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Article

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Sectoral dynamics and environmental quality in Côte d'Ivoire: assessing the impact of structural transformation

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ABSTRACT

As global consumption patterns continue to exert unprecedented pressure on ecological systems, the urgent need for sustainable development frameworks has become increasingly evident. This study explores the critical intersection of structural transformation and environmental quality within the context of Côte d'Ivoire, as the country navigates its National Development Plan aimed at structural transformation. Specifically, this research explores how structural changes across the agricultural, industrial, and service sectors impact environmental quality in Côte d'Ivoire. Employing a Nonlinear Autoregressive Distributed Lag (NARDL) model, it investigates the asymmetric effects of sectoral contributions to the Gross Domestic Product (GDP) on the ecological footprint, distinguishing between positive and negative shocks during the period 1961–2021. The findings reveal that positive changes in the agricultural sector's share reduce the ecological footprint by 0.222% in the long term, with no significant short-term impact. Conversely, a 1% negative shock in the sector results in a 0.391% increase in the ecological footprint in the short term. For the industrial sector, a 1% increase in its share leads to a 0.178% reduction in the ecological footprint over the long term, while negative shocks show no significant impact. The service sector demonstrates a positive environmental outcome, where a 1% increase in value-added reduces the ecological footprint by 0.368% in the long term and by 0.288% in the short term. For policymakers, these results highlight the importance of promoting sustainable practices within the agricultural and industrial sectors to achieve long-term environmental goals in Côte d'Ivoire. These results are critical for the implementation of Côte d'Ivoire's National Development Plan, which emphasizes the important role of agriculture and industry in its economic transformation, while addressing environmental sustainability.

IMPACT STATEMENT

This study provides important understanding into the relationship between structural transformation and environmental quality in Côte d'Ivoire. The research reveals how sectoral shifts in the agricultural, industrial, and service sectors influence the country's ecological footprint, with a focus on the asymmetric effects of these shifts on environmental outcomes. The findings show that while the agricultural and industrial sectors can reduce the ecological footprint over the long term, negative short-term impacts can arise from rapid sectoral changes, particularly in agriculture. A growing service sector appears to have positive environmental contributions. These results are particularly relevant for Côte d'Ivoire's policymakers, emphasizing the need to adopt sustainable practices across key sectors to balance economic growth with environmental sustainability. They also highlight the importance of promoting green growth strategies and aligning sector-specific policies with the country's long-term environmental objectives.

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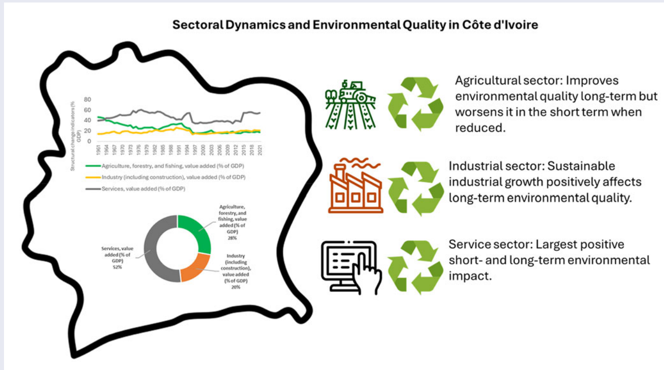
GRAPHICAL ABSTRACT



1. Introduction

The Global Footprint Network reports that the average worldwide ecological footprint per person stood at 2.58 Gha,[1] while the biocapacity was 1.51 Gha, resulting in a 1.07 Gha ecological deficit. In a broader context, the world transitioned from an ecological reserve[2] between 1961 and 1970 to a notable turning point in 1971, marked by a deficit of 0.06 Gha. This deficit has escalated to 1.07 Gha in 2022, underscoring the heightened stress on the planet due to prevailing consumption and production patterns. Awareness of planetary perils is not novel, prompting international actions and commitments by states. Notable initiatives include Sustainable Development Goals (SDGs) 11 to 15 and the Paris Agreement, mandating countries to present a Nationally Determined Contribution (NDC). These commitments aim to address various aspects, including sustainable cities and communities, establishment of sustainable consumption and production patterns, measures to combat climate change, conservation and sustainable use of oceans, seas, and marine resources, as well as the preservation and restoration of terrestrial ecosystems. These efforts collectively tackle challenges such as managing forests sustainably, combating desertification, halting and reversing land degradation, and preventing biodiversity loss.

In the specific case of Côte d'Ivoire, data from Global Forest Watch reveal a concerning trend from 2001 to 2021. Over this period, the country experienced a substantial loss of 3.46 million hectares (Mha) of vegetation cover, equivalent to a 23% reduction since 2000. This loss corresponded to 1.71 gigatons (Gt) of CO_2 equivalent emissions. While being part of international commitments in terms of environment and climate, Côte d'Ivoire is also pursuing a strategy to expedite structural transformation by industrializing its economy. This trajectory appears to pose a potential contradiction to previous environmental commitments, unless the ongoing structural transformation is executed in a sustainable manner. Outlined in Côte d'Ivoire's National Development Plan for 2021–2025, the envisioned structural transformation entails several key elements. First, there is an emphasis on enhancing the quality of products, particularly in the agricultural sector. Second, the plan underscores the importance of developing industrial activities that have the potential for significant job creation and added value, including advanced processing and the manufacturing of more complex products. Last, there is a focus on harnessing the potential of service activities through formalization and professionalization. To achieve these goals, the plan advocates for the acceleration of modernization and increased productivity in the agricultural sector, alongside efforts to enhance productivity and competitiveness in both the industrial and service sectors. The success of this process hinges on ensuring sustainability in the structural transformation of Côte d'Ivoire's economy.

Côte d'Ivoire faces significant challenges and opportunities in balancing economic growth with environmental sustainability. Key challenges include deforestation due to agricultural expansion, pollution from urbanization and industrialization, vulnerability to climate risks like flooding and drought, inadequate infrastructure that limits access to clean energy and waste management, and land use conflicts among agriculture, urban development, and conservation. Conversely, there are promising opportunities such as promoting sustainable agriculture through agroforestry, investing in renewable energy sources like solar and wind, leveraging ecotourism for economic gain while encouraging conservation, and strengthening policy frameworks for sustainable practices.

