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5. Decoupling Carbon Emissions and Economic Growth in Tunisia: Pathways to Sustainable Development

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Abstract: This chapter examines the link between economic growth and carbon dioxide emissions in Tunisia and explores the multiple impacts on key sectors such as agriculture, energy, health, and tourism. Using a robust analytical framework consisting of the LMDI-II decomposition method, the Kaya identity, and the Tapio decoupling model, the study analyzes CO2 emission trends in Tunisia from 1980 to 2021. It identifies the main drivers of these emissions and provides insights into the complex relationship between demographic growth, energy consumption and economic activities. The chapter highlights several challenges linked to climate change and aims to provide a deeper understanding of how Tunisia can balance environmental needs with economic development, and ultimately propose targeted strategies and policy recommendations for sustainable growth and effective emissions reduction.

Keywords: Carbon dioxide emissions; Economic growth; Energy; Climate change; Tunisia; Sustainability.

5. 1. Introduction

Climate change is considered one of the most pressing challenges of our time, posing a threat to environmental stability, economic progress, and societal well-being around the world. Reflecting the plight of many nations, Tunisia finds itself at a critical juncture where the push for curbing carbon dioxide (CO_2) emissions intersects with the growing demand for energy to fuel its economic and social development. The complexity of this situation is compounded by Tunisia's unique environmental and economic context.

Tunisia's vulnerability to climate change is particularly evident in its dwindling water resources and encroaching desertification, which are severely affecting the agricultural sector (ONAGRI, 2022). Agriculture is not only an important part of the Tunisian economy, but also a vital source of livelihood for a significant part of the population. The adverse effects of climate change are manifesting themselves in a variety of ways - from declining crop yields and soil degradation to escalating irrigation costs and looming threats to food security. These challenges raise serious questions about the sustainability of agricultural practices and the future of food security in Tunisia.

Tunisia's energy sector, which relies heavily on fossil fuels, also faces its own challenges. The sector's growing energy consumption has led to an increase in GHG emissions, particularly CO_2. The critical issues for the energy sector in the face of climate change include the need to reduce overall energy consumption, increase energy efficiency, and transition to renewable energy sources (Arouri et al., 2012). These measures are not only essential for reducing the environmental footprint, but also for ensuring long-term energy security and economic stability.

The impact of climate change in Tunisia also extends to the health sector, particularly affecting the prevalence and severity of infectious and heat-related diseases. Vulnerable populations, including the elderly, children, and people with chronic health conditions, are disproportionately affected by these health risks. Changing climate conditions, characterized by rising temperatures and changing weather patterns, require a reassessment of health policies and infrastructure to effectively protect public health.

Tourism, an important pillar of the Tunisian economy, also faces significant challenges due to climate change. Issues such as deteriorating beach quality, water scarcity and biodiversity loss directly affect the attractiveness and viability of the tourism sector. These challenges not only have an immediate economic impact, but also pose a long-term threat to the sustainability of tourism in Tunisia.

In addition, climate-induced migration has emerged as a critical issue, particularly affecting vulnerable populations who are most susceptible to environmental changes. The phenomenon of climate migration poses complex socio-economic challenges that require comprehensive policy interventions and support systems.

This study aims to analyze in detail the determinants of CO_2 emissions in Tunisia over the period 1980 to 2021. Using sophisticated analytical tools such as the LMDI-II decomposition method, the Kaya identity, and Tapio's decoupling model, the study seeks to dissect the factors driving CO_2 emissions. The objective is to gain a deeper understanding of these dynamics, thereby informing the development of effective policies and strategies to reduce emissions and mitigate the multiple impacts of climate change on Tunisia's economy and society. In doing so, the study will traverse through a detailed literature review, elaborate on the methodological framework, present and discuss the findings, and culminate with actionable recommendations aimed at promoting sustainable development while addressing the pressing issue of carbon emissions in Tunisia.

5.2. Literature review

The complex interplay between sustainable development and carbon emissions is emerging as a central issue in environmental discourse, reflecting the global challenge of reconciling economic growth with environmental sustainability. This chapter examines recent methodological advances, focusing on the Tapio decoupling model, the Kaya identity, and the Logarithmic Mean Divisia Index (LMDI) decomposition method. These tools are instrumental in unraveling the multifaceted dynamics of carbon emissions and provide insights into regional and economic strategies for sustainable development.

The Tapio decoupling model, a key tool in this analysis, provides insights into the relationship between economic growth and environmental degradation. Rajabi Kouyakhi's (2022) study in the Middle East, using the LMDI approach, shows that factors such as population growth, energy intensity and economic growth are important drivers of CO_2 emissions. In particular, the application of the Tapio decoupling model reveals a gradual decoupling trend in West Asian economies, especially in Saudi Arabia and Kuwait, indicating effective decarbonization. This trend is mirrored in the study of Ghana by Oteng-Abayie et al. (2022), where a weak decoupling state was identified between 1990 and 2018, interspersed with periods of strong and negative decoupling, highlighting the complex interplay between economic development and environmental sustainability. Extending the application of the Tapio model, Wang et al. (2023)

investigate the impact of trade protectionism on carbon neutrality and find a general trend of weak decoupling between economic growth and carbon emissions in the context of trade openness. This suggests that free trade may promote global carbon neutrality, illustrating the nuanced effects of globalization on emissions. Similarly, Han et al. (2022a) reassess China's CO2 emissions and economic growth using the EKC and Tapio models and find that China has not fully achieved decoupling due to the significant influence of industrial and energy structures. In Guangdong Province, Tang and Jiang (2023) apply the Tapio model and the LMDI method to evaluate the transportation sector and identify urbanization, income growth, and energy intensity as key drivers of weak decoupling. Jiang et al. (2023) extend this analysis to key industries in Fujian Province, finding variable decoupling levels and highlighting the need for strategic shifts in energy and industrial policies. Dahmani et al. (2021a) contribute to the discourse with their analysis of Tunisia's GHG emissions using the extended STIRPAT model, the Tapio decoupling model, and the ARDL bounds test approach. Their study confirms an inverted U-shaped relationship between GDP and GHG emissions and highlights the long-term benefits of renewable energy consumption in reducing emissions. Han et al.'s (2022b) integration of the Tapio model with Kaya's equation and the LMDI method in the Yellow River Basin reveals a complex pattern of decoupling states influenced by economic intensity, population size, industrial structure, and energy consumption. Huang and Guo (2023) examine the different environmental impacts of financial development on carbon decoupling in different regions. In addition, Foster et al. (2023) examine the decoupling of transport-related CO2 emissions from economic growth in developing countries and find that high-income countries are better able to achieve relative decoupling, highlighting the importance of policy, urbanization, and industrialization in emissions management.

The Kaya identity, also an important tool in this analysis, provides a detailed breakdown of the components contributing to carbon emissions, allowing a deeper understanding of their origins and potential mitigation strategies. Lin et al. (2023) use this model to assess China's potential for carbon mitigation through improved technical efficiency in its energy systems. Their results highlight the critical relationship between technological progress and environmental sustainability, and illustrate how improvements in technology can lead to significant reductions in carbon emissions. In the context of the European Union, Bigerna and Polinori (2022) examine the bloc's path toward its 2050 decarbonization goal, emphasizing the alignment of Kaya identity components among member states. Their study highlights the need to synchronize economic, social, and technological factors to achieve collective carbon neutrality goals within the region. This approach highlights the importance of integrated strategies that address a range of factors that contribute to carbon emissions. Rasheed et al. (2022) apply the Kaya identity to a sector-specific study in Pakistan, focusing on the cement manufacturing sector. Their analysis identifies labor productivity, energy structure, and carbon intensity as key drivers of emissions in this sector, shedding light on the unique challenges and opportunities for reducing emissions in industrial settings. Extending the application of the Kaya identity, González-Torres et al. (2021) propose an innovative emissions indicator pyramid. This framework allows for a comprehensive analysis of changes in energy use and emissions, covering both OECD and non-OECD countries. Their work highlights the evolving nature of energy use and emissions trends, and underscores the need for robust and adaptive climate policies that can effectively respond to these changes. Apeaning (2021) examines the relationship between carbon emissions and economic growth, with a focus on the decoupling process in less mature and emerging economies. The study highlights the technological barriers that these economies face in reducing emissions and points to the need for investment in technology and innovation to promote sustainable growth. Similarly, Khusna and Kusumawardani (2021) use the Kaya identity for a comprehensive decomposition analysis of CO2 emissions in the ASEAN region. Their work provides a comprehensive view of the environmental challenges facing ASEAN countries, as well as the opportunities for reducing emissions through various policies. This regional analysis underscores the diversity of environmental impacts and strategies in different economic contexts, highlighting the importance of tailored approaches to reducing carbon emissions.

