry objectives within the scope of forest management plans. General Directorate of Forestry (GDF) data confirm this. According to the 2020 report, Türkiye's forest cover has increased steadily compared to previous years. According to the data, 2.7 million hectares of new forest areas were acquired, increasing the total area from 26.1% to 29.4%. In terms of tree wealth, there was an increase of 744 million m^3, while the current increment increased from 1.4 m^3 to 2.07 m^3 per hectare. The amount of eta increased by 7 million m^3 from 15.3 m^3 to 22.3 m^3. These data show that in recent years, Türkiye has experienced significant improvements in all forest-related indicators (GDF 2021). The data on tree wealth, current increment, and allowable cut—supporting the observed improvements—clearly demonstrate the positive impact of sustaining forest resources in all its dimensions.

Tree wealth, a concept that holds significant value in terms of forests and forestry, refers to the total volume in cubic meters of living trees with a trunk diameter of 8 cm or more that possess productive potential. This potential has shown a consistent upward trend within the framework of forestry activities. The current increment, which represents the end-of-year net increase in the country's forest wealth, is based on the calculation of the annual change in forest volume in cubic meters. It encompasses the height and diameter growth of trees within a vegetation period. The increase in tree wealth, along with the maintenance of forested areas, has supported this growth.

Viewing forests through a holistic perspective and treating them as assets that align with economic, ecological, and sociocultural functions in accordance with the principles of forestry has also contributed to the rise in the allowable cut. The General Directorate of Forestry's data on the average annual yield indicates a steady increase in both annual and periodic harvesting volumes (GDF 2021, GDF 2024).

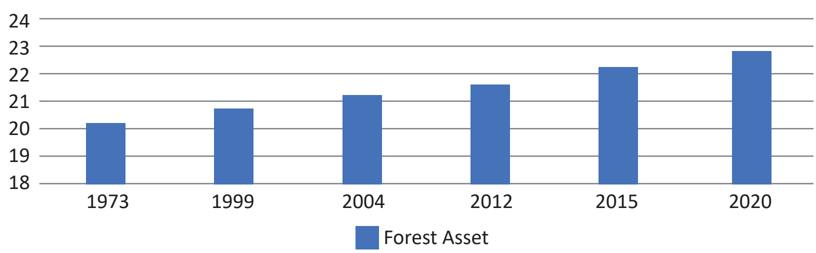

Figure 1. Forest Asset of Türkiye (GDF 2021).

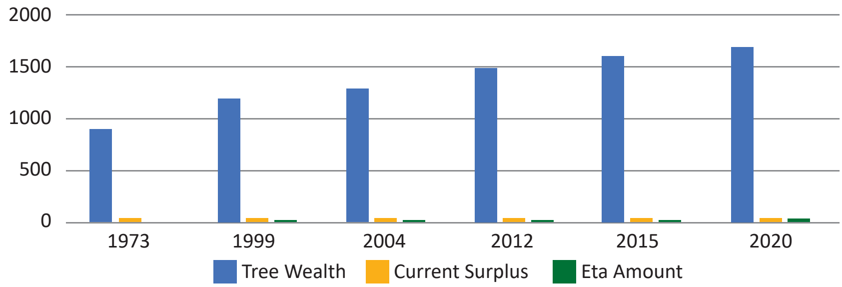

Figure 2. Türkiye Tree Wealth, Current Surplus and Eta Amount (GDF 2024).

Türkiye maintains its energy needs based on fossil fuels, with a large proportion of imports. Due to the insufficiency of energy resources, it is far from a supply to meet the demand. However, the renewable energy potential is quite high. The studies carried out in recent years on energy production from these sources are aimed at utilising this potential (Özbek and Oğul 2023).

Türkiye is located in a lucky geography in terms of solar energy, which is an important renewable energy source. Türkiye Solar Energy Potential Atlas (GEPA) shows that the average annual total sunshine duration is 2,741 hours. Therefore, the data indicate that the potential is high while the utilisation capacity remains relatively low (Republic of Türkiye Ministry of Energy and Natural Resources 2024).

In wind energy, which is an environmentally friendly energy source, there is an investment and production below its potential. This situation has been revealed by the Wind Energy Potential Atlas (REPA). However, it can be stated that there is a will to establish power plants in this field (Republic of Türkiye Ministry of Energy and Natural Resources 2024).

As a clean and renewable energy source, hydroelectric energy resources have a long life and low operating costs. Therefore, it is not desirable to waste this potential. The will to manage water resources, which are particularly pressurised by drought caused by global warming and climate change, imposes an indispensable mission for both the present and the future. Türkiye is a country that cannot utilise its hydroelectric potential at the desired level (Republic of Türkiye Ministry of Energy and Natural Resources 2024).

Türkiye, geothermal energy sources—which boast a wide range of applications—holds a remarkably strong position. While it ranks first in Europe in terms of potential, it stands fourth globally in terms of installed capacity. This advantage is largely due to its geological position and location along an active tectonic belt. Another notable renewable energy source is biomass. Its broad field of application, combined with Turkey's high biomass production potential, can be seen as a significant opportunity. The biomass offered by forestry activities and forest products not only provides the means to generate renewable energy but also opens new windows in terms of capacity and capability for reducing carbon emissions. Forest residues—particularly non-wood forest products, waste and leftovers from the forestry industry, forests established specifically for energy, and energy crops cultivated for production—highlight the critical role forests play in biomass. Alongside forestry, agriculture, and animal husbandry, organic urban waste sources also present promising potential. However, it cannot be said that this potential is being adequately utilised (Republic of Türkiye Ministry of Energy and Natural Resources 2024).

Nuclear energy, which is controversial as an environmentally friendly energy source, is another energy source that is agreed to have great potential in meeting the energy needs. Although it involves some serious risks, it is seen as an advantage that it does not produce emissions like fossil fuels. The accidents experienced reveal how destructive these risks are. However, the increasing need for energy encourages the establishment of nuclear power plants. In Türkiye, the first unit of the plant being built in Mersin Akkuyu is planned to start generating electricity by the end of 2024. This four-unit plant will be one of the largest nuclear power plants in the world. This plant has the potential to meet approximately 10% of Türkiye's electricity demand (Republic of Türkiye Ministry of Energy and Natural Resources 2024).

Sustainability and environmental impacts have contributed to increased investments in renewable energy sources. The share of energy production in areas such as nuclear energy, solar and wind energy has increased, and it is even aimed to minimise fossil energy as a measure against global warming and climate change-related problems. However, coal, oil and natural gas resources have not yet ceased to be the main energy sources (Birol et al. 2013).