The existing body of literature unequivocally highlights the detrimental impact of industrial activity on the environment. Cherniwchan (2012), for instance, explicitly linked the industrialization process to the generation of CO_2 emissions. Consequently, it is reasonable to infer that a contradictory relationship exists between the imperative of growth, often pursued through industrialization and deemed vital for the advancement of African nations, and the imperative of environmental protection. This raises a fundamental question: would protecting the planet mean abandoning the growth process? This dilemma becomes more pronounced when considering the potential conflict between attaining green growth objectives and the foundational pillar of the 'Côte d'Ivoire, industrial power' vision outlined in the Côte d'Ivoire 2040 prospective study. The core tenet of this vision aspires for Côte d'Ivoire to evolve into an industrial powerhouse, marked by a holistic transformation encompassing cultural, educational, health, agricultural, technological, and infrastructural domains. The envisioned outcome includes a high per capita industrial output, ensuring a populace with a superior standard of living and access to a diverse array of manufactured products and services.

Grossman and Krueger (1991) pivotal discovery of the Kuznets Environmental Curve (KEC) offers a relief to decision-makers, revealing that economic growth becomes environmentally beneficial beyond a specific threshold. Specifically, the relationship between environmental degradation and economic growth is characterized by a 'U-Inverse' pattern, involving an initial phase of degradation followed by a reversal of the trend and a 'greening' of growth at higher levels of economic development. This raises a pertinent question: What strategies can decision-makers employ to instigate this process of 'greening' growth? Grossman and Krueger (1996) identify three significant levers. First, there is the potential for a shift in the composition of production (structural change) as increased income correlates with changes in production (initially favoring more manufactured goods over agriculture, and later transitioning to more services and fewer manufactured goods, for instance). Second, the evolution of technology, as highlighted by Grossman and Krueger (1996), suggests that the adoption of more modern technologies could contribute to a cleaner environment. Last, an enhancement in institutional quality is identified as a crucial lever, wherein governments can respond to environmental demands by implementing stricter regulations, as proposed by Grossman and Krueger (1996).

Prior studies, such as Senzele (2022), which validated the Kuznets Environmental Curve hypothesis in Côte d'Ivoire, illustrate the potential for a reversal threshold in environmental degradation as economic growth progresses. Furthermore, the implications of economic activities on environmental quality are critical for formulating effective policy responses, a concern echoed in the works of Grossman and Krueger (1991) and Yassin and Aralas (2017), which highlight the intricate dynamics between structural transformation, economic activities, and environmental outcomes. In addition, previous studies, such as those by Ali et al. (2020) and Udemba (2021), emphasize the nuanced relationship between economic activities and environmental degradation, particularly in developing countries.

The main research question of this paper is as follows: How does structural change influence the impact of economic activity on environmental quality in Côte d'Ivoire? The study's objective is to investigate the relationship between structural change and environmental quality in Côte d'Ivoire by quantifying the impact of different economic sectors on environmental degradation. Specifically, the study seeks to: (1) identify and quantify the individual contributions of various economic sectors (such as agriculture, industry, and services) to environmental degradation resulting from economic activities; (2) assess the environmental consequences of sectoral shifts by examining the effects of each percentage point of growth in a specific sector on environmental quality, particularly when such growth occurs at the expense of contraction or decline in other sectors; (3) provide insights into how structural changes within Côte d'Ivoire's economy can be managed to promote sustainable development, minimizing negative environmental impacts while fostering economic growth.

In this study, the nonlinear autoregressive distributed lag (NARDL) cointegration approach is employed, enabling the identification of asymmetries in both short and long-term predictions. This methodology is utilized to examine the potential nonlinear cointegration of time series. Simultaneously, it assesses short- and long-term nonlinearities by decomposing the positive and negative partial sums of the regressors. Ultimately, this approach facilitates the measurement of distinct responses to positive and negative shocks from the regressors in the context of asymmetric dynamic multipliers.

This study contributes to the existing literature by focusing specifically on Côte d'Ivoire, a country undergoing significant structural changes. The choice to focus on Côte d'Ivoire is therefore significant because its structural changes and industrial policies could provide insights into how developing nations might navigate the challenges of sustainable development amidst rapid growth. The existing literature presents a wealth of insights into the interactions between economic growth, structural transformation, and environmental quality; however, a significant research gap remains in understanding the sector-specific dynamics within the context of Côte d'Ivoire. While previous studies, such as those by Senzele (2022) and Udemba (2021), have examined the Kuznets Environmental Curve and the general relationship between economic activities and environmental degradation, they often overlook the nuanced effects of structural change across different sectors—agriculture, industry, and services—on environmental outcomes. Côte d'Ivoire, as it embarks on a transformative economic journey, exemplifies the need for detailed analysis that dissects how shifts within these sectors influence environmental quality.

Based on the theoretical framework provided in Section 3.2, we formulate three (3) hypotheses for the research:

H1: Positive structural transformation in Côte d'Ivoire's agricultural sector reduces the ecological footprint in the long term, while negative structural shifts increase environmental degradation in the short term.

H2: Structural changes in Côte d'Ivoire's industrial sector, specifically increased industrialization, contribute to a long-term reduction in the ecological footprint, with insignificant short-term impacts of negative shocks.

H3: Growth in Côte d'Ivoire's service sector significantly reduces the ecological footprint in both the short and long term.

The subsequent sections of the article are organized as follows: Section 2 provides a succinct literature review. Section 3 details the data and methodology employed in the study, while Section 4 presents the obtained results. Section 5 serves as the conclusion and puts forth policy recommendations.

2. Literature review

Given the critical role of economic growth in the process of structural change, the primary aim of this literature review is to underscore relevant research that investigates the connection between economic growth and the environment. The theoretical underpinnings established by Grossman and Krueger (1991) and Jänicke et al. (1989), among others, remain foundational for understanding the nature of the impact of economic activities on the environment. Notably, the work of Ali et al. (2020) contributes to this discourse by examining the influence of technology and structural change on the environment in Malaysia. Their study employs a theoretical framework rooted in Romer's endogenous growth model, where production is a function of capital (measured by energy consumption) and technological advancement. Deriving the environment-economic growth relationship, the authors formulate an equation connecting carbon emissions, energy consumption, technological progress, economic growth (including its squared term to account for the Kuznets Environmental Curve, KEC), and structural change. Importantly, they posit that structural change serves as a potent representation of KEC, underscoring its significance in estimating environmental quality in relation to the KEC. Building on a similar approach, Villanthenkodath et al. (2022) and Adebayo et al. (2023) also adopt a cumulative production function with a temporal dimension and constant returns. However, these authors employ distinct measures of structural change in their respective studies.

