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Investigating the Dynamic Relationship Between Greenhouse Gas Emissions and Gross Domestic Product in Türkiye

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Abstract

This study aims to investigate the causal relationship between Gross Domestic Product and greenhouse gas emissions in Türkiye from 1951 to 2018, using the Causal Decomposition Method that integrates Ensemble Empirical Mode Decomposition, Hilbert-Huang Transform, and Phase Coherence Methods. The primary focus is on identifying the key sectors contributing significantly to greenhouse gas emissions, particularly those connected to industrial production. The analysis reveals a one-way, short-term causal relationship from Gross Domestic Product to greenhouse gas emissions, spanning approximately 3 years. This finding suggests that changes in Gross Domestic Product have short-term effects on emissions, but not vice versa. Special emphasis is placed on the gases Cardon Dioxide, Methane and Nitrous Oxide, as they demonstrate a strong, consistent causal connection with Gross Domestic Product. The significance of this study lies in its utilization of the Ensemble Empirical Mode Decomposition approach to investigate this dynamic causality and address a notable gap in the existing literature. Empirical results indicate a complex yet observable association between Gross Domestic Product growth and greenhouse gas emissions in Türkiye, and that this relationship becomes more important, especially in the short and long term, with periodic fluctuations.

Keywords: Greenhouse Gas Emissions, Gross Domestic Product, Casual Decomposition Method, Macroeconomics, Türkiye

Türkiye'de Sera Gazı Emisyonları ile Gayrisafi Yurtiçi Hasıla Arasındaki Dinamik İlişkinin İncelenmesi

Öz

Bu çalışma, 1951 ile 2018 yıllarını kapsayan dönemde Türkiye'deki Gayrisafi Yurtiçi Hasıla ile sera gazı emisyonları arasındaki nedensel ilişkinin incelenmesini amaçlamaktadır. Bu inceleme, Topluluk Ampirik Kip Ayrıştırma, Hilbert-Huang Dönüşümü ve Faz Uyumluluk Yöntemlerinin entegre edilmesiyle birlikte Nedensel Ayrıştırma Yöntemi kullanılarak gerçekleştirilmiştir. Çalışmanın odak noktası, sanayi üretimiyle bağlantılı olan ve sera gazı emisyonlarına önemli ölçüde katkıda bulunan birincil sektörlerin belirlenmesidir. Analiz, Gayrisafi Yurtiçi Hasıladan sera gazı emisyonlarına doğru tek yönlü ve kısa vadeli bir nedensel ilişkiyi, yaklaşık olarak 3 yıllık bir dönemi kapsayacak şekilde ortaya koymaktadır. Bu bulgu, Gayrisafi Yurtiçi Hasıladaki değişikliklerin emisyonlar üzerinde kısa vadeli etkilere sahip olduğunu, ancak tersinin geçerli olmadığını öne sürmektedir. Çalışmada Karbondioksit, Metan ve Nitröz Oksit gazlarına özel önem verilmekte olup bu gazların Gayrisafi Yurtiçi Hasıla ile güçlü ve tutarlı bir nedensel ilişkisi olduğu gözlenmektedir. Çalışmanın önemi, ilgili dinamik nedenselliği incelemek için Topluluk Ampirik Kip Ayrıştırma yaklaşımının kullanılması ve mevcut literatürde önemli bir boşluğu doldurmasıdır. Ampirik sonuçlar, Türkiye'de Gayrisafi Yurtiçi Hasıla büyümesi ile sera gazı emisyonları arasında karmaşık ancak gözlemlenebilir bir ilişkinin olduğunu ve bu ilişkinin dönemsel dalgalanmalar ile birlikte özellikle kısa ve uzun vadede daha da önem kazandığını göstermektedir.

Anahtar Kelimeler: Sera Gazı Emisyonları, Gayrisafi Yurtiçi Hasıla, Nedensel Ayrıştırma Yöntemi, Makroekonomi, Türkiye

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Introduction

Air pollution and global warming endanger all life because of their negative consequences on biodiversity, the environment, the economy, human health, and welfare. Anyone seeking a global solution is worried about mitigating the negative consequences of climate change, and the world is discussing potential remedies through legislation and regulations (WHO, 2021; World Bank, 2022; Zhang et al., 2022).

Global warming is a fact that pertains to the observed or projected rise in global surface temperature, which is primarily attributed to human activities that result in radiative forcing. The phenomenon known as the greenhouse effect pertains to the assimilation of infrared radiation by diverse constituents present in the atmosphere, encompassing greenhouse gases (GHG), clouds, and aerosols. The aforementioned constituents absorb radiation emanating from the Earth's surface and other atmospheric elements, subsequently discharging infrared radiation uniformly in all directions. As concentrations of GHG elevate and the temperature of the Earth's surface and troposphere escalate, the magnitude of this phenomenon intensifies. GHG are a class of atmospheric gases that possess the ability to absorb and emit radiation at distinct wavelengths within the spectrum of terrestrial radiation emanating from the Earth's surface, atmosphere, and clouds. This phenomenon, in turn, leads to the occurrence of global warming and climate change, ultimately resulting in the greenhouse effect. It is noteworthy that GHG are of both natural and anthropogenic origin. The main types of GHG present in the Earth's atmosphere are Water Vapor (H_2O), Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), Methane (CH_4), and Ozone (O_3). Furthermore, the Montreal Protocol relates to a multitude of anthropogenic GHG present in the atmosphere, including Halocarbons and other compounds that contain Chlorine (Cl) and Bromine (Br) (IPCC, 2007; Allwood et al., 2014; Abbass et al., 2022; World Bank, 2022; European Parliament, 2023). In addition, the Kyoto Protocol pertains to GHG encompassing non-fluorinated gases, namely CO_2, CH_4, and N_2O, as well as Fluorinated Gases, including Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6), and Nitrogen Trifluoride (NF_3). From a practical standpoint, the representation of these gaseous substances as a singular unit concerning CO_2 equivalents facilitates their comparison and enables the assessment of their respective and cumulative impact on the phenomenon of global warming. The unit denoted as CO_2e signifies the quantity of GHG that has undergone standardization with respect to a unit mass of CO_2, taking into account the global warming potential of the gas (Eurostat, 2023a; UN, 2023; EPA, 2023a).

On the other hand, Gross Domestic Product (GDP) is an essential macroeconomic indicator used to quantify the total economic output of a country over a specific time period. GDP is a valuable instrument for determining a country's economic condition, growth, and productivity which is commonly calculated quarterly or annually including both tangible and intangible products. As stated before, due to its various advantages, GDP is a valuable indicator. GDP provides a comprehensive and standardized assessment of economic output, enabling international comparisons. GDP is also beneficial in tracking the growth of the economy and identifying business cycles. Additionally, it helps decision-makers develop fiscal and monetary policies and assess the effectiveness of economic interventions. Economists employ GDP to study long-term economic growth, income disparities, and the impact of economic policies. Policymakers rely on GDP to assess economic performance, identify areas of improvement, and make informed decisions regarding fiscal and monetary policies. Additionally, investors, businesses, and international organizations use GDP to evaluate market potential, allocate resources, and assess country risk. Besides, acknowledging the limitations of GDP is crucial in complementing it with additional indicators to provide a more complete assessment of societal welfare and progress (Callen, 2014; OECD, 2014; Eurostat, 2023b).

Furthermore, the relationship between GDP and GHG emissions in an economy is a critical area of study for achieving sustainable development. Throughout history, there has been a positive correlation between GDP growth and GHG emissions, driven by various factors. Typically, economic growth leads to increased emissions, primarily driven by production, energy consumption and the structural composition with countries heavily reliant on emissions-intensive industries. However, advancements in technology, policy interventions, and efforts to improve energy efficiency can help decouple economic growth from emissions. Striking a balance between economic growth and environmental sustainability, it is crucial to examine the relationship for achieving a sustainable and resilient economy that minimizes the negative impacts of GHG emissions on the environment and society (CBO, 2003; IPCC, 2022; Abbass et al., 2022).

In order to address the relevant research inquiries, this study examines the causal relationship between GDP and GHG emissions focusing on Türkiye, with a periodicity-based approach focusing on the primary sectors that exhibit noteworthy GHG emissions in relation to industrial production. Undoubtedly, if no measures are taken, Türkiye will experience the adverse impacts of global warming. Türkiye is considered to be a country with a high level of vulnerability to the potential impacts of global warming, which are further exacerbated by its rapidly growing economy.

Accordingly, to examine the relationship mentioned above, this study utilizes the Causal Decomposition Method by integrating Ensemble Empirical Mode Decomposition (EEMD), Hilbert-Huang Transform (HHT) and Phase Coherence Methods. The main contribution of the study to the academic literature is evidenced by the absence of any scholarly investigation utilizing the EEMD approach to analyze the dynamic causality between GDP and GHG emissions in Türkiye by including a focus on gas categories and industrial sectors, as revealed by the literature review. Conversely, the acquisition of high-quality data in ascertaining the causes of climate change is of utmost importance in mitigating GHG emissions, alongside emission push factors, ramifications, and climate change adaptation. Additionally, this study aims to contribute to potential solutions about the climate crisis and assess the extent to which commitments made under international agreements have been fulfilled.

The overall structure of the study is as follows. Beginning with an introduction to the study's significance and an elucidation of its core concepts, the paper proceeds to Section 1, which provides historical perspectives on the climate crisis in the World and Türkiye. In Section 2, the analysis shifts towards a comparative and descriptive assessment of GHG emissions and GDP at the global and top emitter countries level and situating Türkiye within this framework. To contextualize the study, Section 3 presents a comprehensive literature review, synthesizing existing knowledge and identifying gaps. Moreover, Section 4 describes the methodology of the study while Section 5 presents the data and empirical insights. Finally, the paper concludes in Section 6, where the accumulated findings are integrated and discussed in a conclusive reflection on the study's implications for addressing the climate crisis, recommendations, and its far-reaching consequences for Türkiye.

1. The Struggle Against the Climate Crisis in the World and Türkiye with Historical Outlines

Many countries around the World are anticipated to encounter significant environmental challenges in the near future, encompassing the consequences of extreme weather events, natural disasters, and climate change. The World is grappling with climate change and attempting to reduce GHG emissions in this context. For these reasons, various international agreements have been made to deal with the climate problem globally.

The foundational instance of the United Nations Environment Programme (UNEP) tackling the matter of ozone depletion occurred in 1976. In 1977, an assembly of ozone layer experts convened subsequent to the establishment of the Coordination Committee on the Ozone Layer (CCOL) by the UNEP and the World Meteorological Organization (WMO) to conduct periodic evaluations of ozone depletion. The year 1981 is noteworthy for being the time of the inception of the initial intergovernmental negotiations concerning the diminution of ozone-depleting substances (ODS). The Vienna Convention for the Preservation of the Ozone Layer was adopted by the aforementioned initiative in March 1985. Subsequent to the conclusion of the Convention, efforts have been initiated toward establishing a protocol that will provide immediate regulation of the utilization and production of ODS. The United Nations Framework Convention on Climate Change (UNFCCC), a worldwide environmental agreement that regulates the global fight against climate change, went into effect in 1994 and was validated by almost most of the world, encompassing all European Union (EU) member states. The principal objective of the agreement is to maintain the stability of GHG concentrations in the atmosphere at a level that would prevent detrimental human interference with the climate system. Besides, the Kyoto Protocol is an additional global environmental agreement that went into effect in 2005 which has the primary goal of the establishment of binding carbon reduction targets for industrialized countries, including all EU member states. Furthermore, the Paris Agreement, which went into effect in 2016 and is the first global climate agreement that is both universal and legally binding, is the most recent international environmental agreement. The Paris Agreement's objectives are to control global warming, develop adaptive capacity, increase resilience, and minimize vulnerabilities. In terms of decreasing GHG emissions under the 2030 Climate and Energy Framework, the EU has led international efforts to achieve the requirements of the Paris Agreement, especially with the European Green Deal Agreement. Similarly, the EU recently reaffirmed its goal of becoming the first climate-neutral continent by 2050 (MFA, 2023; DCC, 2023a; DCC, 2023b; DCC, 2023c; DCC, 2023d; DCC, 2023e; UNFCCC, 2023, 1992; Ministry of Trade, 2021).