Electrical energy, which is a secondary energy source, constitutes the basis of the energy needs of mankind. Türkiye has a significant share of fossil fuels both as a primary energy source and in electrical energy production. However, fossil-based electricity generation is decreasing. For example, while the share of coal was 36.3% in 2023, it decreased to 20.3% as of February 2024. On the other hand, the share of renewable energy sources is increasing. Figure 3 shows the ratio of Türkiye's renewable energy sources in total installed capacity, and it can be seen that there is an increasing trend from year to year (Republic of Türkiye Ministry of Energy and Natural Resources 2024). This is in line with the Climate Change Action Plan (2011-2023) targets of increasing the share of renewable energy in electricity generation, reducing the use of fossil fuels, especially coal, and limiting greenhouse gas emissions (NCCAP 2012). Again, in the

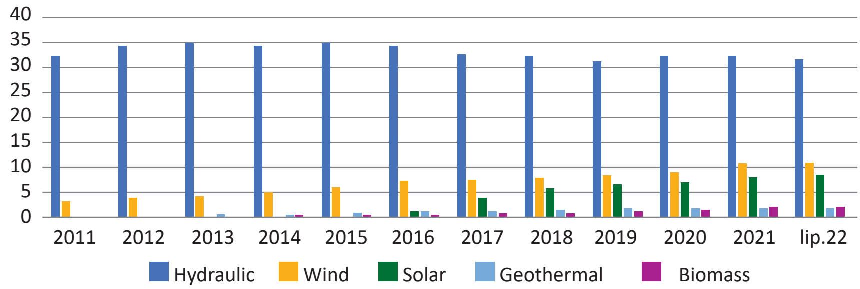

Figure 3. Türkiye Renewable Energy Resources (Republic of Türkiye Ministry of Energy and Natural Resources 2024).

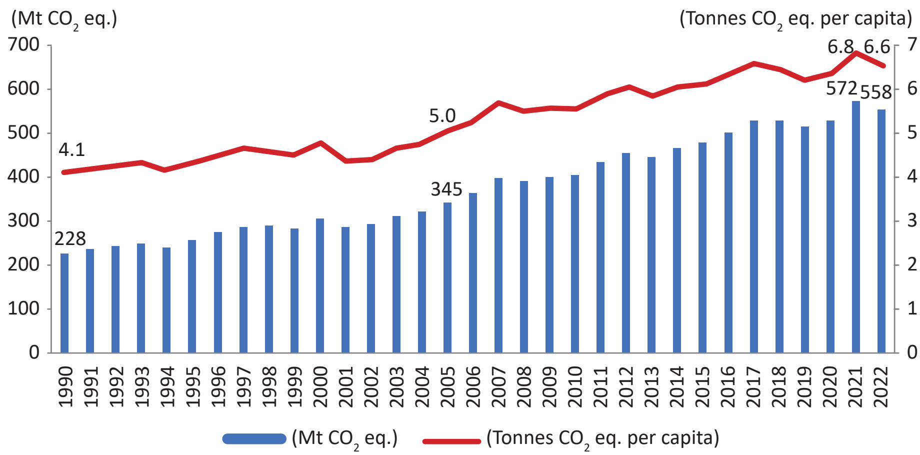

Figure 4. Total and Per Capita Greenhouse Gas Emissions (1990-2022) (TURKSTAT 2024).

Climate Change Mitigation Strategy and Action Plan (2024-2030), the strategy of reducing carbon-intensive production processes and strengthening alternative production processes in electricity generation, which is shown as one of the important emission sources of Türkiye and has a large share, has been determined (NCCMSAP 2024).

As can be seen in Figure 4, according to TURKSTAT data, total emissions, which were 228 mt CO_2 equivalent in 1990, increased to a very high amount of 558 mt CO_2 equivalent by 2022. The amount per capita has increased from 4.1 tonnes CO_2 equivalent in 1990 to 6.6 tonnes CO_2 equivalent. This situation shows us an increasing emission trend.

Figure 5 shows the distribution of greenhouse gas emissions by sectors in 2022, with the energy sector leading with 71.8%, agriculture coming second with 12.8%, followed by industrial activities with 12.5% and waste with 2.9%. In

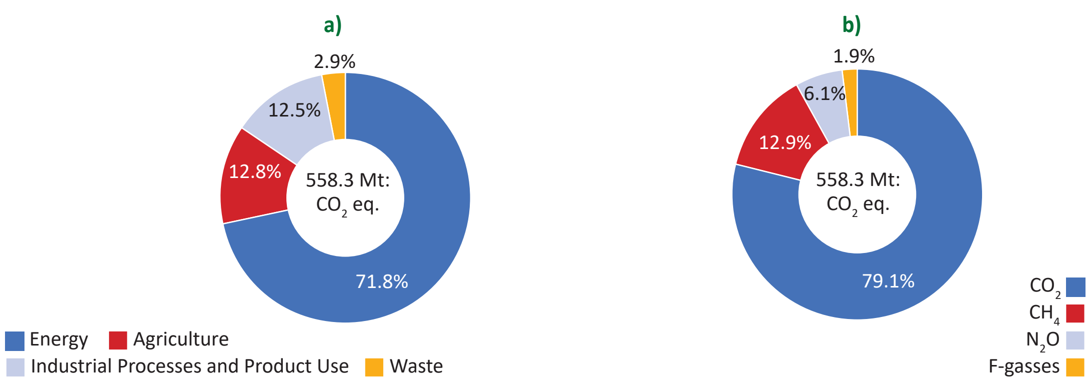

Figure 5. Greenhouse Gas Emission Rates by **(a)** Sectors and **(b)** Gases 2022 (TURKSTAT 2024).

the emission rates according to gases, CO_2 has a very high rate of 79.1%. This was followed by methane (12.9%), diazotmonoxide (6.1%) and fluorinated gases (1.9%).

In Figure 6, Türkiye's reaction to climate change, the policies it has developed and its performance are measured. Scoring was made according to the parameters of renewable energy (20%), energy use/consumption (20%), climate policy (20%) and greenhouse gas emission (40%). According to the scoring system, very high, high, medium, low and very low categories were determined. In 2019, a total of 57 countries were included in the assessment and Türkiye ranked 50th with a score of 40.22 and was in the very low category (Burck et al. 2019). In 2020, when 58 countries were evaluated, Türkiye ranked 48th with a score of 40.76, but could not leave the very low category (Burck et al. 2020). In 2021, Türkiye scored 43.47 points and moved from the very low category to the low category. In the ranking created by analysing the data of 58 countries, Türkiye found itself in 42nd place (Burck et al. 2021). In 2022, 61 countries were evaluated, and Türkiye was again in the low category. However, Türkiye's score was 50.53 (Burck et al. 2022). These data and performance show that Türkiye is constantly improving itself in this field and is serious about adaptation to climate change. Türkiye has demonstrated this by preparing action plans, ratifying the Paris Agreement, accepting the 2030 target, and setting a net-zero emission target for 2053 with the National Contribution Declaration.

Literature Review

In recent years, identifying the factors contributing to the reduction of carbon emissions, reshaping energy policies, and understanding the role of forested areas within the framework of environmental sustainability have gained increasing significance in the academic literature. In this context, numerous empirical studies encompassing different groups of countries and time periods have examined the impact of variables such as economic growth, renewable and non-renewable energy use, forest cover, urbanisation, agricultural productivity, population growth, and environmental policy implementations on carbon dioxide emissions. These studies not only reveal the factors affecting carbon emissions but also contribute to the development of policy recommendations aimed at improving environmental quality. Accordingly, the literature review section of this study aims to present a comprehensive and up-to-date perspective on the dynamic relationships between carbon emission levels, renewable energy production, and forest areas, through empirical research conducted in various regions and timeframes.