The LMDI decomposition method enriches this analysis by providing a more refined examination of CO2 emissions across sectors and regions. Essaber (2023) uses this method to decompose energy-related CO2 emissions in Tunisia, identifying GDP growth as a significant factor. This study highlights how the environmental impact of economic expansion depends on energy intensity and structural dynamics within the economy. Following this approach, Ben Hammamia and Dhakhlaoui (2023) combine the LMDI method with an error-correction model to project Tunisia's future CO2 emissions, predicting significant potential for emission reductions through improved energy efficiency. Rajabi Kouyakhi (2022) extends the application of the LMDI method to the Middle East, providing a thorough analysis of CO2 emissions. The study identifies population growth, energy intensity and economic growth as the main drivers of CO2 emissions in the region. This reinforces the need for focused strategies to address these key drivers in emissions reduction efforts. Hasan and Chongbo (2020) explore future emission scenarios in Bangladesh, highlighting the key role of renewable energy technologies in transforming the country's energy landscape and reducing emissions. Mousavi et al. (2017) conduct a similar analysis for Iran, pointing to increased energy consumption as a main driver of emissions and highlighting the urgency of adopting more sustainable energy practices. In China, Huang et al. (2023) integrate the LMDI method with the LEAP model to assess CO2 emissions in line with the country's ambitious goals to peak emissions by 2030 and achieve carbon neutrality by 2060. This comprehensive approach sheds light on the effectiveness of China's strategies and policies in achieving these goals. Jain and Rankavat (2023) apply the LMDI methodology to India's transportation sector, unraveling the complex relationship between energy systems, economic growth, and population dynamics, and their collective impact on emissions. Zhang et al. (2022) use the LMDI method to assess the costs associated with CO2 mitigation in China's biogas systems. Their study reveals a notable discrepancy between theoretical and actual abatement costs, highlighting the complexity of implementing effective abatement strategies. Chun et al. (2023) integrate the LMDI and Tapio models to conduct a multi-sector analysis of CO2 emissions in Henan Province, China, providing a holistic view of emission trends across industries. Alajmi (2022) applies the LMDI methodology to assess carbon emissions and electricity generation in Saudi Arabia, contributing to the understanding of the energy-emissions nexus in the context of the Kingdom's energy sector. Finally, Wang et al. (2022) extend the scope of the LMDI method to the rail transport industry in the BRIC countries, identifying economic output, population size, energy structure, and transport intensity as key factors influencing emissions, further highlighting sectoral differences in emissions dynamics.

As the broader impacts of climate change on the Tunisian economy are explored, the insights from these analytical tools become increasingly relevant. Ben Youssef (2022) provides a critical policy-oriented perspective, highlighting the challenges faced by Tunisian cities in addressing climate change. This study shows that while the majority of municipalities are experiencing the effects of climate change, there is a gap in specific mitigation and adaptation strategies at the local level, mainly due to a lack of financial resources and funding. This underscores the urgent need for investment in climate action and the adoption of effective practices. Hammami and Ferchichi (2023) examine the vulnerability of pastoral ecosystems in northwestern Tunisia to climate change. Their field study reveals different vulnerabilities of pastoral systems influenced by socio-economic resources. The research highlights the fragility of these systems, even with adaptation measures in place, highlighting in particular the acute vulnerability of landless and impoverished pastoralists. In a different vein, Saadaoui and Chtourou (2023) examine the interplay between institutional quality, financial development, and economic growth in Tunisia's transition to renewable energy. They find that financial development surprisingly has a negative impact on renewable energy consumption, while economic growth and institutional quality appear to promote it. This finding suggests a way forward for Tunisia to fight energy poverty and make progress on climate change mitigation. Fragkos and Zisarou (2022) assess Tunisia's energy system transition, particularly in light of its Nationally Determined Contribution (NDC) and mitigation strategies. Their analysis, based on a detailed energy system model, shows that current policies need to be significantly strengthened to meet the 2030 NDC targets. The study advocates for a significant shift towards renewable energy technologies and a reduction in reliance on oil and gas, highlighting both the opportunities and challenges of achieving deep decarbonization of the Tunisian economy. Pechan et al. (2023) contribute with a comparative study of the impacts of climate change on fruit production in Chile and Tunisia. Their interviews with farmers reveal specific climate-related challenges such as water scarcity and extreme weather events, highlighting the need for adaptation measures tailored to regional differences. Similarly, Soltani and Mellah (2023) explore farmers' adaptation strategies to water scarcity under climate change in the semi-arid regions of Tunisia. Their study categorizes farmers according to their adaptation strategies, revealing a dichotomy where some resort to intensive water use for high-value crops, while others, especially smallholders, face the risk of abandoning farming due to resource constraints. Essaber et al. (2023) discuss climate finance mobilization in MENA countries, focusing on Egypt, Morocco and Tunisia. They emphasize the need for an integrated, multi-stakeholder strategy for climate finance, highlighting the availability of various domestic and foreign funds, but also the need for collaborative efforts to effectively address climate change. Furthermore, Kwakwa et al. (2022) examine the relationship between natural resources, economic growth and political regimes in Tunisia. Their analysis reveals a positive impact of natural resources on economic growth, which is enhanced by a democratic regime, highlighting the importance of political frameworks in harnessing natural resources for sustainable growth. Ghorbal et al. (2022) analyze the relationship between CO2 emissions, renewable energy consumption, and various economic factors in Tunisia and find that renewable energy consumption and exports have a positive impact on CO2 emissions, while foreign direct investment has a negative impact, suggesting a complex interplay of economic activities in environmental sustainability. In addition, Talbi et al. (2022) assess CO2 emissions in Tunisia's industrial sector using a dynamic vector autoregression method. Their findings indicate that natural gas use and energy efficiency are key to reducing emissions, while economic growth and energy consumption contribute significantly to emissions, suggesting the need for a well-designed energy strategy for environmental mitigation. Saadaoui and Chtourou (2022) explore the potential of renewable energy in Tunisia, highlighting the opportunities for substituting renewable energy for non-renewable energy. Their recommendations include policies to reflect the true cost of energy, encourage investment in research and development, and implement carbon taxes to accelerate the energy transition. Finally, Dakhlaoui et al. (2022) address the hydrological impacts of projected climate change on headwater catchments in northern Tunisia. Their ensemble approach, which shows a marked decrease in precipitation and an increase in temperature, leads to significant reductions in runoff and soil moisture. This study highlights the importance of considering different sources of uncertainty in hydrological projections and the challenges of applying global climate model results at local scales.

The combination of the Tapio decoupling model, the Kaya identity, and the LMDI decomposition method forms a comprehensive analytical suite for studying carbon emissions and their determinants, shedding light on the complexities of sustainable development and carbon emission reduction. These frameworks, applied in different studies, highlight the importance of region-specific strategies in addressing the diverse challenges of climate change. The findings from these methodologies, particularly in the context of Tunisia, reveal a spectrum of challenges and adaptation strategies, ranging from local community initiatives to broader economic and policy interventions. Collectively, they underscore the need for integrated, tailored, and financially supported approaches to effectively address the multidimensional impacts of climate change.