On the other hand, Türkiye took several steps to fight the climate crisis. Türkiye's major international agreements on behalf of the climate crisis include the Montreal Protocol, Kyoto Protocol, Paris Agreement, and European Green Deal. A summary of the developments, measures and agreements implemented globally and within Türkiye to cope with the critical matter of the global climate crisis can be presented in the following.

- 1976: The matter pertaining to the depletion of ozone was initially deliberated upon in the Executive Council of the UNEP.
- 1977: Following the establishment of the CCOL by the UNEP and the WMO with the aim of conducting periodic evaluations of ozone depletion, a conclave of proficient ozone layer specialists convened.
- 1979: The first World Climate Conference (WCC) took place.
- 1981: The initial intergovernmental dialogue pertaining to the mitigation of ODS.
- 1985: The detection of the ozone hole over Antarctica was ascertained.

  The Vienna Convention pertaining to the safeguarding of the Ozone Layer convened.
- 1987: The adoption of the Montreal Protocol on ODS occurred.
- 1991: Türkiye became a party to the Montreal Protocol and ratified all its amendments.
- 1992: The UNFCCC adopted.

  Türkiye included, as an OECD member, in both the Annex-I and Annex-II lists alongside other developed countries.
- 1994: The UNFCCC was established.
- 1995: The first Conference of the Parties (COP 1) took place.
- 1997: Kyoto Protocol was adopted.
- 2001: The seventh session of the Conference of the Parties (COP7) held in Marrakech noticing Türkiye's unique status among Annex-I Parties and consequent removal from the Annex-II list of the UNFCCC while Türkiye's name remained on the Annex-I list.
- 2004: Türkiye became the 189th Party to accede to the UNFCCC.
- 2005: The Kyoto Protocol went into effect.
- 2008: The Regulation on Reduction of Substances that Deplete the Ozone Layer was officially published in the Turkish Official Gazette. Since then, the applicable agreement has undergone periodic revisions and updates up to the present time.
- 2009: The Turkish Grand National Assembly's adoption of the Law on the Approval of Türkiye's Participation in the Kyoto Protocol to the UNFCCC and the Council of Ministers' Decision signify the country's adoption of the Kyoto Protocol.

  Türkiye acceded to the Kyoto Protocol by submitting the requisite participation tool to the United Nations.
- 2015: The Paris Agreement was adopted.

  Türkiye officially submitted its Statement of Intended National Contribution to the Convention Secretariat regarding the Paris Agreement.
- 2016: The Paris Agreement went into effect.

  Türkiye signed the Paris Agreement.
- 2019: The European Green Deal has been announced.
- 2021: The Turkish Grand National Assembly's Law on Approval of the Paris Agreement has been enacted and published in the Official Gazette.

  The Ministry of Commerce of the Republic of Türkiye has formulated and released the Green Deal Action Plan under a Presidential Circular in the Official Gazette as part of its efforts to align with the European Green Deal (UNFCCC, 2023, 1992; MFA, 2023.; DCC, 2023a; DCC, 2023b; DCC, 2023c; DCC, 2023d; DCC, 2023e; Ministry of Trade, 2021; prepared by the authors).

2. Information About Greenhouse Gas Emissions and Gross Domestic Product of the World, Top Emitter Countries and Türkiye

The economic sectors have been identified as the principal sources of GHG emissions, and the ramifications of climate change are significant for human activities. In addition, it is noteworthy to mention that the economies in question exhibit five principal sectors that are responsible for the emission of GHG. These sectors comprise fuel combustion and fugitive emissions encompassing energy and logistics; industrial processes and product use (IPPU); agriculture; land use, land-use change, and forestry (LULUCF); waste management. Actually, the principal origin of atmospheric contamination and the phenomenon of global warming is the disproportionate worldwide discharge of GHG (predominantly CO_2 and CH_4) resulting from the combustion of non-renewable resources for the purpose of energy and electricity production besides industrial production (EPA, 2023b; IPCC, 2021; CBO, 2003; WRI, 2020; Şahin et al., 2021).

The GHG emissions data utilized in this study for Türkiye are presented in Figure 1, categorized by gas type and sector, and encompassing the data for the World, the top emitter countries (countries with the highest GHG emissions) in order to make comparisons with Türkiye.

Upon examination of the GHG emissions data of the World, the top emitter countries [China, United States, EU (27), India, Russia, Japan, Brazil, Iran, Indonesia, South Korea], and Türkiye, it is evident that all these regions have demonstrated an upward trajectory in their emissions output, measured in units of $mtCO_2e$, over the period spanning from 1951 to 2018. In contemporary times, it is noteworthy that the energy sector has emerged as the foremost contributor to GHG emissions. Specifically, CO_2 has been identified as the most prevalent gas type released into the atmosphere. This fact is observed not only on a global scale but also both in the top emitter countries and Türkiye (Climate Watch, 2023) (see Figure 1).

The data indicate that the ratio of emissions stemming from the energy sector in the World was 65.2% in 1951, which increased to 73% in 1990 and further rose to 74.0% in 2018. Upon analyzing the GHG emissions concerning the IPPU sector, which constitutes another subject of this study, it is observed that its contribution to the overall GHG emissions (according to the Kyoto GHG definition) stood at 6.5% in 1951, 7.3% in 1990, and 9.6% in 2018. The data indicates a notable increase in emissions stemming from the energy and IPPU sectors, both in terms of volume and ratio. It is noteworthy that the energy sector is responsible for the majority of the total emissions. Furthermore, upon examining the CO_2, CH_4, and N_2O emissions data in relation to their gaseous classifications, it is observed that they constituted 61%, 29%, and 10% of the total GHG emissions in 1951. In 1990, these figures rose to 71%, 20%, and 8%, respectively. Similarly, in 2018, the percentages of CO_2, CH_4, and N_2O emissions were recorded as 75%, 16%, and 6% of the total GHG emissions, as can be seen in Panels (a) and (b) of Figure 1.

Through a closer examination of the aggregated data pertaining to the top GHG emitter countries, it is revealed that the energy sector's emissions accounted for 69.5% in 1951, 75.6% in 1990, and 76.9% in 2018. It is observed that the energy sector's emissions constitute the most significant ratio of the aggregate emissions in the top emitter countries. Upon analysis of the GHG emissions related to the IPPU sector, it is observed that the corresponding percentages were 6.7%, 7.5%, and 10.3% in the years 1951, 1990, and 2018, respectively. Furthermore, upon inspecting the distribution of CO_2, CH_4, and N_2O emissions with respect to their respective gas categories, it is observed that in 1951, the percentages were 66.4%, 25%, and 8.4%, respectively. In 1990, these percentages were 75.8%, 16.1%, and 6.9%, respectively. Lastly, in 2018, the percentages were 80.2%, 12.0%, and 5.6%, respectively, as can be seen in Panels (c) and (d) of Figure 1.

Furthermore, the provision of data regarding the GHG emission levels of Türkiye is of utmost importance for the formulation of policies pertaining to climate change both within the country and globally. Consequently, it is essential to analyze the status of Türkiye regarding GHG emissions and compare it with other geographical locations. Alongside the expeditious growth of its economy, Türkiye has been confronted with a noteworthy increase in its GHG emissions. A consistent upward trajectory has been noted in both aggregate and industry-specific emissions within the confines of Türkiye, particularly during the time span between 1990 and 2018. The GHG emissions stemming from both the energy and IPPU sectors exhibit a notable upward course between 1990 and 2018. Upon conducting an analysis of CO_2, CH_4, and N_2O emissions with respect to gas types, it was observed that in 1951, the ratios of these gases were 23.8%, 50.2%, and 25.8%, respectively. In the year 1990, these ratios endured a shift, with CO_2, CH_4, and N_2O accounting for 68.6%, 18.8%, and 12.5%, respectively. In 2018, the ratios of these gases further evolved, with CO_2, CH_4, and N_2O contributing to 79.6%, 10.9%, and 8.4%, respectively. The Panels (e) and (f) of Figure 1 demonstrate that the total GHG emissions amounted to roughly 530 metric tons in the year 2018. According to data, a significant increase of 135% compared to the levels recorded in 1990 and an even more substantial surge of 1,025% when compared to the data from 1951.

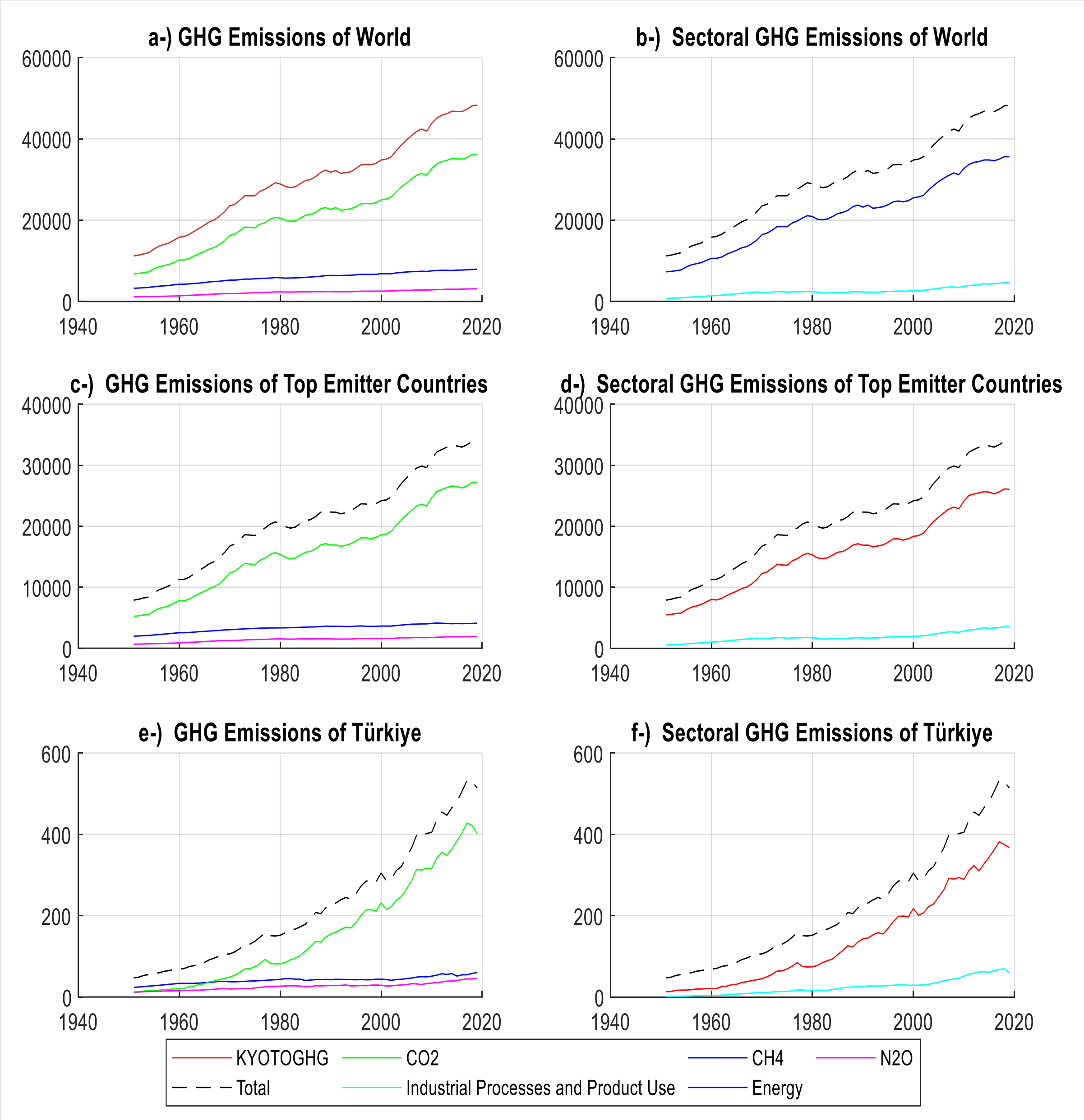

Figure 1. GHG Emissions of the World, Top Emitter Countries, and Türkiye ($MtCO_2e$) (1951-2018). **Source:** Climate Watch (2023), prepared by the authors.