In the context of the environmental impact of economic growth, the prevailing perception is that economic growth is often associated with adverse effects on the environment. This association arises from production activities across three key sectors: agriculture, industry, and services, wherein the energy-intensive nature of growth becomes a notable source of CO_2 emissions (Udemba, 2021). Examining the reciprocal causation between the environment and economic growth, Horii and Ikefuji (2014) illustrate a dual relationship. First, growth influences the environment through pollution generated, particularly in the form of CO_2 emissions, during the growth process. Second, the deteriorated environment, in turn, acts as a limiting factor for sustained economic growth. In the context of underdeveloped countries, this causal link, known as the environment-poverty trap, offers insights into the persistence of environmental and income inequalities between nations. Alam (2014) delves into the intricacies of economic structure changes and trends in carbon dioxide (CO_2) emissions relative to GDP per capita in Bangladesh. His study also explores the relationship between economic growth, measured by GDP per capita, and CO_2 emissions. Employing the Environmental Kuznets Curve (EKC) framework, Alam challenges the validity of the EKC hypothesis in the case of the Bangladesh economy and shows that the EKC hypothesis is not valid. Furthermore, he uncovers that structural change, marked by a shift from an agriculture-based economy to one less reliant on it and the ascendance of the service sector, leads to an increase in CO_2 emissions. Senzele's (2022) research in Côte d'Ivoire validates the Kuznets environmental curve hypothesis, identifying a reversal threshold at US$2,008. He also identifies energy consumption, urbanization, and industry as determinants of CO_2 emissions. Additionally, Senzele reveals that trade openness and the share of services in GDP exert a negative impact on CO_2 emissions. Utilizing the Toda and Yamamoto causality analysis approach, he establishes a one-way causal relationship, highlighting the influence of economic growth on environmental degradation.

Awad's (2021) evaluation of structural transformation, focusing on the impact of industry on environmental quality across a sample of 20 low-income Sub-Saharan African countries, yields a noteworthy finding: there is a non-significant effect of industrialization on environmental quality. This result is attributed to the substantial underdevelopment of the industrial sector in Sub-Saharan African nations. In these countries, the transition occurs directly from agriculture to the service sector, bypassing significant development in the secondary sector. Notably, the determinant of environmental quality is found to be more strongly influenced by population size, with larger populations exacerbating environmental impact, aligning with the explanation provided by Grossman and Krueger (1996).

In their study, Yassin and Aralas (2017) concentrate on the dynamics of structural transformation and its specific impact on environmental pollution. Adopting Timmer's (2012) comprehensive definition of structural transformation, encompassing technological progress, structural change, demographics, and trade openness, the study unfolds the multifaceted dimensions of this process. Structural transformation, as outlined by Timmer, unfolds through several stages: it commences with a decline in the agricultural sector's contribution to GDP, accompanied by a decrease in employment. Subsequently, there is progression towards the development of industry and services, coupled with a notable shift in population from rural to urban areas, indicative of rapid urbanization. The final stage involves a demographic transition from high birth and death rates to lower ones. The outcomes of their research reveal the impact of structural transformation on environmental pollution through two distinct pathways. First, industrialization, marking the transition from an agricultural to an industrial economy, is identified as a factor contributing to increased pollution. Second, tertiarization, representing the shift from an industrial to a service-based economy, is associated with a reduction in environmental pollution. This dual influence underscores the nuanced relationship between the various phases of structural transformation and their divergent effects on environmental quality.

In a study conducted by Luukkanen et al. (2015), the authors examine the prospective impact of structural changes in the Chinese economy on CO_2 emissions. Employing a ChinaLINDA model, their findings suggest that a shift toward service-oriented growth could reduce China's cumulative CO_2 emissions by one-fifth by the year 2030. This underscores the potential environmental benefits associated with a structural transformation emphasizing the service sector. To capture the asymmetric effects of both structural change and the integration of renewable energies on carbon emissions, Adebayo et al. (2021) employ a nonlinear autoregressive distributed lag (NARDL) model. Subsequently, they conduct a spectral causality analysis, revealing a significant nonlinear influence of all explanatory variables on CO_2 emissions. Notably, the study identifies that structural change, particularly the dominance of the service sector, has a positive impact on the environment, leading to a reduction in CO_2 emissions. Conversely, economic growth is identified as a factor that could diminish this positive environmental impact, given its association with increased CO_2 emissions. This complex interplay highlights the importance of considering various factors, including structural changes and economic growth, in understanding and formulating effective strategies for environmental sustainability.

Building on recent studies, the role of sector-specific dynamics and environmental policies in shaping environmental outcomes has gained increasing attention. Kartal (2022, 2023, 2024a) explores how Research and Development (R&D) investments in energy and sectoral CO_2 emissions are interlinked, demonstrating that such investments, particularly in nuclear and renewable energy, have varying impacts across different sectors and timeframes. These findings underscore the importance of sectoral differentiation in environmental policy, highlighting that while R&D in renewable energy may reduce emissions in the long run, it can have adverse short-term effects. Similarly, Kartal (2024b, 2024c) examines the role of environmental taxes in the G7 and EU5 countries, revealing heterogeneous effects based on tax type and sector. In the context of structural transformation in Côte d'Ivoire, these insights suggest that targeted R&D investments and tax policies need to consider the specific characteristics of each sector—agriculture, industry, and services—to effectively mitigate environmental degradation while supporting sustainable economic growth.