Derouez and Ifa (2025) analysed the relationships among CO_2 emissions, GDP, financial development, forest area, renewable energy, non-renewable energy consumption, and trade openness for eight Southeast Asian countries (Indonesia, Malaysia, China, South Korea, Vietnam, Singapore, Thailand, and Japan) using annual data from 1990–2023 and employing the Autoregressive Distributed Lag (ARDL) approach and the Vector Error Correction Model (VECM) technique. Their analysis found that GDP and non-renewable energy consumption significantly increased CO_2 emissions in countries such as Indonesia, Malaysia, Japan, and South Korea, whereas increases in forest area, financial development, renewable energy consumption, and trade openness were effective in reducing emissions, particularly in Vietnam and China.

Yeboah et al. (2025) utilised Dynamic Common Correlated Effects (DCCE) and Bayesian Stochastic Quantile Regression (BSQR) methods with balanced panel data from 19 African countries between 2000 and 2020 to investigate the environmental determinants of CO_2 emissions, including renewable energy capacity, biocapacity, forest cover, population growth, R&D expenditures, and government environmental policies. Forest cover data, representing the percentage of land under forest area, were sourced from the World Bank's environmental indicators database. The analysis revealed significant cross-sectional dependencies in renewable energy (51.2786, $p < 0.01$) and forest cover (33.2233, $p < 0.01$). According to the DCCE estimates, both forest area (-0.3818, $p < 0.01$) and renewable energy (-0.0123, $p < 0.01$) had significant negative effects on emissions, while biocapacity exhibited a notable transformative effect (-54.1978, $p < 0.01$). The BSQR analysis indicated quantile-dependent relationships, with the impact of renewable energy ranging from -0.001 at low quantiles to -2.641 at high quantiles. Long-term government policy

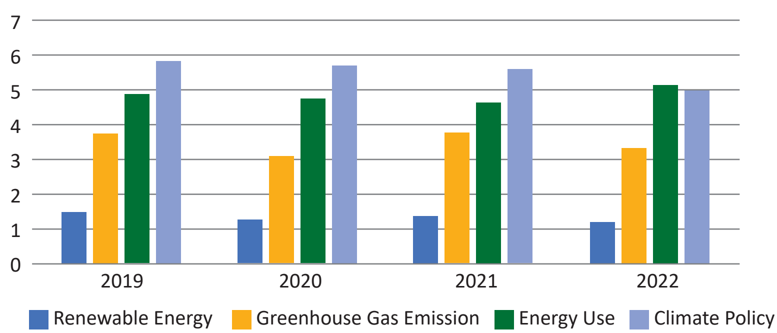

Figure 6. Türkiye's Climate Change Policy and Performance (2019-2022) (Burck et al. 2019, 2020, 2021, 2022).

showed a consistent negative effect (-0.0070, $p < 0.01$), and R&D gained importance at higher quantiles (-0.0347, $p < 0.01$). Sensitivity analysis confirmed the robustness of these findings, especially for population growth (-1.4613, std = 0.2569) and R&D (-0.2064, std = 0.0459). These results highlight the need for temporally calibrated and regionally coordinated green policy strategies that account for varying emission levels across Africa.

Nzabarinda et al. (2025) explored the relationship between CO_2 emissions and deforestation, forest gain, and land use changes in Africa using data from 1992 to 2020. Utilising ArcGIS for reclassification of land use changes, the InVEST model to calculate carbon storage and sequestration, and annual forest cover changes evaluated through the K and S indices, they found that 77.36% of African countries experienced net forest loss, amounting to 32×10^3 kha, which led to 15.73 Pg C in carbon emissions. The annual deforestation rate was 1.6×10^3 kha, equating to 0.786 Pg C in emissions. Consequently, carbon storage and sequestration declined to -0.69 and -1.37, respectively. The findings underscore that deforestation—especially in the Democratic Republic of the Congo—has significantly driven CO_2 emissions and that continued tropical deforestation will impact future greenhouse gas concentrations.

Rahman et al. (2024) analysed the effects of carbon-reducing factors such as renewable energy and forestry on India's carbon footprint, considering economic growth and demographics, using World Bank and International Energy Agency development data for the period 1980–2021. Employing the Augmented Dickey-Fuller (ADF) test, they found that a 1% increase in economic growth tends to raise the carbon footprint by 0.33% to 0.36% in the long run, while demographic changes had no significant short- or long-term effects. Conversely, a 1% increase in forest coverage reduces the carbon footprint by 0.39% in the short term and by 1.84% in the long term. Additionally, each 1% increase in renewable energy use decreases the carbon footprint by 0.05% to 0.49% in the long term.

Raihan et al. (2024) used Dynamic Ordinary Least Squares (DOLS) to examine the impacts of Vietnam's growing economy, increasing energy consumption, rising agricultural output, technological advances, and forest cover on CO_2 emissions from 1990 to 2020. They determined the order of integration using ADF, DF-GLS, and P-P unit root tests. The empirical findings from the DOLS estimates suggest that a 1% increase in energy use leads to a 0.09% increase in CO_2 emissions and a 1.32% increase in economic growth. In contrast, a 1% increase in technological development, agricultural productivity, and forest cover would reduce CO_2 emissions by 0.08%, 0.28%, and 1.47%, respectively.

Nesirov et al. (2024) employed panel data covering the 1996–2019 period to investigate the effects of agricultural value-added, forest area, and renewable energy on CO_2 emissions in GUAM countries (Georgia, Ukraine, Azerbaijan, and Moldova—post-Soviet states). Using panel unit root tests, Pedroni and Kao panel cointegration tests, and long-run estimations with OLS, FMOLS, and DOLS, they found a negative relationship between these variables and CO_2 emissions. According to FMOLS results, a 1% increase in agricultural value-added, forest area, and renewable energy consumption reduced CO_2 emissions by 0.339%, 1.103%, and 0.344%, respectively.

Raihan et al. (2023) examined the relationship between CO_2 emissions, economic growth, renewable energy use, technological progress, and forest cover in Indonesia for the 1990–2020 period using the DOLS approach. Their findings indicate that a 1% increase in economic growth leads to a 1.17% rise in CO_2 emissions, whereas a 1% increase in renewable energy use results in a 1.40% reduction. Likewise, technological innovation reduces emissions by 0.17%, and increased forest cover leads to a substantial 3.94% decline in CO_2 emissions.

Akpanke et al. (2023) conducted a comparative analysis of seven developing, seven developed, and fifteen developing West African countries for the 1990–2019 period using CS-ARDL, AMG, and CCEMG techniques, which account for cross-sectional dependence, heterogeneity, and dynamics. Their results reveal that renewable energy and energy efficiency reduce carbon emissions in all regions, while GDP growth increases emissions. Population size and forest resources reduce emissions in developing countries and developed nations, respectively. Interestingly, non-renewable energy use increases emissions in developed countries but reduces them in developing countries.