Notably, the investigated data provide valuable insights into the sectoral distribution of GHG emissions in Türkiye and can inform future policy decisions aimed at reducing emissions. Upon conducting an analysis of GHG emissions in various economic sectors of Türkiye, it was observed that the energy sector accounted for the highest ratio of emissions. Specifically, in the years 1951, 1990, and 2018, the energy sector contributed 28.0%, 63.3%, and 70.8% of total emissions, respectively. On the other hand, the IPPU sector's share of total GHG emissions was 2.7%, 11.2%, and 13.1% in the years 1951, 1990, and 2018, respectively. When the emissions data on the energy and IPPU sectors are investigated with a focus on the share of CO_2, CH_4 and N_2O emissions, the results indicate as follows. In the energy sector, CO_2, CH_4, and N_2O

emissions accounted for 79.0%, 19.7%, and 2.1% of the total GHG emissions in 1951; 93.0%, 5.4%, and 1.4% in 1990; 96.5%, 2.6%, and 1.0% in 2018. In the IPPU sector, the corresponding figures were 71.2%, 0.8%, and 28.0% in 1951; 83.4%, 0.04%, and 13.8% in 1990; 84.0%, 0.03%, and 7.9% in 2018 (see Figure 2 and Figure 3).

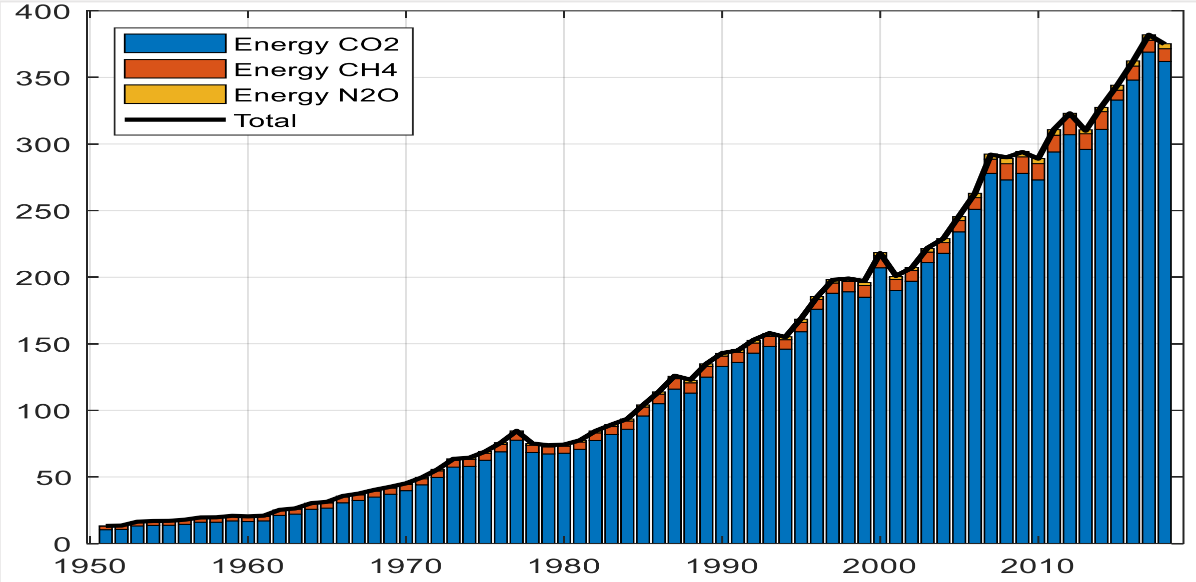

Figure 2. GHG Emissions Decomposition in Energy Sector of Türkiye ($MtCO_2e$) (1951-2018).
Source: Climate Watch (2023), prepared by the authors.

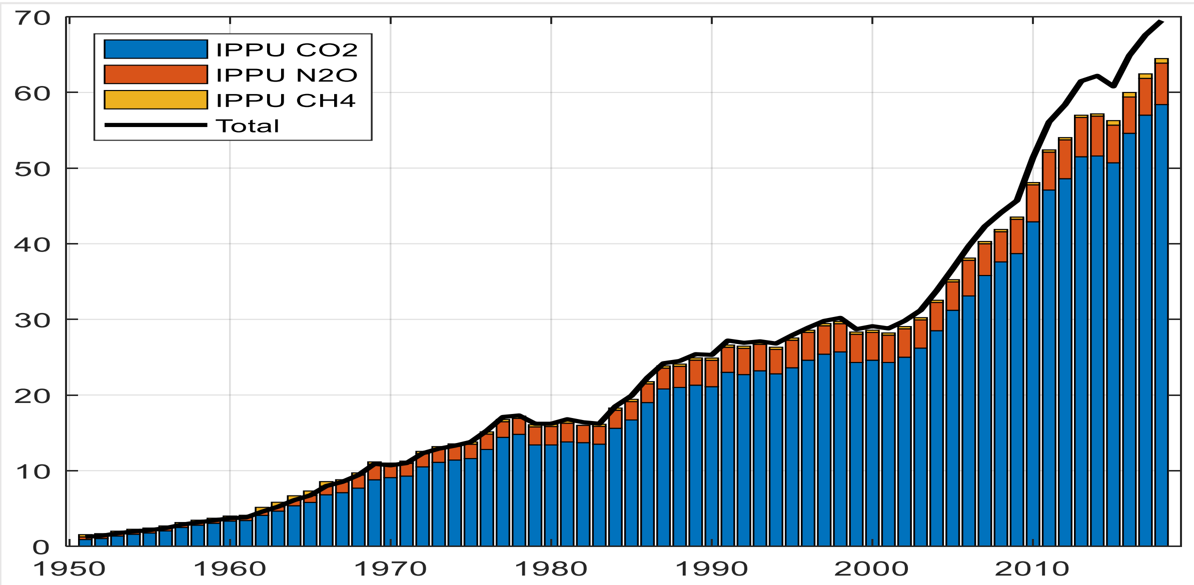

Figure 3. GHG Emissions Decomposition in IPPU Sector of Türkiye ($MtCO_2e$) (1951-2018).
Source: Climate Watch (2023), prepared by the authors.

Moreover, there exists a strong correlation between the GDP and GHG emission levels in Türkiye as well as other countries. Upon conducting a relevant analysis of Türkiye spanning from 1951 to 2018, which constitutes the focal point of this study, a notable association between the GDP and GHG emissions is evidently apparent. When the GDP data historically examined in Türkiye, a prevailing tendency of overall increase can be observed (95.97 billion dollars in

1951, 647.46 billion dollars in 1990, 2222.58 billion dollars in 2018). Türkiye's GDP progress has shown a mix of robust growth and economic volatility throughout its history. After the 1950s, especially during the 1960s and 1970s, Türkiye experienced rapid expansion driven by industrialization and modernization. In the 1980s, market-oriented reforms aimed at liberalization and private sector development contributed to moderate GDP growth. Economic stabilization programs and structural reforms in the 1990s improved the country's economic performance. The 2000s saw a period of strong growth, supported by structural reforms, export competitiveness, and fiscal discipline. Nonetheless, despite challenges encountered during the latter part of the decade and subsequent years including, such as currency depreciation, escalating inflation, and political uncertainties, Türkiye's economy continues to exhibit a representation of sustainable growth. It is important to note that Türkiye's GDP progress has not been without fluctuations and challenges, reflecting a complex economic landscape influenced by various factors, including policy choices, reforms, and external circumstances. The progress in GDP also affected the GHG emission levels of Türkiye. The observed economic growth and increase in GDP in Türkiye, which is over the years have also become evident in GHG emissions. Upon sectoral analysis, it is evident that the growth rates of sectors exhibit variations across different years, and this fact significantly influences the levels of increase observed in GHG emissions. Especially the increase in production within the energy and IPPU sectors, and its impact on the rise in GHG emissions, have attained even more noteworthy levels with the acceleration of industrialization (see Figure 4).

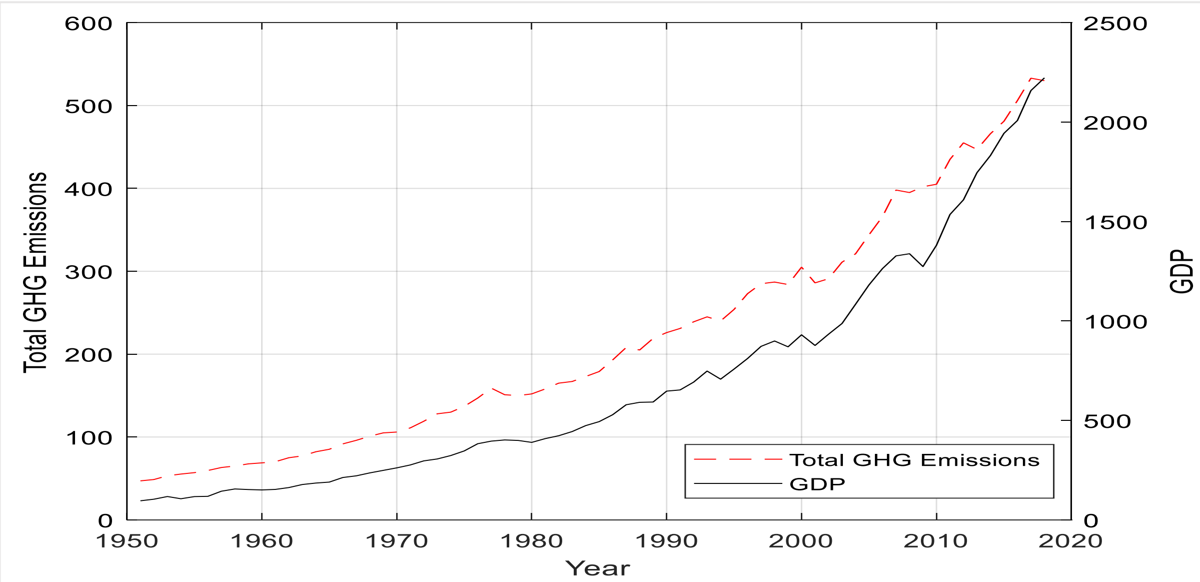

Figure 4. Total GHG Emissions ($MtCO_2e$) and GDP (US Dollars, billions, 2017=100) of Türkiye (1951-2018). **Sources:** Climate Watch (2023), FRED (2023), prepared by the authors.

In this context, the underlying causes behind the observed increases in GHG emissions within the domains of energy and IPPU sectors, which are the main investigation subjects of this study, can be explicated through a multitude of factors. Firstly, the energy sector is a significant contributor to GHG emissions in Türkiye. This is primarily due to the country's heavy reliance on fossil fuels, particularly coal and natural gas, for electricity generation and other energy needs. The combustion of these fossil fuels releases CO_2 and other GHG into the atmosphere. Türkiye's energy-related GHG emissions have been on the rise in recent years, largely due to increased energy consumption and economic growth. However, various efforts have been made to address this issue. Türkiye has been gradually diversifying its energy mix by increasing the share of renewable energy sources such as wind, solar, hydroelectric, and geothermal power. Additionally, energy efficiency measures have been promoted to reduce energy consumption and emissions intensity in various sectors. Secondly, the IPPU sector covers emissions resulting from industrial processes, such as the production and use of chemicals, cement, and other materials. These activities can generate GHG through the release of CO_2 and other gases during production and chemical reactions. In Türkiye, the IPPU sector contributes to GHG emissions, but its specific impact varies depending on the industrial activities and processes involved. To address emissions in the IPPU sector, Türkiye has implemented measures such as improving industrial processes, adopting cleaner technologies, and promoting energy efficiency. These efforts aim to reduce emissions intensity and improve the environmental performance of industrial activities (Tucker, 1995; Doll et al., 2000; Huang et al., 2008; Kaygusuz, 2009; Sözen et al., 2009; Öztürk & Acaravcı, 2010; Marrero, 2010; Haberl et al., 2020; Eskander & Fankhauser, 2020).