Other recent research highlights the intricate relationship between resource management, technological innovation, and environmental sustainability, further contextualizing the implications of structural transformation in Côte d'Ivoire. For instance, Omri and Kahia (2024) demonstrate that effective institutional quality enhances the positive impacts of natural resource wealth on well-being, suggesting that strong governance is critical in managing resource-driven growth. Moreover, Kahia and Omri (2024) emphasize the necessity of transitioning to renewable energy to counteract the environmental degradation associated with resource reliance, illustrating how technological advancements can mitigate negative ecological effects. Charfeddine et al. (2024) underscore the significance of digitalization and renewable energy in improving environmental quality, advocating for policies that leverage these innovations. Similarly, Omri et al. (2024) and Kahia et al. (2020) provide evidence that technological and environmental innovations are essential in addressing the challenges posed by economic growth on sustainability. As structural transformation progresses, an approach that accounts for sectoral heterogeneity is essential for designing policies that balance economic development and environmental quality.

The literature review provides an overview of the relationship between economic growth, structural change, and environmental quality, highlighting various theoretical frameworks and empirical findings across different contexts. The foundational theories established by Grossman and Krueger (1991) and the Environmental Kuznets Curve (EKC) hypothesis remain central to understanding this nexus. Recent studies, such as those by Ali et al. (2020) and Adebayo et al. (2021), have expanded on these theories by incorporating technological advancements and sectoral shifts, revealing both positive and negative environmental impacts stemming from structural transformations. However, despite the depth of existing research, several critical gaps persist. Firstly, while many studies focus on specific regions or countries, there is a scarcity of comprehensive analyses that consider cross-country comparisons, particularly among underdeveloped nations. This limits the generalizability of findings and insights applicable to similar economic contexts. Secondly, while the impact of sectoral dynamics on environmental outcomes has been recognized, there remains a lack of detailed studies that disaggregate the effects of different sectors—particularly in the context of low-income countries undergoing rapid transformation such as Côte d'Ivoire. There is also a need for more differentiated exploration of how sector-specific policies can effectively address environmental concerns without stifling economic growth.

Table 1. Dictionary of the study variables.

Variables	Codes	Source
Ecological footprint for consumption	EFC	National Footprint and Biocapacity Accounts (NFBAs), Global Footprint Network (2023)
Agriculture, forestry, and fishing, value added (% of GDP)[3]	AGR	World Development Indicators (WDI),) (2023)
Industry (including construction), value added (% of GDP)[4]	IND	WDI
Services, value added (% of GDP)[5]	SER	WDI
GDP per capita (constant 2015 US$)	GDP	WDI
Energy use (kg of oil equivalent per capita)	ENE	WDI
Individuals using the Internet (% of population)	INT	WDI

Table 2. Descriptive statistics and correlation matrix.

Descriptive statistics	EFC	AGR	IND	SER	GDP	ENE	INT
Number of observations	61	61	61	61	61	61	61
Mean	0.289	3.163	2.891	3.822	7.586	6.104	4.921
Median	0.281	3.197	2.883	3.836	7.554	6.062	0
Standard Deviation	0.172	0.333	0.163	0.177	0.187	0.180	12.327
Minimum	−0.001	2.717	2.618	3.526	7.317	5.887	0
Maximum	0.583	3.837	3.268	4.103	8.012	6.530	45.425
Correlation matrix							
EFC	1.000						
AGR	0.629***	1.000					
IND	−0.012	0.145	1.000				
SER	0.596***	0.315**	0.439***	1.000			
GDP	0.717***	0.224*	0.228**	0.786***	1.000		
ENE	−0.010	−0.462***	0.055	0.101	0.006	1.000	
INT	−0.047	−0.354***	0.276**	0.291**	0.139	0.794***	1.000

Note. All the variables are taken in the natural logarithm, except the 'INT' variable. Source: Authors' calculations.

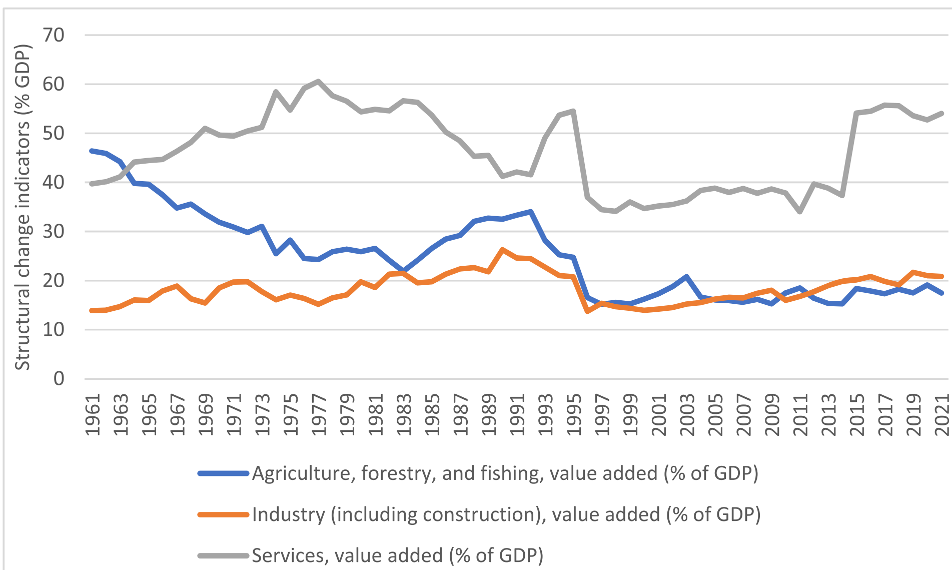


Figure 1. Evolution of sectors' contribution to Côte d'Ivoire's GDP.
Source: Authors, using World Bank's World Development Indicators data.

3. Data and methodology

3.1. Data

The central research question addressed in this paper is around assessing the degree to which the process of structural change in Côte d'Ivoire influences its environmental quality.

The data used come from a variety of sources and cover the Ivorian economy between 1961 and 2021. These were obtained from the World Bank's latest World Development Indicators (WDI) database and the National Footprint and Biocapacity Accounts (NFA) public data for the ecological footprint (Table 1). Descriptive statistics for the study's variables and their correlation matrix are presented in Table 2. Both the mean and median values consistently fall within the range defined by the variables' minimum and maximum values. This indicates a high level of coherence in the dataset. The correlation matrix reveals that there is no substantial correlation among the explanatory variables, signaling the absence of multicollinearity issues.