Raihan (2023) used annual time series data from 1990 to 2020 and applied the ARDL bounds testing approach and DOLS methodology to assess the dynamic effects of economic growth, renewable energy use, urbanisation, industrialisation, tourism, agricultural productivity, and forest area on CO_2 emissions in the Philippines. The results showed that a 1% increase in economic growth, urbanisation, industrialisation, and tourism increases CO_2 emissions by 0.16%, 1.25%, 0.06%, and 0.02%, respectively. Meanwhile, a 1% increase in renewable energy consumption, agricultural productivity, and forest area is estimated to reduce CO_2 emissions by 1.50%, 0.20%, and 3.46%, respectively.

Raihan and Tuspekova (2022a) examined the long-run relationships between total CO_2 emissions and energy consumption, industrialisation, and forest cover in Russia using time series data from 1990 to 2020. The Autoregressive Distributed Lag (ARDL) bounds testing technique and the Dynamic Ordinary Least Squares (DOLS) method were employed. The analysis found that a 1% increase in energy consumption would lead to a 1.3% rise in CO_2 emissions, while a 1% increase in industrialisation would raise emissions by 0.23%. Conversely, a 1% increase in forest area was projected to reduce CO_2 emissions by 4.29% in the long run.

Raihan and Tuspekova (2022b) employed time series data from 1990 to 2019 to assess the potential of economic growth, renewable energy use, and forest area in achieving environmental sustainability in Malaysia through the reduction of CO_2 emissions. Using the DOLS method, the findings revealed that the coefficient of economic growth was positive and statistically significant, with a 1% increase in growth leading to a 0.78% rise in emissions. Although the coefficient for renewable energy was negative, it was not statistically significant, indicating that a 1% increase in renewable energy use would reduce emissions by 0.10%. The coefficient for forest area was negative and significant, showing that a 1% increase in forest area could reduce emissions by 3.86%. These empirical results suggest that while economic growth has deteriorated environmental quality in Malaysia, increasing renewable energy use and expanding forest cover can play a critical role in reducing CO_2 emissions.

Raihan and Tuspekova (2022c) analysed the dynamic effects of economic growth, renewable energy use, urbanisation, industrialisation, tourism, agricultural productivity, and forest area on CO_2 emissions in Turkey using DOLS based on annual time series data from 1990 to 2020. The results indicate that a 1% increase in economic growth, urbanisation, industrialisation, and tourism leads to increases in CO_2 emissions by 0.39%, 1.22%, 0.24%, and 0.02%, respectively. In contrast, a 1% increase in renewable energy consumption, agricultural productivity, and forest area results in reductions in CO_2 emissions by 0.43%, 0.12%, and 3.17%, respectively.

Raihan and Tuspekova (2022d) used DOLS and the ARDL bounds testing technique to explore the long-term cointegration and dynamic impacts of economic growth, energy consumption, urbanisation, agricultural productivity, and forest cover on CO_2 emissions in Kazakhstan for the 1996–2020 period. Cointegration among the variables was confirmed by Johansen and Engle-Granger tests. The results showed that a 1% increase in economic growth, energy use, and urbanisation increased CO_2 emissions by 0.14%, 0.81%, and 1.28%, respectively. Meanwhile, a 1% increase in agricultural productivity and forest area led to long-term reductions in CO_2 emissions by 0.34% and 2.59%, respectively.

Raihan et al. (2022), using time series data from 1990 to 2019 derived from World Development Indicators, analysed how economic growth, renewable energy use, urbanisation, industrialisation, technological innovation, and forest area can contribute to environmental sustainability in Bangladesh through reducing CO_2 emissions. The ARDL bounds test and DOLS approach revealed that economic growth, urbanisation, and industrialisation increased emissions, while renewable energy use, technological innovation, and forest expansion contributed to lower emission rates and improved environmental outcomes.

Ponce et al. (2021) examined the causal relationship between renewable energy consumption, GDP, non-renewable energy prices, population growth, and forest area using the autoregressive distributed lag (ARDL) model for high-, middle-, and low-income countries with time series data from 1990 to 2018. The findings revealed that for middle- and low-income countries, there existed a common long-run relationship among the analysed variables. A positive relationship was found between renewable energy consumption and forest area, with a 1% increase in renewable energy leading to an expansion of 0.041512 km^2 in middle-income countries and 0.027512 km^2 in low-income countries. However, no conclusions could be drawn about short-run equilibrium effects.

Anwar et al. (2021) investigated the long-run and causal relationships between renewable energy consumption, forest area, and CO_2 emissions across 33 Belt and Road Initiative (BRI) economies for the 1986–2018 period using panel cointegration and ARDL methodologies. To estimate long-term coefficients, they also applied FMOLS, DOLS, and PMG techniques, and conducted Granger causality tests to identify short-run causal directions. The results revealed that increases in renewable energy use and forestry activities helped reduce CO_2 emissions in BRI economies. In other words, empirical evidence suggests that renewable energy expansion and forest cover growth contribute positively to long-term environmental quality. However, increased trade among BRI countries was found to have a detrimental long-run impact on the environment. Granger causality tests revealed bidirectional short-run causality between renewable energy use and forest area, and unidirectional causality from per capita income to carbon emissions.

Koondhar et al. (2021) used annual time series data from 1998 to 2018, sourced from the World Bank and the National Bureau of Statistics of China, to analyse the long- and short-term relationships between carbon emissions, renewable energy consumption, forestry, and agricultural financial development in China using the Autoregressive Distributed Lag (ARDL) model. The analysis revealed that forest area alone maintained a negative and statistically significant relationship with carbon emissions in both the short and long term. The expansion of forested areas contributed significantly to the reduction of carbon emissions. While renewable energy consumption also exhibited a negative and significant correlation with emissions, agricultural financial development showed a positive and significant relationship with emissions only in the short run. Granger causality test results confirmed unidirectional causality running from renewable energy consumption, forest area, and agricultural financial development to CO_2 emissions. Therefore, the findings suggest that in the long run, causality flows from renewable energy, forest area, and agricultural financial development to carbon emissions.

Pratiwi and Juerges (2020) conducted a systematic literature review based on 132 articles and reports to examine the effects of renewable energy development on the environment and nature in Southeast Asia. Their review concluded that the most significant negative impacts of renewable energy development stemmed from hydroelectric power, biofuel production, and geothermal plants. Solar and wind energy also had adverse effects on the environment and biodiversity, although these effects were less pronounced compared to other types of renewable energy. The reported negative consequences included environmental pollution, biodiversity loss, habitat fragmentation, and the disappearance of wildlife.

Waheed et al. (2018) analysed the long- and short-term impacts of renewable energy consumption, agricultural production, and forest area on CO_2 emissions in Pakistan using the ARDL model with annual data from 1990 to 2014. Their findings suggested that in the long run, increasing renewable energy use and expanding forest areas contribute to the reduction of carbon emissions, while agricultural production increases emissions. In the short run, renewable energy use and forest expansion continued to have effects similar to the long-term findings. However, the impact of agriculture became statistically insignificant in the short term. Moreover, the study concluded that afforestation was more effective in reducing CO_2 emissions compared to renewable energy use or agricultural development.