3. Literature Review

Since its introduction, the Empirical Mode Decomposition (EMD) Method has been extensively applied across various fields, including mechanical engineering (Ricci & Pennacchi, 2011), signal cleaning (Li et al., 2011; Lahmiri, 2014a; Lahmiri & Boukadoum, 2015a), speaker identification (Wu & Tsai, 2011), biomedical image processing (Ai et al., 2011; Lahmiri & Boukadoum, 2014b, 2015b), DNA analysis (Zhang & Yan, 2012), and machine diagnostics (Cheng et al., 2012). Furthermore, EMD has gained considerable attention in analyzing financial and economic data for forecasting purposes, such as modeling and predicting crude oil prices (Zhang et al., 2008, 2009; Awajan et al., 2018; Ahmad et al., 2021), agricultural prices (Das et al., 2020; Fang et al., 2020), stock markets (Cheng & Wei, 2014; Gyamfi et al., 2021), carbon prices (Zhu et al., 2015), electricity prices (An et al., 2013; Lisi &

Nan, 2014), inflation rates (Amar & Guennoun, 2012; Xia & Huang, 2022), foreign exchange rates (Lin et al., 2012; Premanode & Toumazou, 2013; Rashid et al., 2016), and GDP (Lin, 2022).

In recent carbon emissions and climate change studies, decomposition methods, especially the EMD Method and its variants, have been pivotal. Zhang & Tang (2023) introduced a hybrid model integrating Variational Mode Decomposition (VMD) and CEEMDAN, processed alongside LSSVM and LSTM networks for predicting carbon prices. Kong et al. (2022) combined EEMD with a PSO-BP neural network for short-term carbon emissions prediction. Meanwhile, Zhou & Wang (2021) incorporated both EMD and VMD in a carbon price prediction model optimized by the Sparrow search algorithm. Bokde et al. (2021) emphasized the importance of short-term CO_2 forecasting using the EEMD Method, proving its superior precision for timely renewable energy integration and CO_2 reduction strategies.

However, EMD has its limitations, and various modifications have been proposed over the years to address these shortcomings. One frequently employed modification in the literature is the Ensemble Empirical Mode Decomposition (EEMD) method, proposed by Wu and Huang (2009). The EEMD method serves as the foundation for the causal decomposition method employed to analyze causal relationships. Combining EEMD with phase coherence yields the concept of causal decomposition, which is employed to determine the relationships between two series' components (Yang et al., 2018). Granger (1969) introduced the idea of prediction, which has since governed the scientific criteria for evaluating causal linkages between two time series. Granger Causality assumes that cause and influence can be separated (Sugihara et al., 2012). This assumption works well for linear stochastic systems but may fail for nonlinear deterministic systems where cause and influence cannot be distinguished (Takens, 1981; Deyle & Sugihara, 2011). Moreover, Time-domain Granger Causality tests overlook the possibility that causality strength, direction, or presence may change at different frequencies (Lemmens et al., 2008). Granger (1988) emphasized the significance of frequency-domain causality decomposition, particularly in cointegrated systems with zero-frequency causality (Granger & Lin, 1995). Yang et al. (2018) presented a novel causal decomposition method based on instantaneous phase dependency between cause and effect, independent of prediction, time, or state information. This approach first decomposes two time series into several intrinsic mode functions (IMFs) using EEMD (Wu & Huang, 2009) and then detects causality transferred into instantaneous phase dependency between two signals at a specific time scale. Researchers have applied the EEMD-based causal decomposition method to analyze the economic growth fluctuations of ten major countries (Mao et al., 2020) and investigate the causal relationship between COVID-19 dissemination and mobility levels across multiple time scales (Cho et al., 2022). Xu et al. (2022) presented a new causal decomposition method to explore the information flow between two financial time series on distinct time scales.

In summary, the EMD method and its modification, EEMD, have been widely applied in various disciplines, including financial and economic data analysis for forecasting purposes. While traditional Granger causality approaches have limitations in handling nonlinear deterministic systems and frequency changes, causal decomposition methods based on EEMD, and phase coherence have been introduced to address these issues. Recent studies have successfully employed these methods, highlighting their potential for further research and applications in diverse fields.

4. Methodology

This study uses a comprehensive methodology that integrates the EEMD Method, HHT Method, and Phase Coherence Method for Causal Decomposition to analyze the complex relationships between non-stationary and nonlinear economic time series. This integrated approach allows for a more robust examination of the underlying dynamics, leading to better informed policy decisions and strategies.

The first step of the methodology involves the application of EEMD, which advances upon the original EMD Method of Huang et al. (1998) by addressing mode mixing issues (Wu and Huang, 2009). By adding white noise to the data, EEMD allows for better separation of the IMFs. This decomposition enables the analysis of the relationships between the time series at different time scales:

$$c_i(t) = \lim_{nw \to \infty} \sum_{k=1}^{nw} \left(c_i(t) + r \times w_k(t)\right) \tag{1}$$

where, $w_k(t)$ is the white noise added and k donates the kth experiment of the i^{th} IMF.

Next, the HHT is employed to derive the instantaneous phase and frequency of the mutual IMF and trends of the two signals. This provides insights into the instantaneous relationships between the time series:

$$z(t) = c(t) + jH[c(t)] = a(t)e^{j\phi(t)} \tag{2}$$

where $H[c(t)]$ is the Hilbert Transform, and $a(t)$and $\phi(t)$ are the instantaneous amplitude and phase, respectively. The instantaneous frequency can be calculated using the deviation of the phase function:

$$\omega(t) = \frac{d\phi(t)}{dt} \tag{3}$$

Building upon the decomposed time series using EEMD and the instantaneous phase and frequency information from HHT, the phase coherence between the connected IMFs of two time series is calculated to evaluate the strength of the causal relationships:

$$\text{Coh}\ (c_{1i}, c_{2i}) = \frac{1}{T}\left|\int_0^T e^{j\Delta\phi_{12i}(t)}dt\right| \tag{4}$$

The integration of EEMD and HHT facilitates the quantification of the absolute and relative causal relationships using the R and Cau values, respectively:

$$R(c_{1i} \to c_{2i}) = \left\{\sum_{i=1}^{n} W_i[\text{Coh}\ (c_{1i}, c_{2i}) - \text{Coh}\ (c_{1i}, c'_{2i})]^2\right\}^{\frac{1}{2}} \tag{5}$$

$$R(c_{2i} \to c_{1i}) = \left\{\sum_{i=1}^{n} W_i[\text{Coh}\ (c_{1i}, c_{2i}) - \text{Coh}\ (c'_{1i}, c_{2i})]^2\right\}^{\frac{1}{2}} \tag{6}$$

$$W_i = (\text{Var}_{1i} \times \text{Var}_{2i}) / \sum_{i=1}^{n} (\text{Var}_{1i} \times \text{Var}_{2i}) \tag{7}$$

A Cau value of 0.5 indicates no evident causal link, while values of 0 or 1 suggest a significant causal difference.

By integrating EEMD, HHT, and Phase Coherence Models, the methodology of the study provides a comprehensive analysis of the causal relationships between non-stationary and nonlinear economic time series at different time scales. This interconnected approach yields valuable insights into the dynamics and interactions between economic variables, allowing for a more nuanced understanding of their behavior and the potential implications for policy-making and strategic decisions.

In summary, the integrated methodology of the study proceeds as follows:

(i) Apply EEMD to decompose the non-stationary and nonlinear time series into a set of IMFs at different time scales.

(ii) Utilize HHT to derive the instantaneous phase and frequency of the mutual IMF and trends of the two signals, revealing the relationships between the time series at various time scales.

(iii) Calculate the phase coherence between the connected IMFs of the two-time series, providing a measure of the strength and direction of the causal relationships.

(iv) Quantify the absolute and relative causal relationships using R and Cau values, offering insights into the intensity and direction of the causal links between the time series.

The abovementioned methodology enables a more comprehensive understanding of the complex relationships between economic time series, which can inform policy decisions and guide strategic actions in response to various economic events and trends. By examining the causal relationships at different time scales, this approach allows researchers and policymakers to uncover hidden patterns and dependencies that may not be apparent when using traditional econometric methods.

5. Data and Empirical Findings

In this study, annual data from 1951 to 2018 for GDP and three sectors (total, energy, IPPU) alongside four different categories of GHG [Kyoto GHG (total), CO_2, CH_4, N_2O] emissions are analyzed. GDP data are obtained from the Federal Reserve Bank of St. Louis (FRED), while GHG emission data are sourced from the Climate Watch (see Table 1). To disregard the impact of the COVID-19 pandemic period, data from the years 2019 and 2020 have not been considered. Furthermore, the most up-to-date data available in the relevant database is for the year 2020. Since an examination of the pandemic period and beyond cannot be conducted with this dataset, these years have been omitted. Before starting to analyze the data, firstly, the logarithmic difference of each series is calculated to ensure stationarity. The level of noise added to the original time series is set at 0.35, and the ensemble number is chosen to be 10,000.

The analysis involves two primary steps in the study. First, applying the EEMD algorithm to obtain all series' IMFs. Second, proceeding to examine the relationship between the GDP and the IMFs of the GHG. This approach allows to uncover the complex interactions between economic progress and GHG emissions, providing insights into the potential implications of these relationships for policy-making and strategic decision-making in the context of climate change and sustainable development.

Table 1. Data Summary

Variable	Abbreviation	Time Span	Unit	Source
Gross Domestic Product	GDP	1951-2018	US Dollars (billions) (2017=100)	Federal Reserve Bank of St. Louis
Kyoto Greenhouse Gas (Total)	KYOTOGHG	1951-2018	$mtCO_2e$	Climate Watch
Carbon Dioxide	CO_2	1951-2018	$mtCO_2e$	Climate Watch
Methane	CH_4	1951-2018	$mtCO_2e$	Climate Watch
Nitrous Oxide	N_2O	1951-2018	$mtCO_2e$	Climate Watch

Sources: FRED (2023), Climate Watch (2023).

5.1. Ensemble Empirical Mode Decomposition Analysis

Figure 5 and Figure 6 illustrate the EEMD analysis of the series. The IMFs obtained from the EEMD algorithm show the decomposition of the original series. The decompositions are presented from short-term (IMF1) to long term (IMF5).

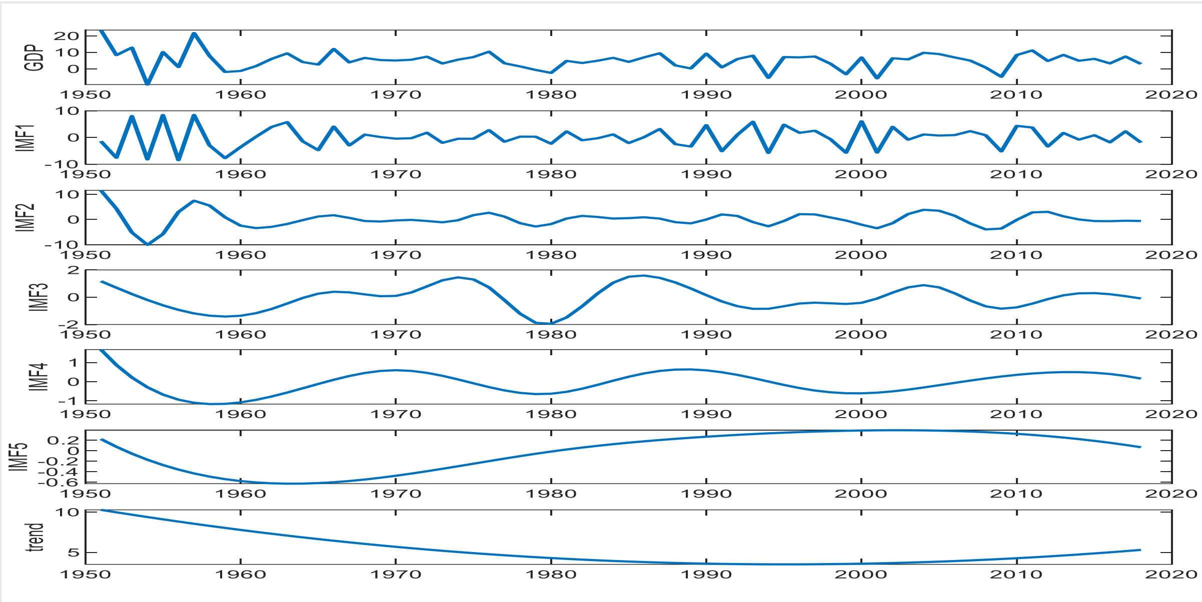

Figure 5. EEMD Analysis of the Change of GDP

IMF4 and IMF5 depict the long-term oscillations of GDP. Based on these trends, there is a discernible decline in GDP growth from 1950 to 1990, followed by an upswing post-1990. Yet, upon examining IMF4 and IMF5, it becomes evident that GDP growth declined post-2010. Upon examining Table 2, it is evident that the two components that account for the highest variance contribution rate to GDP formation are IMF1 and IMF2. Their average period durations are 1.31 and 2.83 years, respectively. Notably, these first two components demonstrate a more significant correlation with GDP compared to subsequent components. From this perspective, the components with the most substantial influence on GDP formation are characterized by short-term oscillations. Specifically, short-term fluctuations, totaling to approximately 4 years (1.31 + 2.83 = 4.14 years), are paramount to GDP's structure.