5.3. Methodological framework

5.3.1. Analytical approaches

To investigate the determinants of CO2 emissions in Tunisia for the period 1980-2021, this study uses a multifaceted analytical approach. The methodology integrates the Logarithmic Mean Divisia Index II (LMDI-II) decomposition method, the Kaya identity, and Tapio's (2005) decoupling model. Each of these methods makes a unique contribution to the analysis and provides insights into different aspects of CO2 emissions in relation to economic activities.

5.3.1.1. Tapio decoupling analysis

The decoupling model developed by Tapio (2005) serves as a central tool for understanding the relationship between CO2 emissions and economic growth in Tunisia. The concept of decoupling refers to the scenario where environmental impacts (such as CO2 emissions) and economic indicators (such as GDP) evolve independently or at different rates. Tapio's model provides a nuanced classification of the nature of decoupling, with eight different categories based on observed variations in GDP and CO2 emissions over time.

To quantify decoupling, we use the following formula:

$$D_t = \frac{\Delta CO2_t}{\Delta GDP_t}$$

Where, D_t represents the decoupling index between carbon emissions and GDP growth for a specific a given time period *t*, $\Delta CO2_t$ denotes the change in CO2 emissions between years *t* and *t-1*, and ΔGDP_t signifies the change in GDP for the same interval.

The interpretation of the decoupling indices, classified into different categories based on the values of D_t, ΔGDP_t, and $\Delta CO2_t$, is presented in Table 5.1. This classification is essential for understanding the nature and extent of the decoupling observed in Tunisia, thus providing insights into the effectiveness of environmental policies and economic transformations.

Table 5.1: Classification of decoupling states according to Tapio's model

Decoupling state		ΔCO_2	ΔGDP	Decoupling Index
Negative decoupling	Weak negative decoupling	<0	<0	$0 < D_t < 0.8$
	Strong negative decoupling	>0	<0	$D_t < 0$
	Expansive negative decoupling	>0	>0	$D_t > 1.2$
Decoupling	Recessive decoupling	<0	<0	$D_t > 1.2$
	Strong decoupling	>0	>0	$D_t < 0$
	Weak decoupling	>0	>0	$0 < D_t < 0.8$
Coupling	Recessive coupling	<0	<0	$0.8 < D_t < 1.2$
	Expansive coupling	>0	>0	$0.8 < D_t < 1.2$

Tapio's (2005) model facilitates the assessment of the effectiveness of CO2 emission reduction policies in the context of economic growth. This analysis is crucial for guiding policies towards a sustainable energy transition and GHG emission reduction. The model's various decoupling categories provide a framework for understanding the dynamics between economic growth and CO2 emissions and for evaluating the effectiveness of environmental policies.

5.3.1.2. Application of the Kaya identity

The Kaya identity, formulated by Yoichi Kaya in 1993, is a fundamental equation in environmental economics that decomposes a country's GHG emissions into four main components: energy intensity of the economy, carbon intensity of energy, GDP per capita, and population. This identity, inspired by the IPAT model, shows that environmental impact is a function of population, affluence, and technology.

The Kaya identity is expressed as:

$$CO2 = \frac{CO2}{PE} \times \frac{PE}{GDP} \times \frac{GDP}{P} \times P$$

In this equation:

- *CO2* represents total carbon dioxide emissions.
- *PE* is the primary energy consumption associated with these emissions.
- *GDP* is the gross domestic product.
- *P* is the total population.

The decomposition of *CO2* emissions allows an analysis based on several critical factors. The carbon intensity of energy $F = \frac{CO2}{PE}$, quantifies the emissions per unit of energy consumed and reflects the environmental impact of different energy sources. The energy intensity of the economy $E = \frac{PE}{GDP}$, measures the energy required per unit of GDP, indicating the overall energy efficiency of the country. GDP per capita $G = \frac{GDP}{P}$, is an essential measure of economic development and well-being. The population component P highlights the demographic influence on emissions.

Reformulating the Kaya identity after decomposition, we get:

$$CO2 = F \times E \times G \times P$$

The Kaya Identity is instrumental in identifying a nation's primary sources of GHG emissions and the key contributing factors. It serves as a valuable tool for comparing CO2 emissions across nations, sectors, or time periods, and for evaluating the effectiveness of energy and climate policies.

5.3.1.3. LMDI decomposition method

The LMDI-II decomposition method is an analytical approach used to separate the influences of different factors on CO2 emissions. It is favored for its axiomatic properties, including the complete decomposition of variations in CO2 emissions and the absence of residual components in the decomposition (Ang, 2004, 2015). This method has been widely used in research focusing on the determinants of CO2 emissions and the evaluation of emission reduction policies (Hasan and Chongbo, 2020; Wang et al., 2022; Zhang et al., 2022; Chun et al.; 2023; Huang et al., 2023).

In this study, CO2 emissions are decomposed into three main factors: energy carbon intensity (ECI), energy intensity (EI), and demographic intensity (DI). Energy carbon intensity refers to CO2 emissions per unit of energy consumed. Energy intensity is defined as the amount of energy consumed per unit of GDP, while demographic intensity measures population relative to GDP.

The LMDI-II decomposition is generally expressed by the following formula (Ang and Zhang, 2000):

$$\Delta C(t) = \sum \left[\omega_i(t) \times \ln\left(\frac{x_i(t)}{x_i(t-1)} \right) \right]$$

In this formula, $\Delta C(t)$ represents the change in CO2 emissions between years *t* and *t-1*; $\omega_i(t)$ represents the relative weight of factor *i* in year *t*; and $x_i(t)$ represents the value of factor *i* in year *t*.

Using the LMDI-II method with interactions, the contributions of each factor and their interactions to changes in CO2 emissions are determined as follows:

$$\Delta C_{total}(t) = \Delta C_{CIE}(t) + \Delta C_{EI}(t) + \Delta C_{DI}(t) + \Delta C_{CIEE}(t) + \Delta C_{EID}(t) + \Delta C_{CEID}(t)$$

These factors include Carbon Intensity of Energy (CIE), Energy Intensity (EI), Demographic Intensity (DI), and their interactions: CIEE (interaction between CIE and EI), EID (interaction between EI and DI), and CEID (interaction between CIE and DI).

Using the LMDI-II decomposition method with interactions allows for a detailed understanding of the driving forces behind changes in CO2 emissions. This approach is critical for evaluating the effectiveness of emission reduction policies and measures. It provides valuable insights for decision makers in designing future policies and strategies to reduce CO2 emissions.

5.3.2. Data sources

For the comprehensive analysis of CO2 emissions and their determinants in Tunisia from 1980 to 2021, this study relies on data from the World Bank's World Development Indicators (World Bank, 2023) and the US Energy Information Agency (EIA, 2023). The following observations are derived from the descriptive statistics summarized in Table 2:

- **CO2 emissions:** There has been a significant increase in CO2 emissions over the years, averaging 16.983 million metric tons. This upward trend, with emissions ranging from a minimum of 8.540 million tons to a maximum of 25.327 million tons, underscores Tunisia's significant contribution to GHG emissions and the urgent need for mitigation strategies.
- **GDP trends:** GDP has also shown a significant increase, averaging 29.630 billion in constant 2015 US dollars. This range, from a minimum of 12.402 billion to a maximum of 49.287 billion constant 2015 US dollars, indicates economic growth, which is likely to be correlated with an increased demand for energy, potentially driving up CO2 emissions.
- **Energy Consumption:** Average energy consumption was 6.977 million tons of oil equivalent, with a range of 3.241 million tons (minimum) to 10.493 million tons (maximum). This increase is in line with the country's economic development trajectory.
- **Population growth:** The average population size was approximately 9.7 million, with numbers ranging from 6.5 million to 12.3 million. This growth pattern highlights Tunisia's demographic expansion over the period.
- **Carbon intensity of energy:** The carbon intensity of energy has increased over time, averaging 2.469, with values ranging from 2.229 to 2.703. This trend can be attributed to increased reliance on fossil fuels for energy production.
- **Energy intensity:** The average energy intensity was recorded at 0.248, suggesting a relatively efficient use of energy in the Tunisian economy. Nevertheless, there has been a significant increase in this indicator over the years.
- **Demographic intensity:** With an average of 2.920 inhabitants per million tons of CO2 emissions, the data indicate that Tunisia's population size is modest relative to its CO2 emissions.