Islam et al. (2017) utilised time series data from 1991 to 2010 to analyse the effects of energy consumption (EC), economic growth, population growth, poverty, and forest cover on CO_2 emissions in Malaysia, Indonesia, and Thailand. Employing panel unit root tests, cointegration analysis, and Granger causality testing, the study found that energy consumption and economic growth contributed to increased CO_2 emissions, while population growth had only a minimal effect. On the other hand, poverty and forest cover significantly reduced CO_2 emissions, highlighting their potential roles in environmental sustainability strategies.

In this study, unlike the general trend in the literature, the effects of carbon emissions on forest areas are examined. While existing literature largely focuses on the role of forest areas in reducing carbon emissions and explores their function in environmental sustainability, our study offers a unique contribution by analysing the possible impacts of increasing carbon emissions on forest areas, thus addressing the relationship from the opposite direction. In this regard, the study reveals that forest areas, far from being merely an outcome, are also dynamic elements influenced by environmental variables, considering the bidirectional nature of environmental interactions. The findings suggest that this reciprocal relationship should be taken into account in the design of environmental policies.

MATERIALS AND METHODS

Methodology

In this study, forest areas were treated as the dependent variable, and the effects of carbon emissions and renewable energy consumption on forest areas in Türkiye were examined. All statistical analyses in this study were performed using Stata version 18. The software was utilised for data cleaning, descriptive statistics, model estimation, and diagnostic testing. The model employed in the empirical analysis is as follows:

$$LCO_2 = \beta 0 + \beta 1LFA_t + \beta 2LREC_t + LFRPC_t + \varepsilon_t \quad (1)$$

In the model, 't' represents time, 'LCO_2' represents carbon emissions in kilo tonnes, 'LFA' represents forest areas within the borders of Türkiye, 'LREC' represents electricity generated from renewable sources, 'LFRPC' represents freshwater resources in Türkiye in cubic metres, and εt represents the error term. Freshwater resources in Türkiye are added to the study as a control variable to obtain more meaningful results. In the study, the coefficients between these variables will be estimated with the Autoregressive Distributed Lag (ARDL) estimator approach. The data range in the study covers the period 1990-2020 due to the last published data constraint, and the data consists of annual observations. The data used in the study were obtained from the World Bank databases. In addition, natural logarithms of the data are used.

RESULTS

The Phillips-Perron (PP) unit root test is a significant econometric method developed to examine whether time series are stationary. Although fundamentally based on the Dickey-Fuller (DF) test, it incorporates more flexible assumptions regarding the structure of the error terms. Phillips and Perron (1988) revised the test statistics to improve the robustness of the Dickey-Fuller test in the presence of autocorrelation and heteroskedasticity in the error terms. In this way, even if there is autocorrelation or heteroskedasticity in the time series, the test can yield reliable and consistent results. The null hypothesis states that the series contains a unit root, while the alternative hypothesis indicates that the series is stationary. The PP test does not require specific assumptions about the autocorrelation structure, which gives it broad applicability and makes it especially preferable for time series that may involve structural breaks. However, the test may have low power in small sample sizes (Ng and Perron 2001). Frequently used in the stationarity analysis of economic data, the PP test is a valuable tool in the analysis of time series.

Table 1. Variables and Abbreviations.

Variables	Abbreviations	Description	Data Source	Period
Carbon Emissions	LCO_2	Kilotone	data.worldbank.org	1990-2020
Forest Areas	LFA	Proportion of total area	data.worldbank.org	1990-2020
Renewable Energy Production	LREC	Share in total energy production	data.worldbank.org	1990-2020
Fresh Water Resources	LFRPC	M^3	data.worldbank.org	1990-2020

Table 2. Phillips-Perron (PP) Unit Root Test Results.

Variables	PP (Level) P-Value*	PP (First Difference) P-Value*	Stability Level
LCO_2	0.8276	0.0000	I(1)
LFA	1.0000	0.0142	I(1)
LREC	0.5831	0.0000	I(1)
LFRPC	0.0002	0.0000	I(0)

Mac Kinnon approximate probability value for z(t)

According to Table 2, the variables LCO_2, LFA, and LREC are not stationary at the level, but they become stationary after taking their first differences. Therefore, these three variables are found to be stationary at the I(1) level. On the other hand, the LFRPC variable is stationary at level, i.e., it is integrated of order zero, I(0). These findings reveal that most of the variables are stationary at their first differences.

The rationale for the ARDL approach is the ability to simultaneously estimate both short-run dynamics and long-run equilibrium in the model. This method can be applied regardless of whether the variables are stationary at the level or at first difference, thus providing diversity in data sets (Pesaran et al. 2001). Moreover, the ARDL bounds test uses the F-statistic to determine the long-run cointegration relationship. This test determines whether there is a long-run relationship by evaluating the boundaries of the critical values. The results obtained are interpreted by comparing the F-statistic with the specified critical values.

The advantages of this model include the fact that the ARDL estimator evaluates short-run and long-run relationships simultaneously and is effective even with small sample sizes. Moreover, the flexible structure of the model offers a wider range of applications by taking into account structural breaks and changing conditions in data sets (Narayan 2005).

The bounds test for the ARDL model reveals the existence of a long-run cointegration relationship between variables. Thanks to this approach proposed by Pesaran et al. 2001, reliable estimates of the parameters of the model can be obtained based on the results of the bounds test for variables integrated at different degrees. In the bounds test approach, it is first determined whether there is a long-run relationship between the series, and then the short and long-run coefficient results are estimated (Narayan and Smyth 2006).

As shown in Table 3, the F-statistic obtained from the ARDL bounds test is 20.234. This value is considerably higher when compared to the critical bounds determined for different significance levels. At the 1% significance level, the lower bound is given as 5.17 and the upper bound as 6.36. According to these results, the F-statistic exceeds the upper bound for both the 1% level and even lower significance thresholds.

Table 3. ARDL Bounds Test.

F-Statistic, Bound Test: 20.234		
Significance Level	Lower Bound	Upper Bound
%1	5.17	6.36
%5	4.01	5.07
%10	3.47	4.45

In this context, there is strong evidence suggesting the existence of a long-run relationship among the variables included in the model. In other words, it can be concluded that there is a cointegration relationship among the variables, as the F-statistic lies well above the critical bounds of the significance levels. The ARDL bounds test is a method used to simultaneously analyse both short-run and long-run relationships. This method, developed by Pesaran et al. (2001), provides flexibility in determining cointegration relationships by taking into account that time series can be both stationary and unit-rooted (I(0) and I(1)). ARDL modeli uzun dönem katsayı sonuçları, aşağıdaki genel formülasyonla ifade edilir: The long-run coefficient results of the ARDL model are expressed through the following general formulation:

$$Y_t = a + \sum_{i=1}^{\rho} \beta_i Y_{t-i} + \sum_{j=0}^{q} \Upsilon_i X_{t-j} + \varepsilon_t \qquad (2)$$

Here, p and q represent the number of lags of Y and X variables, respectively. Constant term, and are the parameters.

When the long-run coefficient results (Table 4) are evaluated, it is observed that the long-run relationship of the three variables in the model has different effects. The coefficient of the LCO_2 variable is -0.0043, the t-statistic is -0.33, and the p-value is 0.750. These results indicate that CO_2 has no statistically significant effect on the dependent variable in the long run.