3.1.1. Measure of structural change

The prevailing literature commonly conceptualizes structural change as a unidirectional progression, transitioning from agriculture to industry and ultimately to services, as indicated by Awad (2021). Consequently, the predominant proxies employed to gauge this phenomenon often involve measuring the value added in either the service sector, as demonstrated by Villanthenkodath et al. (2022), or the

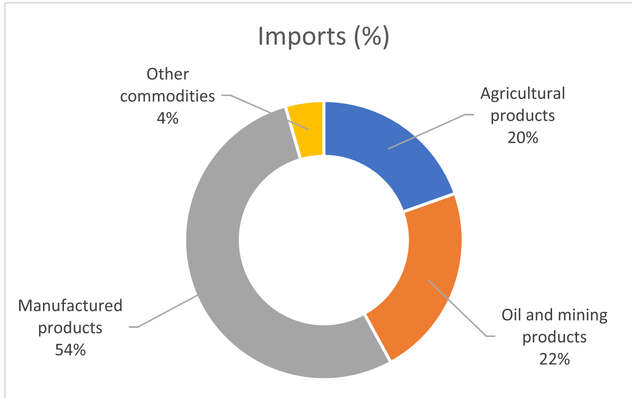


Figure 2. Côte d'Ivoire's imports by type of major categories for goods, 2015.
Source: Authors, using 'Perspective Monde' data.

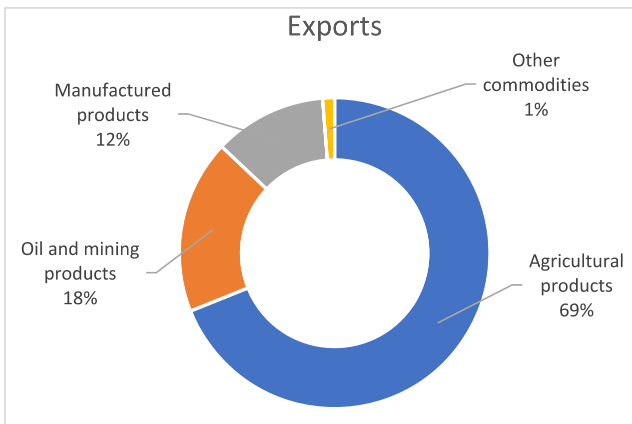


Figure 3. Côte d'Ivoire's exports by type of major categories for goods, 2015.
Source: Authors, using 'Perspective Monde' data.

industrial sector, as exemplified by Ali et al. (2020). However, the case of sub-Saharan African countries, particularly Côte d'Ivoire, deviates from this linear trajectory. In this context, there has been a distinct and abrupt shift from agriculture directly to services, with limited emphasis on the contribution of the industrial sector, as illustrated in Figure 1 for the case of Côte d'Ivoire. Given this unique trajectory, this research takes a focused approach by measuring the distinct and isolated effects of each sector—agriculture, industry, and services—on environmental quality. This emphasis is warranted by the deviation from the traditional linear progression and the potential distortion in comprehending the overall phenomenon when selecting one specific sector as the reference for assessing structural change.

3.1.2. Measure of environmental quality

Studies addressing environmental issues commonly rely on well-defined indicators to measure environmental impact. Typically, two primary groups of indicators are employed in the literature: (1) total greenhouse gas emissions, such as carbon (CO_2) or sulfur (SO_2), as seen in studies by Awad (2021), Yassin and Aralas (2017), Adebayo et al. (2021), and Adebayo et al. (2023) and (2) consumption-based indicators of environmental degradation, including ecological footprint and consumption optics, as explored in research by Ahmed et al. (2019), Alola et al. (2019), Chowdhury et al. (2021), and Dimnwobi et al. (2023).

In the current study, the ecological footprint of consumption is used as a comprehensive measure of environmental quality, capturing the overall pressure imposed on the environment. This measure not only assesses the impact of productive activities on biomass but also considers the degradation exchanged with the rest of the world through exports (footprint for exports) and imports (footprint for imports). Consequently, the ecological footprint for consumption enables the incorporation of the unbalanced structure of Côte d'Ivoire's trade with the rest of the world, characterized by significant exports of agricultural products compared to imports of manufactured goods (refer to Figures 2 and 3). Specifically, the ecological footprint for consumption is the sum of the ecological footprint of production and the net ecological footprint of trade. The net ecological footprint of trade, calculated as the ecological footprint of imports minus the ecological footprint of exports, reveals the use of biocapacity in international trade. The choice of the ecological footprint of consumption is further justified by the comprehensive nature of structural change, which impacts the entire economy, making it pertinent to employ a holistic measure of environmental quality.

3.1.3. Other variables

In the assessment of the impact of structural change on environmental quality, additional variables are incorporated as control factors, namely gross domestic product (GDP), energy use, and internet usage as a proxy for information and communication technologies (ICTs). Below, a rationale for including these variables in the analysis is provided.

3.1.4. Gross domestic product (GDP)

Investigating the effects of economic growth on the ecological footprint, Yang et al. (2021) observed that the economic growth process tends to elevate pollution levels, resulting in a detrimental effect on the environment through the ecological footprint. Similarly, Zhou et al. (2022) found a negative long-term impact of GDP on the ecological footprint. Some studies in the literature frame their analysis of the economic growth-environment nexus within the Environmental Kuznets Curve (EKC) framework. For instance, Kostakis et al.'s (2023) findings confirm the EKC hypothesis for Middle East and North Africa (MENA) countries and demonstrate that energy use has a significant and negative effect on environmental quality.

3.1.5. Energy use

The impact of energy use on environmental quality has been extensively explored in the literature, revealing various findings. For instance, Baz et al. (2020), employing a nonlinear framework, demonstrated that both positive and negative shocks to energy use can impede environmental quality, as measured by the ecological footprint, in Pakistan. Their findings underscore the imperative of decarbonizing the economic growth process by integrating renewable energy technologies into energy portfolios. In alignment with this perspective, Sharma et al. (2021) established a substantial mitigating impact of renewable energy use on the ecological footprint across eight developing countries in South and Southeast Asia. Building on this, Li et al. (2023) conducted a study involving a panel of 130 countries, revealing a threshold effect of renewable energy consumption on the environment. They found that increased use of renewable energy inhibits the growth of ecological footprints and carbon emissions. Notably, the authors highlighted that the least developed countries are more likely to alleviate environmental pressures through the adoption of renewables, in contrast to developed countries. However, the context-specific nature of these relationships is evident in the study by Çakmak and Acar (2022), which focused on most oil-producing countries, including the USA, Russia, Saudi Arabia, Canada, China, Brazil, Kuwait, and Nigeria. Their findings suggest that, in the context of these oil-producing nations, renewable energy consumption does not significantly affect the ecological footprint.