The analysis infers that in Türkiye, GDP formation is significantly influenced by components with short-term oscillations. More precisely, fluctuations spanning roughly 4 years exert the most pronounced impact on GDP growth. These insights underscore the criticality of discerning and managing short-term economic fluctuations when evaluating Türkiye's economic trajectory and when formulating pertinent economic policies.

An examination of Figure 6 indicates an ascending long-term trend in gases released in the industrial domain post-2000. In contrast, the prolonged trend in gases emitted within the energy sector displays a decreasing inclination. When examining the GHG emissions components from Table 2, the initial two components emerge with the highest correlation and variance contribution rates. A particularly robust and linear association exists with IMF1, the dominant component across all GHG. Analogous to the GDP observation, the cumulative average period of the premier two components hovers around 4 to 5 years for all gas classifications. It can thus be inferred that high-frequency components marked by short-term emissions are pivotal in shaping GHG emissions.

Table 2. The Variance Contribution, Correlation and Corresponding Period of Each IMF for All Series

IMFs	Variables	GDP	KYOTOGHG			CO_2			CH_4		N_2O		
			Total	**Energy**	**Industrial**	**Total**	**Energy**	**Industrial**	**Total**	**Energy**	**Total**	**Energy**	**Industrial**
IMF1	Variance ratio	52.37	62.07	61.02	36.78	59.62	62.79	33.07	50.58	58.62	59.51	46.63	36.75
	Correlation	0.31	0.77	0.73	0.52	0.71	0.74	0.52	0.58	0.65	0.71	0.59	0.53
	Average period	1.31	1.48	1.36	1.39	1.42	1.36	1.39	1.26	1.36	1.51	1.51	1.45
IMF2	Variance ratio	31.19	20.96	14.38	22.47	12.89	15.05	15.71	26.76	10.94	25.38	30.01	23.15
	Correlation	0.30	0.49	0.47	0.48	0.48	0.45	0.46	0.56	0.37	0.56	0.63	0.49
	Average period	2.83	3.24	2.72	3.40	2.96	2.96	3.40	3.24	3.24	2.83	2.96	3.58
IMF3	Variance ratio	2.58	5.27	6.26	9.70	4.81	6.21	7.65	11.53	10.59	6.07	12.70	21.20
	Correlation	0.22	0.34	0.39	0.50	0.37	0.37	0.49	0.39	0.37	0.31	0.41	0.60
	Average period	4.86	5.67	4.86	5.67	4.86	4.86	5.67	4.86	5.23	5.23	5.67	5.23
IMF4	Variance ratio	1.01	0.91	3.05	3.61	2.16	3.21	2.31	2.07	4.25	6.32	3.30	6.26
	Correlation	0.11	0.08	0.17	0.41	0.15	0.18	0.36	0.25	0.34	0.30	0.13	0.39
	Average period	8.50	8.50	8.50	9.71	8.50	8.50	9.71	7.56	8.50	9.71	9.71	9.71
IMF5	Variance ratio	0.42	0.65	0.34	1.16	0.42	0.23	0.25	0.88	9.59	0.74	0.38	1.28
	Correlation	-0.16	-0.12	-0.17	0.56	-0.17	-0.12	0.21	0.21	0.15	0.25	0.07	0.34
	Average period	17.00	17.00	13.60	13.60	13.60	13.60	13.60	13.60	17.00	17.00	13.60	13.60

Note: The average period (year) is defined as the value derived from dividing the number of points by the number of peaks for each IMF. The variance ratio is the percentage of an IMF's variance to the total variance of the IMFs and the residual. Correlation is the Pearson correlation between IMFs and original series.

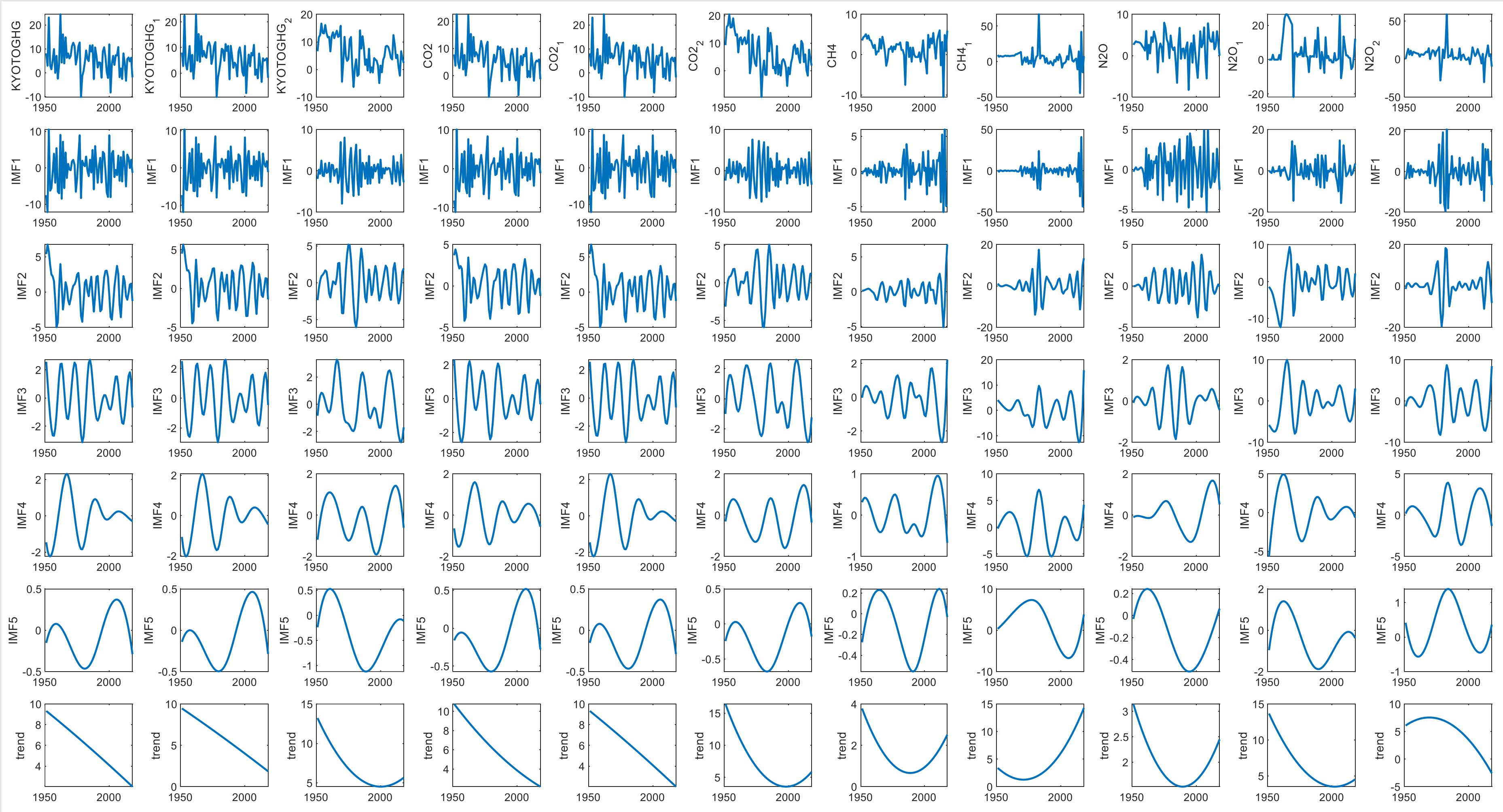

Figure 6. EEMD Analysis of the Change of GHG Emissions. **Note:** Indices 1 and 2 in the graph represent the energy and industry sectors respectively. Those with no indices mean the total amount of emissions.

5.2. Causal Decomposition Analysis

The causal decompositions are illustrated in Figure 7. When Phase Coherences equate to 0.5, it indicates an absence of a relationship between the components. However, this coherence surpasses 0.5, suggesting a causative link from GDP to GHG emissions. An analysis of Figure 7 reveals no such causality within IMF3 to IMF5, implying an absence of a long-term relationship between GDP and GHG emissions. Conversely, causality from GDP to GHG emissions is apparent in all representations within IMF2. With IMF2 having an average period of approximately 3 years, it suggests a short-term causal relationship from GDP to GHG emissions.

This observation underscores policymakers' need to recognize the immediate ramifications of economic growth on national emissions. They should tailor interventions to address the direct effects of economic variances on GHG emissions, without presupposing prolonged continuity of these relationships. By focusing on the short-term dynamics, policymakers can proficiently navigate the environmental implications of economic progression, steering Türkiye towards a sustainable future.

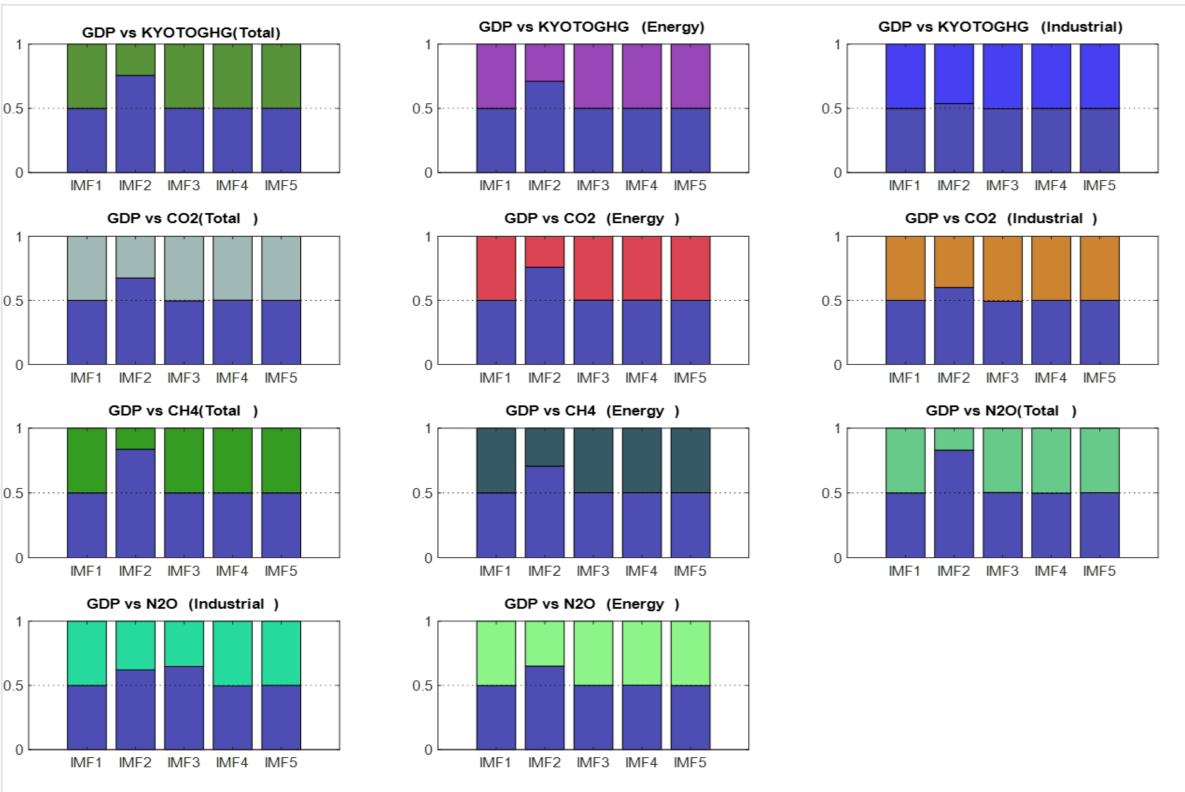

Figure 7. The Causal Relationship of GDP versus GHG Emissions. **Note:** The dark blue colored part at the bottom of the bar graph shows GDP and the upper parts show the GHG emissions.