Table 5.2 below details these descriptive statistics and provides a quantitative overview of the key variables relevant to this study.

Table 5.2: Descriptive statistics

Variable	Observations	Mean	Standard Deviation	Min	Max
CO2 Emissions (Millions of metric tons)	42	16.983	4.836	8.540	25.327
GDP ($ constant 2015 US)	42	29.630	12.530	12.402	49.287
Energy Consumption (Millions of oil equivalent - Mtoe)	42	6.977	2.244	3.241	10.493
Population	42	9723132	1648703	6578156	12300000
Energy Carbon Intensity	42	2.469	0.127	2.229	2.703
Energy Intensity	42	0.248	0.038	0.177	0.312
Demographic Intensity	42	2919.988	812.389	1883.090	4090.433

The in-depth analysis of these data points will provide critical insights into the relationship between economic growth, energy consumption, and environmental impacts in Tunisia, helping to formulate effective policy recommendations for sustainable development and emissions reduction.

5.4. Results and discussion

5.4.1. Analysis of Tapio decoupling dynamics

The application of Tapio's (2005) decoupling model to the Tunisian context from 1980 to 2021 provides important insights into the interplay between economic growth and CO2 emissions. The different types of decoupling observed reflect the changing economic and environmental conditions during this period.

5.4.1.1. Cases of strong decoupling

Tunisia experienced instances of strong decoupling in 1987, 1990, 1991, 1995, 2002, 2003, 2004, 2006, 2007, 2009, 2010, 2016, and 2019, where economic growth coincided with significant reductions in CO2 emissions. These periods suggest effective progress in decarbonizing the economy, possibly driven by robust environmental policies, the adoption of cleaner technologies, improved energy efficiency, and a shift toward renewable energy. However, the intermittent nature of these decoupling episodes highlights the need for sustained and intensified efforts in this direction.

5.4.1.2. Observations of weak decoupling

In the years 1985, 1992, 1996, 1998, 2000, 2012, 2018 and 2021, Tunisia experienced weak decoupling, characterized by slight reductions in CO2 emissions despite economic growth. This indicates some progress towards green economic development, but also signals that current efforts may not be sufficient to meet international climate commitments. There is a clear need to strengthen policies and initiatives focusing on clean energy and energy efficiency to promote stronger decoupling.

5.4.1.3. Cases of recessive decoupling

The year 1982 was characterized by recessive decoupling, where reduced CO2 emissions were the result of an economic downturn rather than active decarbonization efforts. This scenario is of concern because it suggests that emissions reductions were not due to proactive environmental strategies, but rather a by-product of economic contraction, highlighting the critical need for sustainable and beneficial economic growth strategies.

5.4.1.4. Strong and weak negative decoupling dynamics

The years 1986 and 2011, indicative of strong negative decoupling, and 2020, marked by weak negative decoupling, were periods of increasing CO2 emissions against a backdrop of stagnant or declining economic growth. These periods reflect a failure of decarbonization efforts and underscore the urgency of additional and more effective measures to promote sustainable growth.

5.4.1.5. Patterns of expansive negative decoupling

The years 1983, 1988, 1989, 1993, 1994, 1997, 2001, 2008, 2013, 2014, 2015, and 2017 were characterized by expansive negative decoupling, in which CO2 emissions increased along with economic growth, albeit at a slower pace. While these trends show some success in moderating emissions growth, they also highlight the need for Tunisia to intensify efforts to mitigate and reverse emissions trends. Strategic investments in clean technologies, renewable energy and energy efficiency are key to improving the decoupling scenario.

5.4.1.6. Expansive coupling trends

In 1981, 1984, 1999 and 2005, Tunisia experienced expansive coupling, where economic growth and CO2 emissions increased simultaneously. These findings underscore the need for policy interventions aimed at reducing dependence on fossil fuels and promoting sustainable economic growth.

Thus, the analysis of the decoupling of GDP and CO2 emissions in Tunisia shows uneven progress, with an overall need for more robust and consistent efforts. To achieve sustainable and green growth, Tunisia needs to strengthen its commitment to clean energy, energy efficiency, renewable energy, and innovation in environmental technologies.

5.4.2. Insights from Kaya identity analysis

5.4.2.1. Energy intensity: current trends and improvement pathways

Energy intensity, a measure of the amount of energy required to produce a unit of GDP, has shown a trend toward greater efficiency in the Tunisian economy. Analyzing trends and opportunities for improvement in energy intensity can contribute to reducing CO2 emissions and promoting sustainable development. As shown in Figure 5.1, Tunisia's energy intensity has shown fluctuations but an overall decrease from 0.26 in 1980 to 0.21 in 2021, suggesting improved energy efficiency over time, likely due to technological advances and increased focus on energy conservation measures.

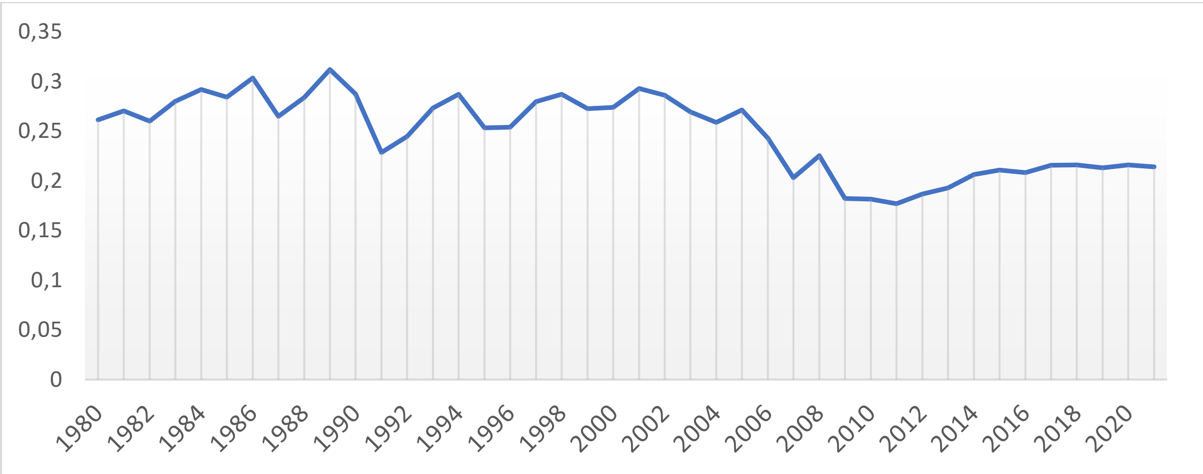

Figure 5.1: Evolution of Energy Intensity (Source: Author's calculations based on WDI & EIA data, 2023)

5.4.2.2. Carbon intensity: evaluating energy sources and renewable energy transition

The carbon intensity of a country's energy sources is a key indicator of its environmental footprint. In Tunisia, carbon intensity has fluctuated, decreasing from 2.64 in 1980 to 2.23 in 2021 (Figure 5.2). This trend, despite occasional increases, indicates a gradual shift away from high-carbon energy sources. Tunisia's reliance on fossil fuels, primarily oil and natural gas, has been a significant contributor to CO_2 emissions. The country's potential for renewable energy development, particularly solar and wind, offers an opportunity to reduce the carbon intensity of its energy sector.