On the other hand, the coefficient for the LREC variable is found to be 0.0228, the t-statistic of this coefficient is 3.50, and the p-value is 0.005. These findings indicate that LREC has a positive and significant effect on the dependent variable in the long run. In particular, the p-value is below 1% significance level, which indicates that this relationship is strong.

Finally, the coefficient for the LFRPC variable is calculated as 0.7907, the t-statistic is 12.59, and the p-value is 0.000. These results indicate that LFRPC has a strong, positive and significant long-run effect on the dependent variable. The fact that the p-value is close to zero proves that this relationship is highly statistically significant.

After calculating the coefficients of the long-run relationship, the appropriateness of the model is checked

Table 4. Long Run Coefficient Results.

Variables	Coefficients	Standard Error	t-Statistic	P-probability
LCO_2	-0.0043	0.1323	-0.33	0.750
LREC	0.0228	0.0065	3.50	0.005
LFRPC	0.7907	0.0628	12.59	0.000

with various diagnostic tests. An ARDL-based error correction mechanism is used to identify short-run relationships, and equation (3) is chosen for this purpose.

$$\Delta Y_t = a_0 + a_1 ECM_{t-1} + \sum_{i=1}^{\rho} \beta_i Y_{t-i} + \sum_{j=0}^{q} \Upsilon_i X_{t-j} + \varepsilon_t \quad (3)$$

ECM_{t-1} in equation (3) represents the error correction term. The error correction coefficient, as the one-period lagged value of the residuals of the model, expresses the correction of the long-term relationship between the variables. The coefficient of ECM (Error Correction Model) term indicates how much of a short-term shock will disappear in the long run (Pesaran et al. 2001).

The error correction model (ECM) results (Table 5) provide important information on how fast the model can return to long-run equilibrium. The coefficient of the ECM (Error Correction Model) term is calculated as -0.9085, and the t-statistic is -2.60 with a p-value of 0.025. These results indicate that the error correction term is both negative and statistically significant. The negative and close to 1 value of the ECM (Error Correction Model) indicates that the deviation in the model is largely corrected in the next period, and there is a rapid return to long-run equilibrium. The fact that the probability value is below the 5% significance level confirms that this relationship is statistically significant.

Regarding the short-run variables, the coefficient for the D(LCO_2) variable is 0.0142, the t-statistic is 1.76, and the p-value is 0.106. Although this shows that CO_2 has a positive effect on the dependent variable in the short run, this effect is not considered statistically significant since it is above the 10% significance level. The coefficient of D(LREC) variable is 0.0048, the t-statistic is 0.79, and the p-value is 0.447. These findings indicate that LREC has no significant effect on the dependent variable in the short run. Similarly, the coefficient for the D(LFRPC) variable is 0.0769, the t-statistic is 0.33, and the p-value is 0.746. This reveals that LFRPC has no significant effect on the dependent variable in the short run.

The results of the diagnostic tests conducted to assess the reliability of the analyses are presented below. These tests are critical to check the basic assumptions of the model and provide important information about the validity of the model (Table 6).

As a result of the Breusch-Godfrey Autocorrelation LM Test, the chi2 value is calculated as 1.414, and the p-value is 0.2344. This result indicates that there is no autocorrelation problem in the model, i.e. the independence condition between error terms is met. The chi2 value for the Breusch-Pagan/Cook-Weisberg Variance Test is 15.16, and the p-value is 0.5128. This result confirms that there is no heteroskedasticity problem in the model and that the variance is constant. The results of the Ramsey RESET Test are calculated with an F-statistic of 5.54 and a p-value of 0.02. These findings indicate that there is no significant specification error in the model, and the accuracy of the model is acceptable. Finally, within the framework of the Jarque-Bera Normality Test, the chi2 value for all equations is 4.309 and the p-value is 0.8282. This result indicates that

Table 5. Error Correction Model Results.

Variables	Coefficients	Standard Error	t-Statistic	P-probability
ECM	-0.9085	0.3490	-2.60	0.025
D(LCO_2)	0.0142	0.0081	1.76	0.106
D(LREC)	0.0048	0.0061	0.79	0.447
D(LFRPC)	0.0769	0.2321	0.33	0.746

Table 6. Diagnostic Test results.

Breusch-Godfrey Autocorrelation LM Test			
chi2	df		P-probability
1.414	1		0.2344
Breusch- Pagan/Cook-Weisberg Variance Test			
chi2	P-probability		
15.16	0.5128		
Ramsey Reset Test			
F(3,8)	P-probability		
5.54	0.0236		
Jarque-Bera normality Test			
Equation	chi2	df	P-probability
All	4.309	8	0.8282

the error terms are normally distributed and the normality assumption of the model is satisfied.

The results of these diagnostic tests prove that the basic assumptions of the model are generally valid and support the reliability of the analyses.

CONCLUSION AND RECOMMENDATIONS

The ARDL model results examining the effects of carbon emissions, renewable energy production, and freshwater resources on forest areas in Türkiye present critical findings for environmental and energy policies. The long-run coefficient analysis clearly illustrates the differentiated impacts of these variables on forest areas. Although the long-term impact of carbon emissions (LCO_2) on forest areas is negative, it is not statistically significant (coefficient: -0.0043, p-value: 0.750). This finding suggests that the current level of carbon emissions in Türkiye has a limited direct impact on forest coverage. However, this does not imply that carbon emissions can be disregarded. Despite its low level of statistical significance, the negative direction aligns with theoretical expectations, highlighting the necessity of controlling carbon emissions within the context of global climate change.

One of the study's striking findings is the positive and statistically significant effect of renewable energy production (LREC) on forest areas (coefficient: 0.0228, t-statistic: 3.50, p-value: 0.005). This result proves that investments in renewable energy directly contribute to forest conservation. A 1% increase in renewable energy production leads to a 0.0228% increase in forest areas, demonstrating how energy policies can align with environmental sustainability goals.

The analysis concerning Türkiye's environmental sustainability goals, energy strategies, and forest conservation underscores the necessity of taking concrete policy actions to achieve sustainable development objectives. Within the framework of the Sustainable Development Goals (SDGs), the effective implementation of such efforts can positively contribute to Türkiye's development process. In this context, renewable energy projects play a vital role in achieving SDG 8 (Decent Work and Economic Growth), SDG 1 (No Poverty), and SDG 12 (Responsible Consumption and Production). Given the positive effects of renewable energy on forest areas, its significance in Türkiye is increasing, making it essential to boost investments in this sector. Although Türkiye possesses considerable potential for renewable energy, this potential remains underutilised. Investments in this area not only ensure energy supply security but also expand green job opportunities, thus promoting economic growth under SDG 8. Enhancing the qualifications of the workforce engaged in renewable energy projects will create more employment opportunities and foster social and economic development through broader stakeholder involvement.

As expected, one of the model's robust findings is the impact of freshwater resources (LFRPC), included as a control variable, on forest areas (coefficient: 0.7907, t-statistic: 12.59, p-value: 0.000). This result indicates that a 1% increase in freshwater resources leads to a 0.79% increase in forest areas. This strong positive relationship highlights the importance of the forest-water ecosystem link and the necessity of integrated forest-water management policies. The tight interconnection between resource abundance and forest protection reflects the interconnected nature of natural resources. The strong positive impact of freshwater resources on forest areas underlines the importance of adopting a watershed-based approach to resource management. Policies for the protection and efficient use of water resources should be integrated with forest conservation strategies. Measures such as watershed rehabilitation, improvement of water quality, and increased efficiency of water usage will also contribute to the expansion of forest areas.