Upon closer examination, the two most pronounced causal relationships are observed from GDP to CH4(Total) and N2O(Total). In contrast, the most tenuous relationship is identified from GDP to KYOTOGHG(Industrial). Furthermore, a causal link from GDP to N2O(Industrial) is evident within the IMF3s, which has an average duration of about 5 years. This suggests that a causative relationship between GDP and N2O(Industrial) exists in short and medium terms.

A noticeable causality is observed between the IMF2 of GDP and CO_2, specifically from GDP to CO_2. A sectoral breakdown reveals this relationship to be more pronounced in the energy sector than the industrial sector, with a causative link from GDP to CO_2 spanning approximately 3 years.

These insights emphasize the need for policymakers in Türkiye to acknowledge the subtle impacts of GDP fluctuations on diversified GHG emissions. Recognizing the specific gases and sectors that are most responsive to GDP shifts will enable the crafting of targeted strategies to counterbalance the environmental repercussions of economic expansion. Addressing these identified causal links over short and medium durations is pivotal in guiding Türkiye toward a sustainable course.

6. Conclusion

The relationship between Gross Domestic Product (GDP) and greenhouse gas (GHG) emissions is a complex and multidimensional issue. Actually, the structure of an economy influences its emissions profile. Countries with a larger share of emissions-intensive industries in their GDP composition tend to have higher emission levels. While economic growth has historically been associated with increased emissions, it is essential to pursue sustainable development pathways that decouple GDP growth from emissions. This necessitates the adoption of cleaner technologies, energy efficiency measures, policy interventions, and the integration of environmental considerations into economic decision-making. By associating economic and environmental objectives, countries can adopt a sustainable and resilient future, balancing economic prosperity with climate change mitigation.

In order to contribute in line with the above-mentioned subjects, this study analyzed the causality relationship between GDP and GHG emissions using annual data for the 1951-2018 period using Causal Decomposition Methods for Türkiye. It has been observed that the first two components of GDP obtained as a result of the EEMD algorithm have the most significant effect on GDP. This means that a significant part of the underlying divergence of GDP consists of approximately 4 years of movements. Similar findings apply to GHG emissions. Moreover, this study has identified that the two most pronounced causal relationships are from GDP to CH4(Total) and N2O(Total), underlining the sectors that require the most immediate attention for emissions reduction. In contrast, the most tenuous relationship is identified from GDP to KYOTOGHG(Industrial). Further enhancing our understanding, a causal link from GDP to N2O(Industrial) is evident within the IMF3s, with an average duration of about 5 years, suggesting that the relationship exists in both short and medium terms.

However, the study also establishes that there is a one-way, short-term causality relationship from GDP to GHG emissions, covering a period of approximately 3 years. Therefore, changes in GDP over 3-year intervals affect gas emissions, but not vice versa. Looking at the historical development in Türkiye, it is clear that while GDP plays an important role in reducing gas emissions, this role has short-term effects. From this perspective, it can be stated that longer-term plans may not be as effective when examined according to the historical process. Another significant finding is the observable causality between the IMF2 component of GDP and CO_2 emissions, specifically flowing from GDP to CO_2. Further sectoral analysis reveals that this causal relationship is more pronounced in the energy sector as compared to the industrial sector. Importantly, this causative link between GDP and CO_2 has been found to span approximately 3 years.

In conclusion, this study has provided valuable insights into the relationship between GDP and GHG emissions in Türkiye. Through a comprehensive analysis using the EEMD algorithm, IMF components, and causal decompositions, the research has uncovered several key findings that have implications for both policymakers and businesses.

The abovementioned findings underline the need for targeted interventions that focus on the specific gases and sectors most affected by changes in GDP. From a decision-making perspective, businesses operating in sectors that are highly influenced by GDP fluctuations, particularly those involving CO_2, CH_4 and N_2O emissions, should be proactive in implementing strategies to minimize their environmental footprint. This may involve adopting cleaner technologies, improving energy efficiency, or investing in renewable energy sources. Furthermore, companies should monitor and anticipate the effects of economic changes on their operations and the environment. By doing so, they can better adapt to changing circumstances and contribute to sustainable development goals. Policymakers should also consider providing incentives and support for businesses that implement environmentally-friendly practices and technologies, as these initiatives can help to mitigate the adverse effects of economic growth on GHG emissions. In summary, this research has shed light on the complex relationship between GDP and GHG emissions in Türkiye. By understanding these dynamics and their implications, both policymakers and businesses can work together to promote sustainable economic growth that minimizes environmental impacts. The findings of this study provide a solid foundation for future research and policy development, with the potential to guide Türkiye on its path towards a greener and more sustainable future.

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, *29*(28), 42539-42559.

Ahmad, W., Aamir, M., Khalil, U., Ishaq, M., Iqbal, N., & Khan, M. (2021). A new approach for forecasting crude oil prices using median ensemble empirical mode decomposition and group method of data handling. *Mathematical Problems in Engineering*, 1-12.

Ai, L., Wang, J., & Yao, R. (2011). Classification of parkinsonian and essential tremor using Empirical Mode Decomposition and support vector machine. *Digital Signal Processing*, *21*(4), 543-550.

Allwood, J. M., Bosetti, N. K., Gomez-Echeverri, L., von Stechow, C., & Smith, P. (2014). Annex I: Glossary, Acronyms and Chemical Symbols. In *Climate Change 2014: Mitigation of Climate Change.: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1249-1279). Cambridge University Press. (Access Date: 22.07.2023)

Amar, A., & Guennoun Z.E.A. (2012). Contribution of wavelet transformation and empirical mode decomposition to measurement of US core inflation. *Applied Mathematical Sciences*, *6*(135), 6739-6752.

An, N., Zhao, W., Wang, J., Shang, D., & Zhao, E. (2013). Using multi-output feedforward neural network with empirical mode decomposition based signal filtering for electricity demand forecasting. *Energy*, *49*, 279-288.

Awajan, A. M., Ismail, M. T., & Al Wadi, S. (2018). Improving forecasting accuracy for stock market data using EMD-HW bagging. *PloS one*, *13*(7), e0199582.

Bokde, N. D., Tranberg, B., & Andresen, G. B. (2021). Short-term CO2 emissions forecasting based on decomposition approaches and its impact on electricity market scheduling. *Applied Energy*, *281*, 116061.

Callen, T. (2014). *Gross Domestic Product: An Economy's All*. https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/gross-domestic-product-GDP (Access Date: 21.07.2023)

CBO (2003). *The Economics of Climate Change: A Primer*. https://www.cbo.gov/sites/default/files/108th-congress-2003-2004/reports/04-25-climatechange.pdf (Access Date: 21.07.2023)

Cheng, C. H., & Wei, L. Y. (2014). A novel time-series model based on Empirical Mode Decomposition for forecasting TAIEX. *Economic Modelling*, *36*, 136-141.

Cheng, J., Yang, Y., & Yang, Y. (2012). A rotating machinery fault diagnosis method based on Local Mean Decomposition. *Digital Signal Processing*, *22*(2), 356-366.

Cho, J. H., Kim, D. K., & Kim, E. J. (2022). Multi-scale causality analysis between COVID-19 cases and mobility level using ensemble Empirical Mode Decomposition and Causal Decomposition. *Physica A: Statistical Mechanics and its Applications*, *600*, 127488.

Climate Watch (2023). *Greenhouse Gas (GHG) Emissions*. https://www.climatewatchdata.org/ghg-emissions (Access Date: 21.06.2023)

Das, P., Jha, G. K., Lama, A., Parsad, R., & Mishra, D. (2020). Empirical Mode Decomposition based support vector regression for agricultural price forecasting. *Indian Journal of Extension Education*, *56*(2), 7-12.

DCC (2023a). *United Nations Framework Convention on Climate Change*. https://iklim.gov.tr/en/un-framework-convention-on-climate-change-i-114 (Access Date: 12.06.2023).

DCC (2023b). *Vienna Convention*. https://iklim.gov.tr/en/vienna-convention-i-119 (Access Date: 12.06.2023).

DCC (2023c). *Montreal Protocol*. https://iklim.gov.tr/en/montreal-protocol-i-120 (Access Date: 12.06.2023).

DCC (2023d). *Kyoto Protocol*. https://iklim.gov.tr/en/kyoto-protocol-i-118 (Access Date: 12.06.2023).

DCC (2023e). *Paris Agreement*. https://iklim.gov.tr/en/paris-agreement-i-117 (Access Date: 12.06.2023).

Deyle, E. R., & Sugihara, G. (2011). Generalized theorems for nonlinear state space reconstruction. *Plos one*, *6*(3), e18295.

Doll, C. H., Muller, J. P., & Elvidge, C. D. (2000). Night-time imagery as a tool for global mapping of socioeconomic parameters and greenhouse gas emissions. *AMBIO: A Journal of the Human Environment*, *29*(3), 157-162.

EPA (2023a). *Basics of Climate Change*. https://www.epa.gov/climatechange-science/basics-climate-change (Access Date: 21.06.2023)

EPA (2023b). *Sources of Greenhouse Gas Emissions*. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (Access Date: 21.06.2023)

Eskander, S. M. S. U., & Fankhauser, S. (2020). Reduction in greenhouse gas emissions from national climate legislation. *Nature Climate Change, 10*(8), 750-756.

European Parliament (2023). *Climate Change: The Greenhouse Gases Causing Global Warming*. https://www.europarl.europa.eu/news/en/headlines/society/20230316STO77629/climate-change-the-greenhouse-gases-causing-global-warming (Access Date: 15.05.2023).

Eurostat (2023a). *Glossary: Greenhouse Gas (GHG) – Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Greenhouse_gas_(GHG) (Access Date: 15.05.2023).

Eurostat (2023b). *National Accounts and GDP – Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=National_accounts_and_GDP&oldid=571240 (Access Date: 15.05.2023).

Fang, Y., Guan, B., Wu, S., & Heravi, S. (2020). Optimal forecast combination based on ensemble Empirical Mode Decomposition for agricultural commodity futures prices. *Journal of Forecasting*, *39*(6), 877-886.

FRED (2023). *Real GDP at Constant National Prices for Turkey* (RGDPNATRA666NRUG). https://fred.stlouisfed.org (Access Date: 21.06.2023).

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society*, *37*(3), 424-438.

Granger, C. W. (1988). Some recent development in a concept of causality. *Journal of Econometrics*, *39*(1-2), 199-211.

Granger, C. W., & Lin, J. L. (1995). Causality in the long run. *Econometric Theory*, *11*(3), 530-536.

Gyamfi, E. N., Sarpong, F. A., & Adam, A. M. (2021). Drivers of stock prices in Ghana: an Empirical Mode Decomposition approach. *Mathematical Problems in Engineering*, *2021*, 1-7.

Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., Mayer, A., Pichler, M., Schaffartzik, A., Sousa, T., Streeck, J., & Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. *Environmental Research Letters*, *15*(6), 065003.

Huang, N. E., Shen, Z., Long, S. R., Wu, M. C., Shih, H. H., Zheng, Q., & Liu, H. H. (1998). The Empirical Mode Decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. *Proceedings of the Royal Society of London. Series A: mathematical, physical and engineering sciences*, *454*(1971), 903-995.

Huang, W. M., Lee, G. W., & Wu, C. C. (2008). GHG emissions, GDP growth and the Kyoto Protocol: A revisit of Environmental Kuznets Curve hypothesis. *Energy Policy*, *36*(1), 239-247.