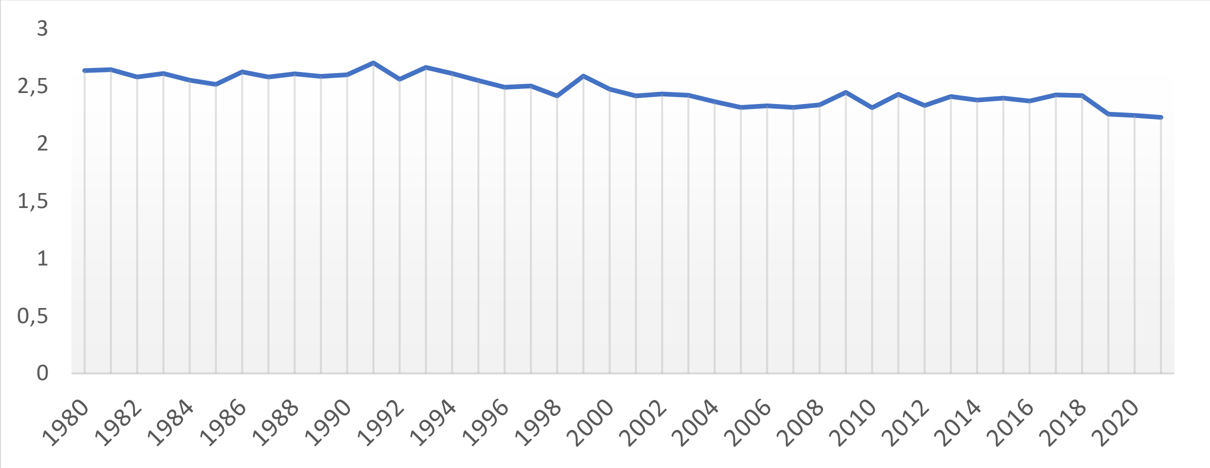

Figure 5.2: Evolution of the Carbon Intensity of Energy (Source: Author's calculations based on WDI & EIA data, 2023)

5.4.2.3. Economic structure impact: sector-specific GHG emissions

An in-depth examination of Tunisia's GHG emissions by economic sector sheds light on the predominant sources and identifies focal areas for reduction initiatives. These sectors are broadly categorized as industry, transportation, and construction.

- **Industrial sector:** Major industrial activities such as cement production, metallurgy, and chemical processing are significant contributors to CO_2 emissions, primarily due to high energy consumption and specific process-related emissions. Mitigation strategies in this sector would include improving energy efficiency, switching to cleaner energy sources, upgrading existing facilities, and adopting environmentally sustainable technologies.

- **Transport sector:** This sector, driven primarily by internal combustion engine vehicles and increased road traffic, is a major contributor to GHG emissions. Mitigation strategies include advocating for public transportation, promoting sustainable modes of transportation such as bicycling and walking, integrating electric vehicles, and promoting energy-efficient transportation methods.

- **Construction sector:** In the construction sector, energy use for heating, air conditioning, lighting, and electrical appliances is a major concern. Efforts in this area should focus on improving energy efficiency in the design and operation of buildings.

5.4.2.4. Demographic influence: population growth and its effects on energy and emissions

Population growth has a profound impact on energy consumption and CO2 emissions in Tunisia. This population growth increases energy demand for housing, travel, and economic activities, which in turn affects per capita CO2 emissions - a key metric for evaluating the effectiveness of emission reduction strategies.

- **Energy use and population growth:** A growing population requires more energy for housing, transportation, and economic needs. In Tunisia, population growth has driven energy consumption, particularly in the residential and transportation sectors. To counter this trend, it is imperative to implement policies aimed at increasing energy efficiency and promoting sustainable living practices.
- **CO2 emissions and per capita analysis:** Population growth also drives CO2 emissions due to increased energy demand, which is primarily met by fossil fuel consumption. However, assessing CO2 emissions on a per capita basis provides a more comprehensive perspective for evaluating efforts to reduce emissions. Tunisia has experienced a slight increase in per capita emissions over time, highlighting the urgency of effective measures to curb these emissions.

Tunisia's economic and demographic dynamics-characterized by growth, urbanization, and industrialization-have led to increased CO2 emissions and energy consumption, particularly in key sectors such as industry, transportation, and residential areas. Despite these challenges, the country's commitment to diversifying energy sources and improving energy efficiency, as evidenced by the reduction in carbon intensity, signals a shift toward less polluting energy solutions. This transition is further supported by government policies focused on renewable energy deployment, energy efficiency improvements, and GHG emission reductions, in line with Tunisia's commitments under the Paris Climate Agreement.

5.4.3. Results of the LMDI decomposition analysis

The results of the LMDI-II decomposition method for Tunisia from 1980 to 2021 are instructive for understanding the drivers of changes in CO2 emissions. This method isolates the influence of specific factors such as carbon intensity (CIE), energy intensity (EI) and demographic intensity (DI) and their interactions on CO2 emissions. The analysis helps to assess the impact of policy and technological changes over time and provides guidance for future environmental strategies.

From the LMDI-II decomposition analysis (Table 5.3), Tunisia experienced an average annual decrease in energy carbon intensity (CIE) of -0.67%, indicating a gradual shift towards less carbon-intensive energy sources. Energy Intensity (EI) also showed an average annual decrease of -0.60%, reflecting improvements in energy efficiency. Demographic intensity (DI) decreased by an average of -0.70% per year, indicating that the impact of population growth on CO2 emissions has decreased over time.

The interactions between these factors also played an important role. The CIEE interaction (CIE and EI) contributed an average 2.20% increase in CO2 emissions, while the EIE interaction (EI and DI) contributed a 4.57% increase. Notably, the EID interaction (CIE and DI) was responsible for a substantial 28.96% variation in CO2 emissions.

A breakdown by time period reveals different trends. For example, the decade from 1991 to 2000 showed the most significant decreases in CIE and EI, possibly due to robust energy policies or global economic factors. Conversely, the years from 2001 to 2010 showed a slight increase in these factors, highlighting the need for continuous policy evaluation and adjustment.

These findings underscore the importance of targeted energy management policies that focus on renewable energy deployment, energy efficiency, and adaptation to demographic changes. Understanding these dynamics is imperative for Tunisia as it continues to develop strategies to meet its environmental goals and commitments under international agreements, in particular the Paris Climate Agreement.

Table 5.3: LMDI-II decomposition method results

	ΔC_CIE	**ΔC_EI**	**ΔC_DI**	**ΔC_CIEE**	**ΔC_EIE**	**ΔC_EID**	**ΔC_total**
1980-2021 (average)	-0.67%	-0.60%	-0.70%	2.20%	4.57%	28.96%	33.76%
1980-1990 (average)	-0.37%	-0.21%	-0.39%	2.85%	5.91%	38.16%	45.95%
1991-2000 (average)	-1.21%	-1.09%	-1.27%	3.82%	7.91%	50.07%	58.23%
2001-2010 (average)	0.06%	0.51%	0.08%	-0.80%	-2.13%	-10.71%	-12.98%
2011-2021 (average)	-1.12%	-1.53%	-1.19%	2.87%	6.41%	37.46%	42.91%

Source: Authors' calculations based on LMDI-II decomposition.

The significant increase in total energy consumption from 4.180 Mtoe in the 1980s to 9.392 Mtoe in 2021 (Figure 5.3) reflects Tunisia's growing energy demand, driven by economic development and population growth. The shift in energy sources is evident, with a significant increase in natural gas consumption (from 1.059 Mtoe to 4.462 Mtoe) and a gradual increase in renewable energy (from 0.075 Mtoe to 0.125 Mtoe). This suggests a transition in Tunisia's energy mix, possibly influenced by policies to promote cleaner energy sources and technological advances in the energy sector.