An examination of short-term dynamics reveals that none of the variables has a statistically significant effect on forest areas. The short-term effect of carbon emissions ($D(LCO_2)$) is positive but insignificant (p-value: 0.106), and the effects of renewable energy (D(LREC)) and freshwater resources (D(LFRPC)) are similarly insignificant. These findings suggest that changes in forest areas are the result of long-term processes and that short-term interventions have limited impact.

In light of these empirical findings, Türkiye's environmental and energy policies require reevaluation. The positive impact of renewable energy investments on forest conservation supports the expansion of investments in this area. Investments in solar, wind, geothermal, and hydroelectric energy sources will not only enhance energy security but also contribute to the preservation of forest ecosystems.

The statistical insignificance of carbon emissions may indicate that current emission levels have not yet crossed a critical threshold for forest areas. However, this does not mean that carbon control can be neglected. A preventive approach to reducing carbon emissions is essential to prevent future adverse effects on forests. Regarding policy recommendations, increasing incentives for the renewable energy sector should be a top priority. Expanding the share of renewable sources in energy production offers dual benefits for both combating climate change and protecting forests. In this context, financial support, tax incentives, and regulatory facilitation should be provided for renewable energy projects.

Adopting a basin-based planning approach in water resource management is critical for optimising the forest-water nexus. The sustainable use of water resources, forest rehabilitation programs, and erosion control efforts must be planned in an integrated manner. Accordingly, watershed protection projects and forest management plans should be carried out in coordination. The changes in forest areas that stem from long-term processes suggest that policymakers must adopt patient and consistent approaches. The limited impact of short-term interventions underscores the importance of long-term strategic planning.

For future research, it is recommended that the findings of this study be supported by regional analyses. Investigating how forest-energy-water relationships differ across Türkiye's various geographic regions can contribute to more effective policy design. Moreover, modelling how these relationships may change under climate change scenarios will provide foresight for future periods.

In conclusion, the empirical findings of this study show that renewable energy investments and integrated water-forest management are of critical importance for Türkiye to achieve its sustainable development goals. The development and implementation of long-term, data-driven policies are essential for both environmental sustainability and economic growth.

Author Contributions

RA and AK conducted the literature review and contributed to the writing of the related sections. MK was responsible for drafting the introduction and the pre-literature section. MAP performed the statistical analyses and contributed to the interpretation of the findings. All authors participated in the writing process, reviewed the final version of the manuscript, and approved it for submission.

Funding

This research received no external funding

Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

Acheampong AO, Opoku EEO, 2023. Environmental degradation and economic growth: Investigating linkages and potential pathways. *Energy Econ* 123: 106734. https://doi.org/10.1016/j.eneco.2023.106734.

Akpanke TA, Deka A, Ozdeser H, Seraj M, 2023. The role forest resources, energy efficiency, and renewable energy in promoting environmental quality. *Environ Monit Assess* 195(1071): 1–19.

Anwar MA, Nasreen S, Tiwari AK, 2021. Forestation, renewable energy and environmental quality: Empirical evidence from Belt and Road Initiative economies. *Journal of Environ Manage* 291: 112684.

Birol F, et al., 2013. 21. Yüzyılda Türkiye'nin enerji stratejisi: Belirsizlikler, yapısal kırılmalar ve bazı öneriler. Global İlişkiler Forumu Çalışma Grubu Raporu, İstanbul, Türkiye.

Burck J, Uhlich T, Bals C, Höhne N, Nascimento L, Wong J, 2019. Climate change performance index. Available online: https://ccpi.org/download/the-climate-change-performance-index-2019/ (Accessed: 04 April 2024).

Burck J, Uhlich T, Bals C, Höhne N, Nascimento L, Wong J, 2020. Climate change performance index. Available online: https://ccpi.org/download/the-climate-change-performance-index-2020/ (Accessed: 04 April 2024).

Burck J, Uhlich T, Bals C, Höhne N, Nascimento L, Wong J, 2021. Climate change performance index. Available online: https://ccpi.org/download/the-climate-change-performance-index-2021/ (Accessed: 04 April 2024).

Burck J, Uhlich T, Bals C, Höhne N, Nascimento L, Wong J, 2022. Climate change performance index. Available online: https://ccpi.org/download/climate-change-performance-index-2022-2/ (Accessed: 04 April 2024).

CO_2Earth, 2024. Daily CO_2. Available online: https://www.co2.earth/daily-co2 (Accessed: 14 June 2023).

Derouez F, Ifa A, 2025. Assessing the sustainability of Southeast Asia's energy transition: A comparative analysis. *Energies* 18(2): 287.

Doğan M, 2011. Enerji kullanımının coğrafi çevre üzerindeki etkileri. *Marmara Coğrafya Dergisi* 23: 36–52.

European Commission, New EU forest strategy for 2030. Available online: https://environment.ec.europa.eu/strategy/forest-strategy_en (Accessed: 08 March 2024).

European Commission, 2024. Forests. Available online: https://environment.ec.europa.eu/topics/forests_en (Accessed: 08 March 2024).

GDF-Republic of Türkiye Ministry of Agriculture and Forestry General Directorate of Forestry, 2021. 2020 Türkiye orman varlığı. Ankara, Türkiye.

GDF-Republic of Türkiye Ministry of Agriculture and Forestry General Directorate of Forestry, 2024. Forestry statistics. Available online: https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler (Accessed: 04 April 2024).

Guler Y, Kumar P, 2022. Climate change policy and performance of Turkiye in the EU harmonization process. *Front Sustain Cities* 4: 1070154. https://doi.org/10.3389/frsc.2022.1070154.

Hoegh-Guldberg O, Jacob D, Taylor M, 2019. Impacts of 1.5°C of global warming on natural and human systems. Available online: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter3_Low_Res.pdf (Accessed: 01 June 2021).

IPCC, 2021. Climate change 2021: The physical science basis. Available online: https://www.ipcc.ch/report/ar6/wg1/ (Accessed: 11 August 2021).

IPCC, 2022. Summary for policymakers. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Cambridge Univ. Press, 3–33. https://doi.org/10.1017/9781009325844.001.

Islam R, Ghani ABA, Mahyudin E, 2017. Carbon dioxide emission, energy consumption, economic growth, population, poverty and forest area: Evidence from panel data analysis. *Int J Energy Econ Policy* 7(4): 99–106.

Koondhar MA, Shahbaz M, Ozturk I, Randhawa AA, Kong R, 2021. Revisiting the relationship between carbon emission, renewable energy consumption, forestry, and agricultural financial development for China. *Environ Sci Pollut Res* 28: 45459–45473.

Narayan PK, 2005. The saving and investment nexus for China: Evidence from cointegration tests. *Appl Econ* 37(17): 1979–1990. https://doi.org/10.1080/00036840500278103.