3.1.6. Internet usage (as a proxy for ICTs)

From a broad perspective, the literature presents a mixed view regarding the impact of information and communication technologies (ICTs) on environmental quality. On the one hand, studies by Batool et al. (2019), Ozcan and Apergis (2018), Higón et al. (2017), and Asongu et al. (2018) provide support for a positive effect of ICTs on environmental quality. For instance, Batool et al. (2019), focusing on South Korea, reveal a significant link between ICT development (measured by investment in the sector) and CO_2 emissions and energy consumption, suggesting that ICT inhibits environmental degradation in the short and medium term. Ozcan and Apergis (2018) approximate ICT development using internet access for a panel of 20 emerging economies over the period 1990–2015, providing evidence of the negative impact of ICT on air pollution. Higón et al. (2017) yield a more nuanced result, indicating a nonlinear, U-shaped relationship between ICT development and environmental degradation. In the African context, Asongu et al. (2018) utilize a GMM model to demonstrate that ICT penetration, specifically internet and mobile penetration, mitigates the negative effect of globalization on environmental quality. In the case of BRICS countries, Haseeb et al. (2019) employ a DSUR model to show that internet use and cell phone subscriptions (ICT) significantly and negatively impact carbon dioxide emissions, thereby improving environmental quality. Balsalobre-Lorente et al. (2019), focusing on the same countries, reveal that mobile penetration (measured by the number of mobile subscriptions) inhibits environmental pollution. For twelve Asian countries from 1993 to 2013, Lu (2018) demonstrates a significantly negative effect of ICT development on carbon dioxide emissions, suggesting an enhancement in environmental quality.

3.2. Model and methodology

This research paper builds on a theoretical framework that integrates the concepts of structural transformation, sectoral shifts, and environmental quality. It draws upon existing theories and empirical evidence to explore the complex relationships between these variables. For instance, Dasgupta et al. (2002) discusses the relationship between economic development, sectoral shifts, and environmental quality, criticizing and expanding on the EKC framework by analyzing the structural changes in economies and their differential impacts on environmental degradation. Stern (2004) critically reviews the theoretical and empirical aspects of the EKC hypothesis and examines the role of structural changes in different sectors (agriculture, industry, services) in explaining environmental quality dynamics. He argues that in the initial stages of development, economies transition from agriculture to heavy industry, leading to higher emissions. However, in the later stages of development, a shift occurs from resource-intensive extractive and heavy industrial sectors to services and lighter manufacturing, which are assumed to have lower emissions per unit of output. More recently, Schlogl and Sumner (2020) demonstrated from a theoretical perspective that development should be envisaged as structural transformation of production and employment.

3.2.1. Model specification

The previous theoretical framework that links structural transformation, sectoral shifts, and environmental quality directly informs and guides the methodological approach presented in paper. Structural transformation refers to the process by which economies evolve from primarily agricultural-based systems to more industrial and service-oriented systems. This shift is important because different sectors have varying environmental footprints, and understanding these shifts helps explain the complex relationship between economic development and environmental quality.

To examine the impact of structural change on environmental quality in Côte d'Ivoire, the study follows Ali et al. (2020) and specifies a model linking environmental quality to structural change, economic growth, energy consumption, and technology.

$$EFC_t = f(SC_t, GDP_t, ENE_t, INT_t) \tag{1}$$

where $SC_t = \{AGR_t, IND_t, SER_t\}$, and t is the time period.

Three (3) different models will therefore be estimated.

3.2.2. Estimation strategy

To fulfill the objective of this paper, the Non-Linear Autoregressive Distributed Lag (NARDL) model proposed by Shin et al. (2014) is used. The NARDL model is particularly suited for capturing the asymmetric effects of structural transformation on environmental quality due to its unique ability to analyze both positive and negative changes in the structural variables simultaneously. This is essential for understanding how different types of structural changes—such as shifts from agriculture to industry—impact environmental quality in divergent ways. For instance, moving from agriculture to industry may increase environmental degradation, while shifts from industry to services may improve environmental outcomes. The NARDL model's strength lies in its ability to capture these asymmetric effects by decomposing the structural change variables into positive and negative shocks (i.e. shifts from one sector to another). This methodological approach is informed by the theoretical understanding that different types of sectoral shifts can have contrasting impacts on environmental quality, as discussed by Stern (2004). Unlike traditional linear models, the NARDL framework allows for the examination of nonlinear relationships, accommodating the possibility that increases in structural change might have different environmental implications than decreases. Furthermore, the NARDL model facilitates the investigation of dynamic adjustments over time, capturing how these asymmetric effects manifest both in the short run and the long run. This is particularly relevant for environmental studies, where the impacts of structural changes often do not occur instantaneously but unfold over time as ecosystems and economies adjust. The NARDL model enhances the robustness of the analysis and provides a clearer picture of the pathways through which structural transformation influences environmental quality. Therefore, the NARDL model's capacity to deal with nonlinear relationships and dynamic adjustments makes it an ideal choice for this study, enabling a full exploration of the relationship between structural change and environmental quality in Côte d'Ivoire.

The following general model is used:

$$EFC_t = \gamma + \alpha_1 SC_t + \alpha_2 GDP_t + \alpha_3 ENE_t + \alpha_4 INT_t + \varepsilon_t \tag{2}$$

where ε_t is the error term.

Then, the structural change variables are decomposed into their positive and negative partial sums:

$$SC_t^+ = \sum_{j=1}^{t} \Delta SC_j^+ = \sum_{j=1}^{t} \max(\Delta SC_j, 0) \tag{3}$$

$$SC_t^- = \sum_{j=1}^{t} \Delta SC_j^- = \sum_{j=1}^{t} \min(\Delta SC_j, 0) \tag{4}$$

where SC_t^+ and SC_t^- are computed as positive and negative shocks of structural change.