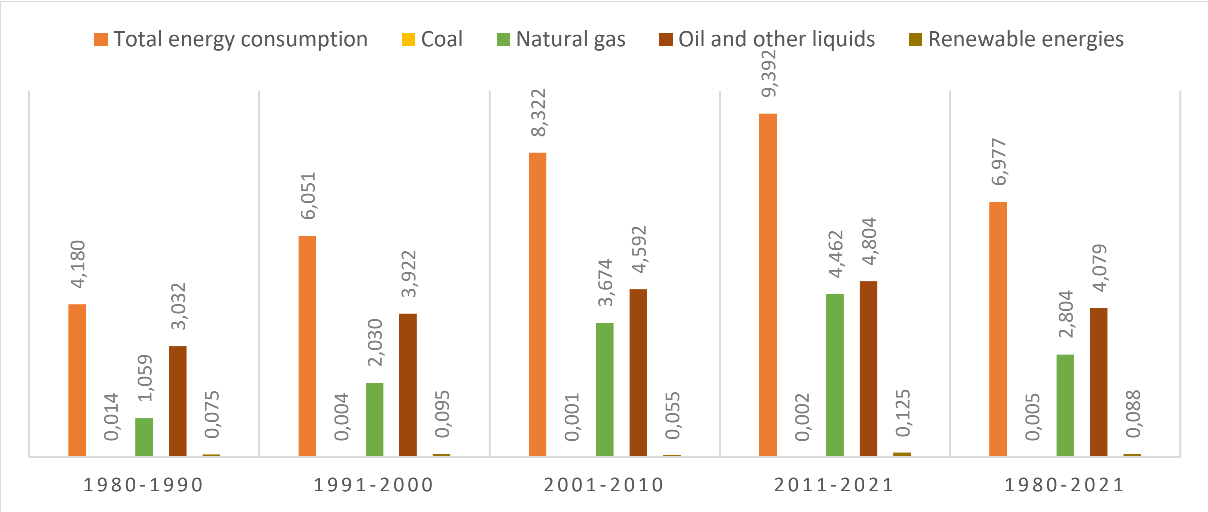

Figure 5.3: Trend of average energy consumption by source in Tunisia (1980-2021) (in Mtoe)

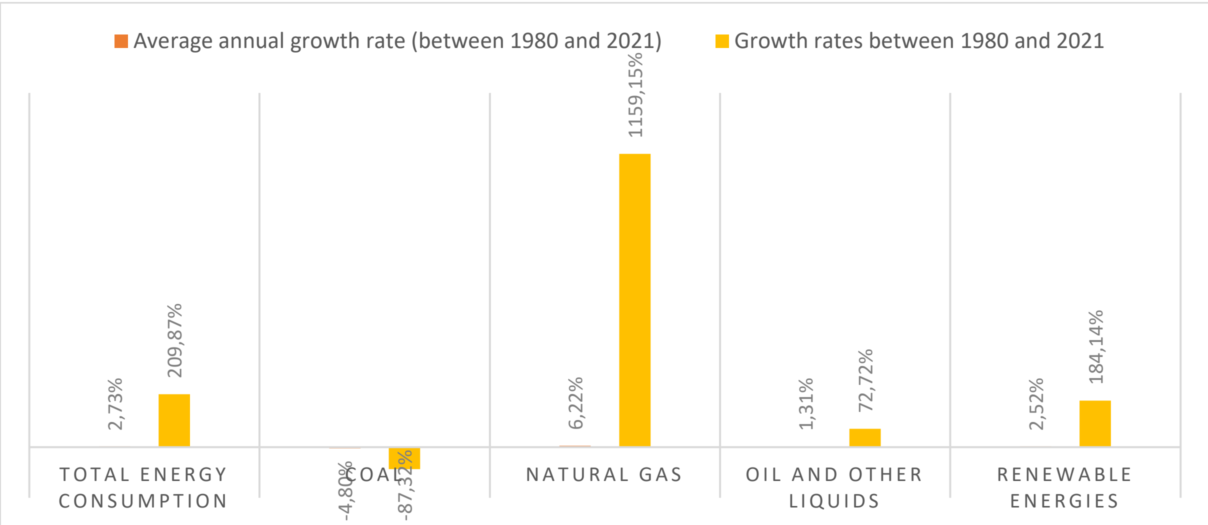

Figure 5.4: Percentile growth in energy consumption by source in Tunisia (1980-2021)

The average annual growth rate of total energy consumption (2.73%) and a total increase of 209.87% highlight the country's escalating energy needs (Figure 5.4). The decline in coal consumption (-87.32%) is in line with the global trend away from highly polluting energy sources. The significant growth in natural gas (1159.15%) and renewables (184.14%) suggests a strategic shift towards these more environmentally friendly and sustainable energy sources.

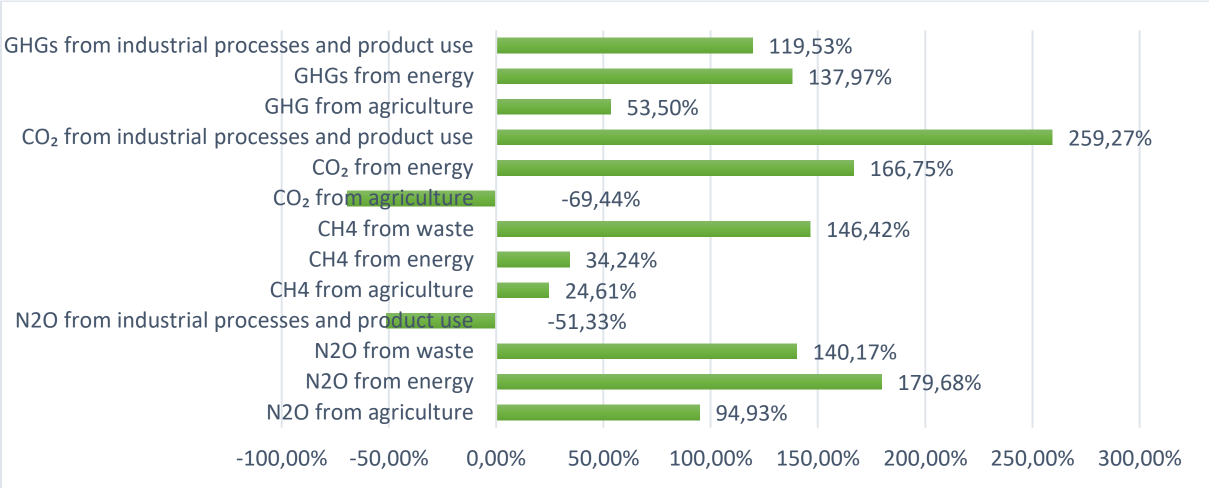

Figure 5.5: Growth rates of energy consumption and GHG emissions by source in Tunisia (1980-2021)

When considering the sector-specific contributions to GHG emissions, the industrial sector stands out (Figure 5.5). Industries such as cement and chemicals have significantly increased CO2 emissions, highlighting the urgent need for energy efficiency and cleaner technologies in industrial processes. The transportation sector, which relies heavily on fossil fuels, is also a significant source of emissions. This trend underscores the need for a comprehensive strategy that includes improving public transport, integrating electric vehicles, and developing sustainable urban mobility.

The residential sector also shows a steady increase in energy consumption, mainly for heating, cooling and electricity. This trend points to the need for energy-efficient building design and sustainable household practices.

At the same time, Tunisia's demographic growth has had a significant impact on energy demand and CO2 emissions. Increasing energy demand for housing, transportation, and industrial activities, driven by a growing population, has exacerbated the challenges of managing energy consumption and reducing emissions. However, per capita emissions provide a more nuanced perspective on Tunisia's environmental impact management, indicating a slight increase over the years and calling for targeted policies to address the balance between population growth and sustainable energy use.

In response to these challenges, Tunisia's transition to renewable energy sources, while significant, needs to be accelerated to align with global climate change mitigation efforts and the country's environmental goals. The government's role in shaping policies that promote the adoption of renewable energy, foster innovation, and facilitate technology transfer in the energy sector is critical.