IPCC (2007). *AR4 WGI Chapter 2: Changes in Atmospheric Constituents and in Radiative Forcing*. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch2.html (Access Date: 21.05.2023).

IPCC (2021). *AR6 Climate Change 2021: The Physical Science Basis*. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i (Access Date: 21.05.2023).

IPCC (2022). *Climate Change 2022: Mitigation of Climate Change*. https://www.ipcc.ch/report/ar6/wg3 (Access Date: 21.05.2023).

Kaygusuz, K. (2009). Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey. *Renewable and Sustainable Energy Reviews*, *13*(1), 253-270.

Kong, F., Song, J., & Yang, Z. (2022). A daily carbon emission prediction model combining two-stage feature selection and optimized extreme learning machine. *Environmental Science and Pollution Research*, *29*(58), 87983-87997.

Lahmiri, S. (2014a). Comparative study of ECG signal denoising by wavelet thresholding in Empirical and Variational Mode Decomposition domains. *Healthcare Technology Letters*, *1*(3), 104-109.

Lahmiri, S., & Boukadoum, M. (2014b). Automated detection of circinate exudates in retina digital images using Empirical Mode Decomposition and the entropy and uniformity of the intrinsic mode functions. *Biomedical Engineering/Biomedizinische Technik, 59*(4), 357-366.

Lahmiri, S., & Boukadoum, M. (2015a). A weighted bio-signal denoising approach using Empirical Mode Decomposition. *Biomedical Engineering Letters*, *5*, 131-139.

Lahmiri, S., & Boukadoum, M. (2015b). Pathology grading in retina digital images using Student-adjusted Empirical Mode Decomposition and power law statistics. In *2015 IEEE 6th Latin American Symposium on Circuits & Systems (LASCAS)*, 1-4.

Lemmens, A., Croux, C., & Dekimpe, M. G. (2008). Measuring and testing Granger Causality over the spectrum: An application to European production expectation surveys. *International Journal of Forecasting*, *24*(3), 414-431.

Li, C., Wang, X., Tao, Z., Wang, Q., & Du, S. (2011). Extraction of time varying information from noisy signals: An approach based on the Empirical Mode Decomposition. *Mechanical Systems and Signal Processing*, *25*(3), 812-820.

Lin, C. S., Chiu, S. H., & Lin, T. Y. (2012). Empirical Mode Decomposition–based least squares support vector regression for foreign exchange rate forecasting. *Economic Modelling*, *29*(6), 2583-2590.

Lin, S. L. (2022). Application of Empirical Mode Decomposition to improve deep learning for US GDP data forecasting. *Heliyon*, *8*(1), e08748.

Lisi, F., & Nan, F. (2014). Component estimation for electricity prices: Procedures and comparisons. *Energy Economics*, *44*, 143-159.

Mao, X., Yang, A. C., Peng, C. K., & Shang, P. (2020). Analysis of economic growth fluctuations based on EEMD and causal decomposition. *Physica A: Statistical Mechanics and its Applications, 553*, 124661.

Marrero, G. A. (2010). Greenhouse gases emissions, growth and the energy mix in Europe. *Energy Economics*, *32*(6), 1356-1363.

MFA. (2023). *Türkiye'nin Çevre Politikası*. https://www.mfa.gov.tr/sub.tr.mfa?c74e3b4e-02fc-45fb-b019-384acb992538 (Access Date: 20.06.2023)

Ministry of Trade (2021). *Yeşil Mutabakat Eylem Planı*. https://ticaret.gov.tr/data/60f1200013b876eb28421b23/MUTABAKAT%20YEŞİL.pdf (Access Date: 20.06.2023)

OECD (2014). *Understanding National Accounts: Second Edition*. https://www.oecd-ilibrary.org/economics/understanding-national-accounts_9789264214637-en (Access Date: 20.06.2023)

Öztürk, I., & Acaravcı, A. (2010). CO2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews*, *14*(9), 3220-3225.

Premanode, B., & Toumazou, C. (2013). Improving prediction of exchange rates using differential EMD. *Expert systems with applications*, *40*(1), 377-384.

Rashid, N. I. A., Samsudin, R., & Shabri, A. (2016). Exchange rate forecasting using modified empirical mode decomposition and least squares support vector machine. *Int. J. Advance Soft Compu. Appl*, *8*(3), 31-47.

Ricci, R., & Pennacchi, P. (2011). Diagnostics of gear faults based on EMD and automatic selection of intrinsic mode functions. *Mechanical Systems and Signal Processing*, *25*(3), 821-838.

Şahin, G., Taksim, M. A., & Yitgin, B. (2021). Effects of the European Green Deal on Turkey's electricity market. *İşletme Ekonomi ve Yönetim Araştırmaları Dergisi*, *4*(1), 40-58.

Sözen, A., Gülseven, Z., & Arcaklıoğlu, E. (2009). Estimation of GHG emissions in Turkey using energy and economic indicators. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *31*(13), 1141-1159.

Sugihara, G., May, R., Ye, H., Hsieh, C. H., Deyle, E., Fogarty, M., & Munch, S. (2012). Detecting causality in complex ecosystems. *Science*, *338*(6106), 496-500.

Takens, F. (1981). Detecting strange attractors in turbulence. *Lecture Notes in Mathematics, 898*, 366-38

Tucker, M. (1995). Carbon dioxide emissions and global GDP. *Ecological Economics*, *15*(3), 215-223.

UN (2023). *Emissions of Greenhouse Gases*. https://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/atmosphere/ghg_emissions.pdf (Access Date: 21.07.2023)

UNFCCC (1992). *United Nations Framework Convention on Climate Change*. https://unfccc.int/resource/docs/convkp/conveng.pdf (Access Date: 12.05.2023)

UNFCCC (2023). *What is the United Nations Framework Convention on Climate Change*?. https://unfccc.int/process-and-meetings/what-is-the-united-nations-framework-convention-on-climate-change (Access Date: 12.05.2023)

WHO (2021). *Climate Change and Health*. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health (Access Date: 11.04.2023)

World Bank (2022). *Climate Change and Air Pollution*. World Bank. https://www.worldbank.org/en/news/feature/2022/09/01/what-you-need-to-know-about-climate-change-and-air-pollution (Access Date: 11.04.2023)

WRI (2020). *Greenhouse Gas Emissions by Countries and Sectors*. https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors (12.05.2023)

Wu, J. D., & Tsai, Y. J. (2011). Speaker identification system using empirical mode decomposition and an artificial neural network. *Expert Systems with Applications*, *38*(5), 6112-6117.

Wu, Z., & Huang, N. E. (2009). Ensemble empirical mode decomposition: A noise-assisted data analysis method. *Advances in Adaptive Data Analysis*, *1*(01), 1-41.

Xia, C., & Huang, J. (2022). Construction of inflation forecasting model based on Ensemble Empirical Mode Decomposition and Bayesian Model. *Journal of Sensors*, *2022*.

Xu, C., Zhao, X., & Wang, Y. (2022). Causal decomposition on multiple time scales: Evidence from stock price-volume time series. *Chaos, Solitons & Fractals*, *159*, 112137.

Yang, A. C., Peng, C. K., & Huang, N. E. (2018). Causal decomposition in the mutual causation system. *Nature Communications*, *9*(1), 3378.

Zhang, L., Xu, M., Chen, H., Li, Y., & Chen, S. (2022). Globalization, green economy and environmental challenges: State of the art review for practical implications. *Frontiers in Environmental Science*, *10*, 870271.

Zhang, T., & Tang, Z. (2023). Multi-step carbon price forecasting based on a new quadratic decomposition ensemble learning approach. *Frontiers in Energy Research*, *10*, 991570.

Zhang, W. F., & Yan, H. (2012). Exon prediction using empirical mode decomposition and Fourier transform of structural profiles of DNA sequences. *Pattern Recognition*, *45*(3), 947-955.

Zhang, X., Lai, K. K., & Wang, S. Y. (2008). A new approach for crude oil price analysis based on empirical mode decomposition. *Energy Economics*, *30*(3), 905-918.

Zhang, X., Yu, L., Wang, S., & Lai, K. K. (2009). Estimating the impact of extreme events on crude oil price: An EMD-based event analysis method. *Energy Economics*, *31*(5), 768-778.

Zhou, J., & Wang, S. (2021). A carbon price prediction model based on the secondary decomposition algorithm and influencing factors. *Energies*, *14*(5), 1328.

Zhu, B., Wang, P., Chevallier, J., & Wei, Y. (2015). Carbon price analysis using empirical mode decomposition. *Computational Economics*, *45*, 195-206.

Genişletilmiş Özet

Hava kirliliği ve küresel ısınma; biyolojik çeşitliliğe, çevreye, ekonomiye, insan sağlığına ve refaha olan olumsuz etkileri nedeniyle tüm yaşamı tehdit etmektedir. Küresel bir çözüm arayan ülkeler, iklim değişikliğinin olumsuz sonuçlarını hafifletme konusunda endişe duymakta ve tüm dünya, bu sorunların çözümü için yasama ve düzenlemeler aracılığıyla potansiyel çözümleri tartışmaktadır. Ayrıca küresel ısınma, küresel yüzey sıcaklığındaki gözlemlenen veya projeksiyonlarla tahmin edilen artışla ilgilidir ve bu artışın temel nedeni, radyoaktif zorlamaya yol açan insan faaliyetlerine dayandırılmaktadır. Sera etkisi olarak bilinen olgu ise atmosferde bulunan çeşitli bileşenler tarafından kızılötesi ışınların emilmesi ile ilgilidir. Bu bileşenler sera gazları (GHG), bulutlar ve aerosoller gibi çeşitli unsurları içerir. Bahsedilen bileşenler, Dünya'nın yüzeyinden ve diğer atmosfer unsurlarından gelen ışınları emer ve ardından kızılötesi ışınları tüm yönlere eşit bir şekilde yaymaya başlarlar. GHG yoğunlukları yükseldikçe ve Dünya'nın yüzeyi ile troposferin sıcaklığı arttıkça, bu olgunun büyüklüğü de artar. Sera gazları, Dünya'nın yüzeyinden, atmosferden ve bulutlardan gelen kızılötesi ışınların spektrumunda belirli dalga boylarında ışını emebilme ve yayabilme yeteneğine sahip bir tür atmosfer gazı sınıfını temsil eder. Bu olgu ise nihayetinde küresel ısınmanın ve iklim değişikliğinin ortaya çıkmasına, sonuç olarak da sera etkisinin meydana gelmesine yol açar.

Öte yandan, Gayrisafi Yurtiçi Hasıla (GSYH), belirli bir zaman diliminde bir ülkenin toplam ekonomik üretimini ölçmede kullanılan temel bir makroekonomik göstergedir. GSYH, bir ülkenin ekonomik durumu, büyüme ve verimliliğini belirlemede değerli bir araçtır ve genellikle çeyreklik veya yıllık olarak hesaplanırken hem somut hem de soyut ürünleri içermektedir.

Ayrıca, bir ekonominin GSYH ile GHG emisyonları arasındaki ilişki, sürdürülebilir kalkınmayı sağlayabilmek adına kritik bir araştırma alanıdır. Tarihsel olarak incelendiğinde, GSYH büyümesi ile GHG emisyonları arasında pozitif bir ilişki gözlenmektedir ve bu durum çeşitli faktörler tarafından desteklenmektedir. Tipik olarak ekonomik büyüme, üretim, enerji tüketimi ve emisyon yoğun endüstrilere ağırlık veren ülkelerin yapısal bileşimi artan emisyonlara yol açmaktadır. Ancak teknolojinin ilerlemesi, politika müdahaleleri ve enerji verimliliğini artırma çabaları, ekonomik büyümeyi emisyonlardan ayrıştırmaya yardımcı olabilir. Ekonomik büyüme ile çevresel sürdürülebilirlik arasında denge kurmak, çevre ve toplum üzerindeki GHG emisyonlarının olumsuz etkilerini en aza indiren sürdürülebilir ve olumsuz etkenlere karşı dayanıklı bir ekonomi elde edebilmek için bu ilişkiyi incelemek önemlidir.