Narayan PK, Smyth R, 2006. What determines migration flows from low-income to high-income countries? An empirical investigation of Fiji–U.S. migration 1972–2001. *Contemp Econ Policy* 24(2): 332–342.

NCCAP–National Climate Change Action Plan 2011–2023, 2012. Republic of Türkiye Ministry of Environment and Urbanization. Available online: https://iklim.gov.tr/eylem-planlari-i-19 (Accessed: 20 November 2022).

NCCMSAP–National Climate Change Mitigation Strategy and Action Plan 2024–2030, 2024. Republic of Türkiye Ministry of Environment and Urbanization. Available online: https://iklim.gov.tr/eylem-planlari-i-19 (Accessed: 25 March 2024).

Nesirov EV, Zeynalli EC, Karimov MI, 2024. Dynamic relationship among agriculture–renewable energy–forestry and carbon dioxide (CO_2) emissions: Empirical evidence from GUAM countries. *Int J Environ Qual* 61: 24–35.

Ng S, Perron P, 2001. Lag length selection and the construction of unit root tests with good size and power. *Econometrica* 69(6): 1519–1554. https://doi.org/10.1111/1468-0262.00256.

Nzabarinda V, Bao A, Tie L, Uwamahoro S, Kayiranga A, Ochege FU, Muhirwa F, Bao J, 2025. Expanding forest carbon sinks to mitigate climate change in Africa. *Renew Sustain Energy Rev* 207: 114849.

Özbek S, Oğul B, 2023. Türkiye'de tarım, orman alanları ve çevre ilişkisi. *Tarsus Univ J Appl Sci* 3(1): 26–35.

Özer YB, 2022. İklim kriziyle mücadelede kentsel iklim yönetişimi: Türkiye'de büyükşehir belediyelerin rolü ve iklim eylem planları. PhD Thesis, University of Marmara, Istanbul, Turkey.

Pesaran MH, Shin Y, Smith RJ, 2001. Bounds testing approaches to the analysis of level relationships. *J Appl Econom* 16(3): 289–326. https://doi.org/10.1002/jae.616.

Phillips PC, Perron P, 1988. Testing for a unit root in time series regression. *Biometrika* 75(2): 335–346. https://doi.org/10.1093/biomet/75.2.335.

Ponce P, Del Río-Rama MDLC, Álvarez-García J, Oliveira C, 2021. Forest conservation and renewable energy consumption: An ARDL approach. *Forests* 12(2): 255. https://doi.org/10.3390/f12020255.

Pratiwi S, Juerges N, 2020. Review of the impact of renewable energy development on the environment and nature conservation in Southeast Asia. *Energy Ecol Environ* 5(4): 221–239.

Rahman MM, Mohanty AK, Rahman MH, 2024. Renewable energy, forestry, economic growth, and demographic impact on carbon footprint in India: Does forestry and renewable energy matter to reduce emission?. *J Environ Stud Sci* 14(2): 415–427.

Raihan A, Hasan MA, Voumik LC, Pattak DC, Akter S, Ridwan M, 2024. Sustainability in Vietnam: Examining economic growth, energy, innovation, agriculture, and forests' impact on CO_2 emissions. *World Dev Sustain* 4: 100164.

Raihan A, Pavel MI, Muhtasim DA, Farhana S, Faruk O, Paul A, 2023. The role of renewable energy use, technological innovation, and forest cover toward green development: Evidence from Indonesia. *Innov Green Dev* 2(1): 100035.

Raihan A, 2023. The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. *Energy Nexus* 9: 100180.

Raihan A, Muhtasim DA, Farhana S, Pavel MI, Faruk O, Rahman M, Mahmood A, 2022. Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy Clim. Change 3:100080.

Raihan A, Tuspekova A, 2022a. Nexus between energy use, industrialization, forest area, and carbon dioxide emissions: New insights from Russia. *J Environ Sci Econ* 1(4): 1–11.

Raihan A, Tuspekova A, 2022b. Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. *Resour Conserv Recycl Adv* 15: 200096.

Raihan A, Tuspekova A, 2022c. Dynamic impacts of economic growth, renewable energy use, urbanization, industrialization, tourism, agriculture, and forests on carbon emissions in Turkey. *Carbon Res* 1(20): 1–14.

Raihan A, Tuspekova A, 2022d. Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan. *World Dev Sustain* 1(8): 100019.

Republic of Türkiye Ministry of Energy and Natural Resources, 2024. Info Bank–Energy. Available online: https://enerji.gov.tr/info-bank-energy (Accessed: 17 March 2024).

Republic of Türkiye Ministry of Foreign Affairs, 2023. International environmental issues. Available online: https://www.mfa.gov.tr/international-environmental-issues.en.mfa (Accessed: 14 June 2023).

Taghiyev A, 2023. Enerji santrallerin sosyo-ekonomik yararları ve doğaya verdiği zararların karşılaştırılmalı analizi: Neom şehir projesi örneği. *Int J Acad Manage* 6(3): 610–625. https://doi.org/10.33712/mana.1328326.

Turgut YN, 2009. Çevre Politikası ve Hukuku. 1st ed. İmaj Yayınevi, Ankara, Türkiye.

TURKSTAT–Turkish Statistical Institute, 2024. Greenhouse gas emissions statistics, 1990–2022. Available online: https://data.tuik.gov.tr/Bulten/Index?p=Sera-Gazi-Emisyon-Istatistikleri-1990-2022-53701 (Accessed: 23 September 2024).

UNEP–The United Nations Environment Programme, 2023. The Climate Emergency. Available online: https://www.unep.org/climate-emergency (Accessed: 15 October 2023).

Waheed R, Chang D, Sarwar S, Chen W, 2018. Forest, agriculture, renewable energy, and CO_2 emission. *J Clean Prod* 172:4231–4238. https://doi.org/10.1016/j.jclepro.2017.10.287.

Warburton CES, 2021. Economic activity and the environmental degradation: an incongruous dissonance. *J Smart Econ Growth* 6(2): 121–140.

WMO–World Meteorological Organization, 2024. Climate. Available online: https://wmo.int/topics/climate (Accessed: 10 October 2023).

Yeboah KE, Feng B, Jamatutu SA, Amoako PYO, Nyarko FE, Amin N, 2025. Unlocking Africa's green potentials for sustainable growth: Examining the role of renewable energy technologies, biocapacity protection, and government policies on CO2 emissions. *Sustain Dev* 0: 1–26.

Yıldırım K, Akın T, 2023. OECD ülkelerinde enerji kaynakları ve CO_2 emisyonu arasındaki ilişkinin STIRPAT modeli ile incelenmesi. *Yasar Univ e-J* 18(71): 316–341.

Yılmaz BA, Mısır M, Kolay O, 2018. Küresel iklim değişikliği ile mücadelede ormanların karbon depolama kapasitesinin uzaktan algılama yöntemleri ile belirlenmesi. Available online: http://uzalmet.mgm.gov.tr/tammetin/2019/26.pdf (Accessed: 01 June 2021).

Yiğit E, 2021. The relationship between economic growth and environmental pollution in D8 countries: Panel VAR analysis. *TOGU Career Res J* 2(2): 31–40.