In addition, initiatives to raise public awareness and promote sustainable lifestyles are key to reducing the environmental footprint of the population. These efforts, combined with strategic policy interventions, can significantly influence Tunisia's trajectory towards sustainable energy consumption and reduced GHG emissions.

Tunisia's trajectory from 1980 to 2021 thus reveals a dynamic interplay between economic development, technological progress and environmental policies. The country has made progress in diversifying its energy sources and improving energy efficiency. However, the continued rise in GHG emissions calls for more robust and comprehensive strategies to achieve a sustainable balance between economic growth and environmental protection.

5.4.4. Sectoral impacts of climate change on the Tunisian economy

5.4.4.1. Water resources and agriculture in the face of climate change

From 1980 to 2021, Tunisia's CO2 emissions recorded a significant average annual increase of 33.76%, mainly influenced by the interplay between carbon intensity of energy (CIE), energy intensity (EI) and demographic intensity (DI). This escalation in emissions has contributed to climate change, which has subsequently affected the country's water resources and agricultural sector.

A significant finding is the positive interaction between EI and DI, which led to a 28.96% increase in emissions. This correlation underscores the impact of population growth on increased energy consumption, particularly from carbon-intensive sources, and its subsequent impact on agriculture and water resources. Rapid population growth leads to increased demand for agricultural products, water and energy, exacerbating the degradation of natural resources and increasing the vulnerability of the agricultural sector to climate change.

5.4.4.1.1. Dynamics of water resources

According to the Food and Agriculture Organization (FAO, 2023), Tunisia has experienced a significant increase in temperature (0.27°C to 2.56°C between 1961 and 2021) and a decrease in precipitation. These climatic changes have a direct impact on water availability, particularly for agricultural irrigation, and increase the risk of water stress during prolonged droughts. Precipitation changes are characterized by a drastic decrease in 2021 (145.53 mm/year) compared to previous years, with a notable peak in 2003 (407.42 mm/year). Schilling et al.

(2020) predict a 10-20% decrease in precipitation by the end of the century, further straining water resources.

This variability in precipitation poses significant challenges to water management, making supply more unpredictable and increasing the risk of shortages. Growing demand for water, which will increase from 1.07 billion m³ in 1975 to 3.96 billion m³ in 2021, will increase pressure on these resources and threaten the sustainability of the agricultural sector. Projections by FTDES (2021) and ONAGRI (2022) indicate a potential decrease in agricultural productivity, aggravated by climate change.

5.4.4.1.2. Vulnerabilities of the agricultural sector

The agricultural sector, which will contribute about 10.72% of Tunisia's GDP in 2021 (World Bank, 2023), has experienced a slight increase in agricultural area, but a decrease in cultivated land from 49810 km² in 1961 to 42500 km² in 2020. Climate change threatens nutrient availability, potentially increasing dependence on fertilizers, which could reduce yields by 10 to 25% by 2050 (Lobell et al., 2008), challenging the growth and sustainability of the sector.

Fertilizer use per hectare of cropland has increased significantly, from 4.94 kg/ha in 1961 to 56.53 kg/ha in 2020. This excessive use can degrade soil quality and contribute to GHG emissions, which have increased to 4.62 $MtCO_2e$ in 2021, while total GHG emissions reach 35.38 $MtCO_2e$. The tripling of energy consumption, mainly from natural gas and oil, between 1980 and 2021 and the corresponding increase in CO2 emissions (from 8.54 $MtCO_2e$ to 22.38 $MtCO_2e$) reflect the growing energy demand driven by an 85% increase in population over the same period.

These climate changes have a direct impact on water resources, reducing their availability and affecting agriculture through lower yields, increased vulnerability to extreme events and pressure on land resources. Therefore, addressing climate change challenges in these sectors is critical for Tunisia's sustainable development and environmental resilience.

5.4.4.2. Climate change and the health sector in Tunisia

The impact of climate change on human health is a global concern, and Tunisia's health sector is increasingly affected by these environmental changes. The country faces a wide range of challenges related to disease prevention, diagnosis and treatment, all exacerbated by factors such as rising temperatures, extreme weather events, deteriorating air quality, and food and water insecurity. Addressing these challenges is critical to ensuring the health and well-being of Tunisians.

5.4.4.2.1. Direct health impacts

Tunisia has experienced an increase in extreme weather events, with 56 events recorded between 1982 and 2021, including 23 floods and 8 droughts (Ministry of Finance, 2023). These events have direct health consequences, such as an increase in respiratory and cardiovascular diseases, trauma, and mental health problems (WHO, 2017). Heat waves in particular pose a significant health risk, causing heat stress and related illnesses such as heat stroke and dehydration, especially among vulnerable populations such as the elderly and children (Chebli et al., 2020; UNICEF, 2021).

Deteriorating air quality due to increasing GHG emissions and air pollutants leads to respiratory diseases such as asthma and bronchitis (Chebli et al., 2020). Water scarcity and declining water quality contribute to the spread of waterborne diseases such as diarrhea and cholera, and an increase in vector-borne diseases (Ben Boubaker, 2010; UNICEF, 2021).

Food security is also affected by climate change, leading to nutritional problems, especially among children and vulnerable groups, and exacerbating malnutrition and diet-related diseases (Ferchichi, 2012; WFP, 2021). Climate-induced internal migration due to factors such as land degradation and coastal erosion poses additional health risks (FTDES, 2021; IOM, 2023).

Healthcare infrastructure, particularly in vulnerable regions, faces increased strain due to the rise in climate-related diseases and extreme weather events (Ministry of Health, 2015). Mental health impacts, including stress, anxiety, and depression, are also notable, especially among displaced populations (ONAGRI, 2022; UNICEF, 2021). Overall, climate change is exacerbating public health risks in Tunisia across a spectrum of respiratory, infectious, nutritional, and mental health issues.

5.4.4.2.2. Indirect health impacts

Climate change disproportionately affects vulnerable groups in Tunisia, including women, children, the elderly and disabled, as well as rural communities. These groups are more vulnerable to health problems that are exacerbated by social inequalities and regional socioeconomic disparities (UNSDG, 2020). Rapid urbanization is exacerbating these problems, leading to environmental degradation in urban areas, which contributes to respiratory and cardiovascular diseases (Ministry of Environment, 2021).

The disruption of ecosystems and loss of biodiversity caused by climate change have indirect effects on health. These changes affect food security, livelihoods, particularly in fishing communities, and the availability of ecosystem services critical for maintaining health (Zahar, 2020). Effective adaptation and mitigation measures are essential in Tunisia to reduce the vulnerability of the population and limit the increase in GHG emissions, thereby reducing the overall impact of climate change on health.

5.4.4.3. Tourism sector: Assessing the impact of climate change

Tunisia's tourism sector, which contributes about 14.2% to the national GDP (ONAGRI, 2022), is increasingly vulnerable to climate change. The sector faces challenges due to temperature fluctuations, extreme weather events, and rising sea levels. These climatic changes affect natural resources, infrastructure, and tourism activities, threatening the vitality and sustainability of the sector. Recognizing and addressing these challenges is critical to maintaining the economic contribution of tourism and preserving Tunisia's attractiveness as a tourist destination.

5.4.4.3.1. Direct impacts on tourism

Climate change in Tunisia directly affects tourism in several ways. Rising sea levels and coastal erosion pose a significant threat to coastal tourism infrastructure, reducing the space available for tourism activities and potentially leading to economic losses. Extreme weather events, such as storms and floods, can cause damage to infrastructure, deter tourists, and increase maintenance costs. Seasonal shifts may also affect the traditional tourist season, requiring adjustments in tourism strategies and offerings.

Health risks associated with climate change, including heat stroke and the spread of disease, affect both tourists and industry workers. The degradation of marine ecosystems threatens water-based activities such as diving, while the loss of terrestrial biodiversity affects ecotourism attractions. In addition, climate change threatens cultural heritage sites, which risk losing their historical and tourist value.