The general form then reads as:

$$EFC_t = \gamma + \alpha_1^+ SC_t^+ + \alpha_1^- SC_t^- + \alpha_2 GDP_t + \alpha_3 ENE_t + \alpha_4 INT_t + \varepsilon_t \tag{5}$$

The NARDL is therefore specified as follows:

$$\begin{aligned}\Delta EFC_t = {} & \gamma + \alpha_0 EFC_{t-1} + \alpha_1^+ SC_{t-1}^+ + \alpha_1^- SC_{t-1}^- + \alpha_2 GDP_{t-1} + \alpha_3 ENE_{t-1} + \alpha_4 INT_{t-1} + \sum_{k=1}^{p} \beta_{0k} \Delta EFC_{t-k} \\ & + \sum_{k=0}^{q} \beta_{1k}^+ \Delta SC_{t-k}^+ + \sum_{k=0}^{r} \beta_{1k}^- \Delta SC_{t-k}^- + \sum_{k=1}^{s} \beta_{2k} \Delta GDP_{t-k} + \sum_{k=1}^{t} \beta_{3k} \Delta ENE_{t-k} + \sum_{k=1}^{u} \beta_{4k} \Delta INT_{t-k} + \varepsilon_t\end{aligned} \tag{6}$$

The short-run coefficients are shown by the summation signs, while long-run dynamics are represented by $\alpha_0,\ \alpha_1^+,\ \alpha_1^-,\ \alpha_2,\ \alpha_3,\ \alpha_4$. The letters $\{p, q, r, s, t, u\}$ represent the lag orders for the variables.

An error correction model can be derived from Eq. (6), should cointegration exists between the variables. The error correction model is shown below:

$$\begin{aligned}\Delta EFC_t = {} & \gamma + \theta ECT_{t-1} + \sum_{k=1}^{p} \beta_{0k} \Delta EFC_{t-k} + \sum_{k=0}^{q} \beta_{1k}^+ \Delta SC_{t-k}^+ + \sum_{k=0}^{r} \beta_{1k}^- \Delta SC_{t-k}^- + \sum_{k=1}^{s} \beta_{2k} \Delta GDP_{t-k} + \sum_{k=1}^{t} \beta_{3k} \Delta ENE_{t-k} \\ & + \sum_{k=1}^{u} \beta_{4k} \Delta INT_{t-k} + \varepsilon_t\end{aligned} \tag{7}$$

where the value of ECT_{t-1} represents the Error Correction Term (ECT) lagged by one period. The ECT term reflects the adjustment process towards the long-run equilibrium following short-term shocks. It quantifies the speed at which the system corrects deviations from the equilibrium in the previous period. The incorporation of an Error Correction Term in the methodology further strengthens the connection to the theory by capturing the speed of adjustment towards long-term equilibrium following shocks, a critical factor in understanding how Côte d'Ivoire transitions between phases of development and environmental outcomes.

Utilizing the F-statistic in a bound test, following Pesaran et al. (2001) approach, helps determine the existence of a cointegration relationship. This study applies the lower bound and upper bound critical values introduced by Pesaran et al. (2001). If the calculated F-statistic exceeds the critical value of the upper bound at a 5% significance level, it indicates the rejection of the 'null hypothesis' and confirms cointegration among the variables.

Determining the order of integration of the variables is a crucial step before estimating an ARDL model. This is necessary because, for model estimation, none of the variables should be integrated of order two, and the dependent variable must be integrated of order one. Consequently, the NARDL model can be applied when the variables are either I(0) or I(1), but not I(2). To maintain coherence with the nonlinear nature of the NARDL model, unit root tests are employed to assess the stochastic properties of the data, specifically considering structural breaks. This approach is justified by the recognition that using a unit root test without accounting for structural breaks may lead to biased conclusions regarding the stochastic properties of the data. By incorporating structural break considerations, the unit root test becomes more robust in capturing the potential nonlinearity inherent in the data.

The next step in the econometric procedure involves examining the stochastic properties of the data. For this purpose, the unit root test proposed by Zivot and Andrews (1992) is employed. This test is chosen because it accommodates structural changes within the testing procedure. It considers structural breaks as unknown and endogenously searches for them. The null hypothesis of the Zivot and Andrews (1992) test posits the presence of a unit root with a structural break. If the t-statistic exceeds the critical value, the null hypothesis cannot be rejected. The structural break identified by the test may occur in the intercept, the trend, or both intercept and trend components. The use of the Zivot and Andrews (1992) unit root test also reflects an understanding from the theoretical framework that economies experience structural changes at different stages, which may not be smooth or linear. This test identifies key moments of transformation that could have profound impacts on environmental quality.

The study further applied the Broock et al. (1996) BDS (Broock, Dechert, and Scheinkman) test to evaluate the adequacy of the data for nonlinear modeling. The purpose of the BDS test is to identify nonlinearities, chaos, or complexity in the underlying structure of the time series. The test is based on the null hypothesis that the series are linearly dependent.

After estimating Eq. (7), the Wald test is used to investigate both short-run and long-run asymmetries. The Wald test is applied to evaluate whether the set of coefficients related to asymmetries collectively have a significant impact on the model. The null hypothesis for the Wald test is that all the coefficients being tested are jointly equal to zero. If the Wald test yields a statistically significant result, it suggests that at least one of the coefficients in the set is different from zero, providing evidence in favor of the alternative hypothesis.

The asymmetric ARDL model offers the benefit of estimating and visually presenting cumulative dynamic multipliers, enabling a detailed exploration of adjustment patterns following positive and negative shocks to the outcome variable Menegaki (2019). In this research, the long-term response of environmental quality to standard asymmetric shocks in structural change variables is examined using dynamic multipliers. The behavior of the dynamic multiplier relies on a blend of factors, including the error correction coefficient (speed of adjustment), long-run equilibrium parameters, and the dynamics estimated within the model. For this reason, this approach appears to be a natural extension of the methods described above.

Table 3. Results of the Zivot and Andrews (1992) unit root tests.