GSYH ile GHG emisyonları arasındaki ilişki karmaşık ve çok boyutlu bir konudur. Aslında, bir ekonominin yapısı, emisyon profilini etkilemektedir. GSYH bileşiminde emisyon yoğun endüstriler açısından daha büyük bir paya sahip olan ülkeler genellikle daha yüksek emisyon seviyelerine sahiptir. Ekonomik büyümenin tarihsel olarak artan emisyonlarla ilişkilendirilmiş olmasına rağmen, GSYH büyümesini emisyonlardan ayrıştırabilmek için sürdürülebilir kalkınma yollarını izlemek önemlidir. Bu durum daha temiz teknolojilerin benimsenmesini, enerji verimliliği önlemlerini, politika müdahalelerini ve çevresel endişelerin ekonomik karar alma süreçlerine entegrasyonunu gerektirmektedir. Ekonomik ve çevresel hedefleri birleştirerek ülkeler, iklim değişikliği ile ekonomik refahı dengeleyen sürdürülebilir bir gelecek benimseyebilmektedirler.

Yukarıda bahsedilen konulara katkı sağlamak amacıyla bu çalışmada, 1951-2018 yılları arasında Türkiye için yıllık verileri kullanarak GSYH ve GHG emisyonları arasındaki nedensellik ilişkisi ele alınmaktadır. Analizde, geleneksel tahmine dayalı yaklaşımların aksine Nedensel Ayrıştırma Yöntemi kullanılmıştır. Bu yöntem, anlık faz bağımlılığına dayanarak sebep-sonuç ilişkilerinin daha derinlemesine incelenebilmesine imkân sağlamaktadır. Açıkçası bu yöntem, zaman veya durum bağımlılığına dayanmamakta olup anlık faz bağımlılığı üzerinden sebep ve sonuç arasındaki ilişkiyi değerlendirmektedir. İlgili metodoloji, iki temel varsayıma dayanmaktadır. İlk olarak herhangi bir sebep-sonuç ilişkisi, kaynak ve hedef arasındaki anlık faz bağımlılığı ile belirli bir zaman ölçeğine özgü bileşenlerde ölçülebilir. İkinci olarak, hedefte kaynaktan kaynaklanan faz dinamikleri, hedefin kendisiyle ayrılabilir. Diğer bir deyişle, bir etkinin kaynağı olan faktörü belirlemek için hedefteki dinamikleri ayrıştırmak mümkündür.

Analizlerde, Topluluk Kip Ayrıştırması ve Hilbert-Huang Dönüşümü gibi karmaşık matematiksel araçlar kullanarak anlık faz ve frekans bilgilerini elde edilmektedir. Faz uyumu, iki zaman serisi arasındaki nedensel ilişkilerin gücünü değerlendirmek için hesaplanmaktadır. Bu entegre yaklaşım, ekonomik değişkenler arasındaki etkileşimleri anlamak için değerli çıkarımlar sunmaktadır. Çalışmada, Türkiye'nin ekonomik performansı ve çevresel etkileri arasındaki nedensel ilişkileri anlamak için kapsamlı bir çerçeve sunulmaktadır. Bu durum, politika yapıcılar için GHG emisyonları ve ekonomik büyüme arasındaki dengeyi daha iyi anlamalarını ve uygun stratejiler geliştirmelerini sağlayabilir.

Çalışmada yapılan analizler temelde iki amaca hizmet etmektedir. Bunlar: (i) Her bir değişkenin Topluluk Kip Ayrıştırması algoritması uygulanarak elde edilen İçkin Kip Fonksiyonlarının (IMF) incelenmesidir. (ii) Değişkenlerin karşılıklı İçkin Kip Fonksiyonları arasındaki nedensellik ilişkilerinin ortaya konulmasıdır.

İlk olarak her iki değişkene ait İçkin Kip Fonksiyonlar incelenmiştir. Ayrışmalar, kısa vadeli İçkin Kip Fonksiyonu (IMF1) ile uzun vadeli İçkin Kip Fonksiyonu (IMF5) bulguları arasında verilmiştir. IMF4) ve IMF5, GSYH'nin uzun vadeli dalgalanmalarını göstermektedir. Bu eğilimlere göre, 1951 ile 1990 yılları arasında GSYH büyümesinde belirgin bir düşüş, 1990 sonrasında ise bir yükseliş gözlenmektedir. Fakat belirli IMF'ler incelendiğinde, GSYH büyümesinin 2010 sonrası düşüş gösterdiği açıktır. GSYH oluşumuna en yüksek varyans katkı oranına sahip iki bileşenin IMF1 ve IMF2 olduğu görülmektedir. Ortalama dönem süreleri sırasıyla 1,31 ve 2,83 yıldır. Özellikle bu ilk iki bileşen, sonraki bileşenlere göre GSYH ile daha fazla korelasyon göstermektedir. Bu perspektiften, GSYH oluşumuna en etkili olan bileşenler kısa vadeli dalgalanmalar tarafından karakterize edilmektedir. Özellikle yaklaşık 4 yıl süren kısa vadeli dalgalanmalar, GSYH'nin yapısı üzerinde oldukça etkilidir. Bu durum, Türkiye'de GSYH oluşumunun kısa vadeli dalgalanmalardan önemli ölçüde etkilendiğini göstermektedir. Daha somut bir ifadeyle, yaklaşık 4 yıl süren dalgalanmalar, GSYH büyümesine en belirgin etkiyi yapmaktadır. Bu bulgular, Türkiye'nin ekonomik yörüngesini değerlendirirken ve ilgili ekonomi politikaları oluşturulurken kısa vadeli ekonomik dalgalanmaları anlama ve yönetme gerekliliğini vurgulamaktadır. Ayrıca, 2000 yılı sonrasında endüstriyel alanda salınan gazlarda yükselen uzun vadeli bir eğilim olduğu gözlenmektedir. Buna karşılık, enerji sektöründe salınan gazlarda uzun vadeli bir düşüş eğilimi söz konusudur. Analiz sonucu elde edilen GHG emisyon bileşenlerine bakıldığında, ilk iki bileşen (IMF1 ve IMF2) en yüksek korelasyon ve varyans katkı oranlarına sahiptir. IMF1, tüm GHG türlerinde baskın bileşen olarak öne çıkmaktadır. GSYH gözleminde olduğu gibi, ilk iki bileşenin toplam ortalama periyodu, tüm gaz sınıflandırmaları için yaklaşık 4 ila 5 yıl arasındadır. Dolayısıyla, kısa vadeli emisyonlarla işaretlenmiş yüksek frekanslı bileşenlerin, GHG emisyonlarını şekillendirmede kritik bir rolü olduğu çıkarılabilir.

İkinci olarak, değişkenlerin karşılıklı IMF'leri arasındaki nedensellik ilişkileri araştırılmıştır. Nedensel ayrışma analizinde karşılıklı IMF'ler arasında hesaplanan faz tutarlılığının 0,5'e eşit olması, bileşenler arasında bir ilişki olmadığını gösterir. GSYH'den GHG emisyonlarına tek yönlü kısa vadeli bir nedensellik ilişkisinin olduğu belirlenmiştir.

Ancak, bu ilişkinin tersi geçerli değildir. Nedensellik ilişkisinin ayrıntılarına inildiğinde ise IMF1'ler arasında nedensellik ilişkisi olmadığı görülürken IMF2'de GSYH'den GHG emisyonlarına nedensel bir bağlantı olduğunu göstermektedir. Ayrıca, IMF3 ile IMF5 arasında böyle bir nedensellik olmadığını göstermekte, bu da GSYH ve GHG emisyonları arasında uzun vadeli bir ilişki olmadığını ima etmektedir. Aksine, tüm IMF2 gösterimlerinde GSYH'den GHG emisyonlarına doğru bir nedensellik açıkça gözlenmektedir. IMF2'nin ortalama süresi yaklaşık 3 yıl olduğu için GSYH'den GHG emisyonlarına kısa vadeli bir nedensel ilişki olduğu önerilmektedir. Bu gözlem, politika yapıcıların ekonomik büyümenin ulusal emisyonlar üzerindeki erken etkilerini tanımaları gerektiğini vurgulamaktadır. Ekonomik değişimlerin GHG emisyonları üzerindeki doğrudan etkilerini ele almak için müdahaleler yapılmalı ve bu ilişkilerin uzun süreli olduğu varsayılmamalıdır. Politika yapıcılar, daha kısa vadeli dinamiklere odaklanarak, Türkiye'yi sürdürülebilir bir geleceğe doğru etkin bir şekilde yönlendirebilirler. Daha yakından incelendiği durumda en belirgin nedensel ilişkiler, GSYH'den toplam Metan ve toplam Nitröz Oksit'e doğrudur. Aksine, en zayıf ilişki ise GSYH'den KYOTOGHG(Endüstriyel) emisyonlarına doğrudur. Ayrıca, GSYH'den N2O(Endüstriyel) emisyonlarına IMF3 içinde nedensel bir bağlantı vardır ve bu bileşenin ortalama süresi yaklaşık 5 yıldır. Bu durum, GSYH ve N2O(Endüstriyel) emisyonları arasında kısa ve orta vadeli bir nedensel ilişkinin olduğunu göstermektedir. GSYH ve Karbondioksit arasında, özellikle GSYH'den Karbondioksite doğru, belirgin bir nedensellik söz konusudur. Sektörel açıdan bir ayrım ile incelendiğinde bu ilişkinin enerji sektöründe, endüstriyel sektörden daha belirgin olduğunu göstermektedir. GSYH'den Karbondioksite doğru olan ilgili nedensel bağlantı yaklaşık 3 yıl sürmektedir.

Genel olarak bu çalışma, 1951 ile 2018 yıllarını kapsayan dönemde Türkiye'deki GSYH ile GHG emisyonları arasındaki nedensel ilişkinin incelenmesini amaçlamaktadır. İnceleme; Topluluk Kip Ayrıştırması, Hilbert-Huang Dönüşümü ve Faz Uyumluluk Yöntemlerini birleştiren Nedensel Ayrıştırma Yöntemi kullanılarak gerçekleştirilmiştir. Çalışmanın odak noktası, sanayi üretimiyle bağlantılı olan ve GHG emisyonlarına önemli ölçüde katkıda bulunan birincil sektörlerin belirlenmesidir. Analiz, GSYH'den GHG emisyonlarına doğru tek yönlü ve kısa vadeli bir nedensel ilişkiyi, ortalama olarak yaklaşık 3 yıllık bir dönemi kapsayacak şekilde ortaya koymaktadır. Bu bulguya dayanarak GSYH'deki değişikliklerin GHG emisyonları üzerinde kısa vadeli etkilere sahip olduğunu ancak tersinin geçerli olmadığını öne sürülmektedir. Çalışmada; Karbondioksit, Metan ve Nitröz Oksit gazlarına özel önem verilmekte olup bu gazların GSYH ile güçlü ve tutarlı bir nedensel ilişkisi olduğu gözlenmektedir. Çalışmanın akademik literatüre önemli katkıları ise ilgili dinamik nedenselliği incelemek için Topluluk Kip Ayrıştırması Yönteminin kullanılması ve gerçekleştirilen literatür taraması ışığında önemli bir boşluğu doldurmasıdır. Ampirik sonuçlar, Türkiye'de GSYH büyümesi ile GHG emisyonları arasında karmaşık ancak gözlemlenebilir bir ilişkinin olduğunu ve bu ilişkinin dönemsel dalgalanmalar ile daha da karmaşıklaştığını göstermektedir.

Çalışmanın bulguları, Türkiye'deki politika yapıcıların GSYH dalgalanmalarının çeşitli GHG emisyonları üzerindeki etraflı etkilerini dikkate almaları gerektiğini ampirik yöntemlerle gerçekleştirilen analizlerle desteklemektedir. Spesifik gazlar ve sektörlerden GSYH değişimlerine en duyarlı olanlarının belirlenmesinin, ekonomik büyümenin çevresel etkilerini dengelemek adına hedefli stratejiler oluşturulmasını sağlayacağı düşünülmektedir. Ayrıca, belirlenen ilgili nedensel bağlantıların kısa ve orta vadelerde ele alınmasının, Türkiye'yi sürdürülebilir bir yol haritasına yönlendirmede kilit bir rol oynayacağı vurgulanmaktadır.