These direct impacts, which include infrastructure risks, health concerns, and the degradation of natural and cultural assets, underscore the need for robust adaptation and mitigation strategies to safeguard Tunisia's tourism sector.

5.4.4.3.2. Indirect impacts on tourism

Indirectly, climate change affects tourist mobility in Tunisia, potentially complicating travel and increasing costs due to impacts on transportation infrastructure. Extreme weather conditions can disrupt travel plans, require significant investments to repair infrastructure, and potentially affect the accessibility of tourist destinations.

Climate change also affects agrotourism by altering agricultural production patterns. Changes in the quality of local products and working conditions on farms could reduce the attractiveness of agritourism experiences. In addition, changing climatic conditions could influence tourist preferences, leading them to destinations that are perceived to be less affected by adverse climate impacts.

These developments could affect Tunisia's reputation as a desirable tourist destination, with economic and employment implications. Reduced tourism revenues could lead to job losses and affect sectors indirectly dependent on tourism. Increased pressure on natural resources, such as water and coastal ecosystems, poses a challenge to the sustainability of the tourism industry. To address these challenges, it is imperative for tourism stakeholders to develop and implement adaptation strategies that enhance the resilience and long-term sustainability of the tourism sector in the face of climate change.

5.4.4.4. Energy sector: responding to climate change

Tunisia's energy sector is increasingly challenged by climate change. Temperature variations, extreme weather events, and changing rainfall patterns affect energy production, distribution, and consumption. Adaptation and diversification of energy sources are critical to ensure energy security, reduce dependence on fossil fuels, and mitigate GHG emissions. Integrating climate change considerations into the planning and management of the energy sector is essential for the resilience and sustainability of the sector, which is vital to Tunisia's economy.

4.4.4.1. Direct impacts on energy production and consumption

Climate change directly affects Tunisia's energy sector in several ways. Rising temperatures increase the demand for energy, especially for cooling in the summer, requiring investments in infrastructure to prevent shortages. Conversely, milder winters could reduce heating demand, but hotter summers could increase electricity consumption.

Energy costs could escalate due to fluctuations in supply and demand and the need to invest in climate adaptation. Climate impacts could also reduce the efficiency of power plants and affect renewable energy production, such as hydropower, due to changes in precipitation patterns. However, solar and wind energy production could benefit from higher temperatures and reduced precipitation.

Climate change poses risks to energy infrastructure, particularly in coastal areas, reducing its durability and increasing maintenance costs. This will require revisions to investment plans and policies to address the impact of climate change on energy production, efficiency, and security.

5.4.4.4.2. Indirect challenges in the energy sector

Climate change indirectly affects Tunisia's economy and employment through changes in the energy sector. The transition to a low-carbon economy and the promotion of renewable energy can create jobs and spur innovation, but can also lead to job losses in traditional energy industries. Adapting to climate-related changes in energy production and demand could impose economic burdens, requiring investment in new infrastructure and replacement of equipment (Ben Youssef and Dahmani, 2024a, 2024b; Dahmani, 2023; Dahmani et al, 2021b, 2023).

Climate change may increase energy demand in agriculture and food production for irrigation, water pumping and processing. Fluctuations in agricultural productivity and water availability could lead to increased energy demand.

Beyond economics, climate change has implications for public health, social inequalities, migration, and geopolitics. Heat waves and increased demand for air conditioning could worsen air quality and public health, particularly in urban areas. Impacts on water resources and agriculture could drive population migration and put additional strain on energy infrastructure.

These challenges underscore the need to improve the resilience of energy infrastructure, invest in new technologies and renewable energy sources, and promote energy efficiency. Tunisia needs to work with the global community to mitigate and adapt to climate change, continuously monitoring and assessing impacts to develop effective long-term policies and strategies.

5.5. Conclusions and recommendations

5.5.1. Conclusion

Tunisia is facing significant challenges linked to climate change, which are having a major impact on key sectors such as water, agriculture, health, tourism, and energy. This study examined the impact of climate change on the Tunisian economy by analyzing the determinants of CO_2 emissions and assessing the sectoral effects of climate change. By applying the Kaya identity, the Tapio model and the LMDI-II method, we were able to identify the main factors influencing CO_2 emissions and observe the decoupling process between economic growth and CO_2 emissions in Tunisia.

The sectoral analysis highlighted the direct and indirect effects of climate change on water resources, agriculture, health, tourism, and energy. The results of this study underline the importance of adopting integrated policies and strategies to mitigate the impacts of climate change and promote resilience and sustainable development.

Tunisia must continue its efforts to reduce CO_2 emissions, while sustaining economic growth. This means adopting cleaner, more efficient technologies, and practices in key sectors, improving water resource management, and promoting climate change adaptation in the most vulnerable sectors. In addition, promoting regional and international cooperation is essential to meet the challenges of climate change and support sustainable development in Tunisia and the region.

5.5.2. Policy recommendations

This study has highlighted the profound challenges that Tunisia faces due to climate change, with significant impacts on critical sectors such as water resources, agriculture, health, tourism, and energy. Tunisia's path forward requires a multifaceted approach. Reducing CO_2 emissions is important but must be balanced with the pursuit of economic growth. Key steps include the adoption of cleaner and more efficient technologies, especially in sectors that are major contributors to emissions. Strengthening water resource management is essential in response to increasing scarcity and fluctuating rainfall patterns. Agricultural practices must be adapted to changing climatic conditions to ensure food security and sustainability. The health sector must be strengthened to cope with the increasing burden of climate-related diseases and to protect vulnerable populations.

Additionally, the tourism industry, a major contributor to Tunisia's GDP, requires adaptation strategies to cope with a changing climate that threatens its attractiveness and infrastructure. In the energy sector, a shift to renewable energy sources and improved energy efficiency is essential to reduce dependence on fossil fuels and contribute to global efforts to combat climate change.

5.5.3. Strategic recommendations for sustainable development and emissions reduction

Tunisia's response to the challenges of climate change, particularly in the water, agriculture, health, tourism and energy sectors, requires a holistic approach that integrates sustainable development principles with effective mitigation strategies. The country must embark on a path that not only strengthens its resilience to the impacts of climate change, but also promotes economic growth.

In the water and agriculture sectors, the focus should be on modernizing irrigation systems to optimize water use, implementing integrated water resource management that includes reuse of treated wastewater and rainwater harvesting, and promoting crop diversification with a special emphasis on drought-resistant varieties. Enhancing food security through improved storage systems and building farmers' capacity to adapt to climate change is critical. Urban agriculture needs to be integrated into urban planning, while watershed management should focus on reforestation and integrated management approaches. The use of advanced technologies to monitor water resources and optimize irrigation is essential, as is the promotion of collaborative research on agricultural innovation and the involvement of civil society and the private sector in water management and agricultural adaptation projects.

In the health sector, the establishment of surveillance networks for the early detection of epidemics and climatic events is crucial. Strengthening existing health infrastructures, especially in rural areas through mobile clinics, and promoting sustainable agricultural practices adapted to climatic conditions are necessary. Action plans tailored to vulnerable populations, ongoing training for health professionals, and local research on climate-health impacts and solutions are essential. Integrated water and sanitation management to prevent waterborne diseases and the use of solar energy in health facilities are essential mitigation measures.

The tourism sector needs to assess the impact of climate change on destinations, manage water efficiently, protect coastal zones, promote ecotourism and integrate sustainable strategies into tourism development. Developing contingency plans and diversifying tourism offerings are necessary to better manage disasters.

Finally, in the energy sector, adapting energy infrastructure to climate impacts is key. Promoting energy efficiency standards, promoting renewable energy, diversifying energy sources, coordinating sectoral policies, promoting research and innovation, and raising awareness of energy efficiency are critical steps towards resilience.

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