	Model A: break in intercept				Model B: break in trend				Model C: break in bothtrend and intercept			
Variables	Break	Lag	Min. t-stat	5% critical value	Break	Lag	Min. t-stat	5% critical value	Break	Lag	Min. t-stat	5% critical value
EFC	2011	1	−2.632	−4.93	2002	1	−3.294	− 4.42	1989	1	−3.697	−5.08
AGR	1996	0	−3.400	−4.93	2007	0	−2.476	− 4.42	1996	0	−4.034	−5.08
IND	1996	0	−6.042	−4.93	2011	0	−2.586	− 4.42	1996	0	−6.269	−5.08
SER	1996	0	−3.209	−4.93	2010	0	−3.044	− 4.42	1996	0	−4.829	−5.08
GDP	2012	2	−3.119	−4.93	2008	2	−3.155	− 4.42	2001	2	−3.011	−5.08
ENE	2004	4	−2.903	−4.93	1998	4	−4.092	− 4.42	1997	4	−3.769	−5.08
INT	2012	2	−1.960	−4.93	2012	2	−6.542	− 4.42	2011	2	−6.041	−5.08

Source: Authors' calculations.

Table 4. Results of the BDS Test.

Variables	$m=2$	$m=3$	$m=4$	$m=5$	$m=6$
EFC	36.046***	40.830***	45.335***	51.615***	59.936***
AGR	27.266***	29.499***	31.806***	34.783***	38.674***
IND	19.356***	20.182***	21.030***	22.232***	24.017***
SER	24.868***	24.832***	24.914***	25.474***	26.305***
GDP	23.426***	24.855***	26.197***	28.027***	30.290***
ENE	10.978***	10.884***	10.904***	10.991***	11.169***
INT	6.533***	6.197***	5.891***	5.693***	5.581***

Note. ***$p<0.01$. Source: Authors' calculations.

The cumulative dynamic multiplier effects of SC_t^+ and SC_t^- on EFC_t are evaluated as:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial EFC_{t+j}}{\partial SC_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial EFC_{t+j}}{\partial SC_t^-}, \text{ for } h = 0, 1, 2, \ldots \tag{8}$$

$$\text{Where if } h \to \infty, \text{ then } m_h^+ \to \frac{-\alpha_1^+}{\alpha_0} \text{ and } m_h^- \to \frac{-\alpha_1^-}{\alpha_0} \tag{9}$$

Finally, various diagnostic tests (Table 6) were conducted to assess the reliability of the model, in line with the recommendations of B. Pesaran and M. Pesaran (2010). These diagnostic tests encompassed evaluations for normality, serial correlation, heteroscedasticity (ARCH), and the Ramsey RESET test. Furthermore, stability tests, specifically the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests following Brown et al. (1975), were performed to ensure the stability of the model over time.

4. Results and discussion

4.1. Results of the unit root test, nonlinearity test, and cointegration test

Table 3 presents the outcomes of the Zivot and Andrews (1992) unit root test, which aims to assess the stochastic properties of the variables under consideration while accounting for potential structural breaks. The test is conducted under three different model specifications: one with a break in the intercept, another with a break in the trend, and a third with breaks in both the trend and intercept. The results indicate that the variables in the analysis have unit roots with structural breaks. This conclusion is drawn from the comparison of the calculated t-statistic with the 5% critical value. In most cases, the t-statistic exceeds the critical value, providing evidence in favor of the presence of unit roots with structural breaks for the specified model specifications. It is important to highlight that none of the variables under consideration exhibit integration of order 2. Simultaneously, the dependent variable is integrated of order 1. These conditions are essential prerequisites for the estimation of an ARDL-type model. The absence of integration of order 2 ensures that the variables are suitable for modeling within the chosen framework. In addition, the integration of order 1 in the dependent variable aligns with the necessary characteristics for conducting an ARDL analysis.

The results of the BDS test (Table 4) indicate that the null hypothesis, which assumes that the series are linearly dependent, is rejected. This suggests evidence of nonlinearity in the time series data. In other words, the data may exhibit patterns or behaviors that cannot be adequately explained by a linear model. For most of the variables, the BDS statistics increased as the embedding dimensions increased, demonstrating strong nonlinearity for large dimensions.

After assessing stationarity and nonlinearity, the study investigates cointegration among the variables in three (3) models. Table 5 presents bounds test results indicating rejection of the null hypothesis of no cointegration at a 5% significance level. Both nonlinear bound test F-statistics and t-statistics exceed the upper bounds, providing evidence of a long-run relationship between the variables. This supports the presence of asymmetric cointegration, validating the use of a nonlinear regression approach.

The adjustment coefficients (ECM) for the different models (Tables 5) are found to be negative and statistically significant. This indicates that there is an adjustment mechanism in place to correct deviations from the long-run equilibrium. The coefficient values are: −0.812, −0.845, and −0.903. These values suggest a relatively faster adjustment. For each unit deviation from the long-run equilibrium, the

Table 5. Results of the NARDL model.

	Coefficients		
Variables	«SC = AGR» model	« SC = IND» model	« SC = SER» model
Long-run effects			
SC+	−0.222**	−0.178**	−0.368***
	(0.088)	(0.061)	(0.101)
SC-	0.068	0.052	−0.008
	(0.046)	(0.060)	(0.085)
GDP	0.279***	0.396***	0.451***
	(0.068)	(0.056)	(0.076)
ENE	0.526***	0.409***	0.533***
	(0.088)	(0.092)	(0.087)
INT	0.0012	0.00013	0.0019
	(0.0015)	(0.00134)	(0.0014)
Short-run effects			
C	−3.888***	−4.188***	−5.534***
	(0.569)	(0.653)	(0.865)
SC+	−0.013	−0.088	−0.288**
	(0.153)	(0.143)	(0.119)
SC-	0.391***	0.213*	0.127
	(0.095)	(0.111)	(0.123)
GDP	0.418**	0.387**	0.483***
	(0.118)	(0.128)	(0.129)
ENE	0.288**	0.093	0.174
	(0.111)	(0.112)	(0.119)
INT	0.0006	−0.0001	0.002
	(0.002)	(0.0018)	(0.002)
CointEq(-1)*	−0.812***	−0.845***	−0.903***
	(0.118)	(0.131)	(0.141)
Long-run asymmetry test (Wald test)	42.132***	102.605***	97.012***
Short-run asymmetry test (Wald test)	17.151***	2.663	3.227*

Note. Dependent variable is Ecological footprint for consumption. *, **, *** denotes significance at 10%, 5%, and 1%, respectively. Values in brackets () are standard deviations. Values in parentheses [] are *p*-values. SC = {AGR, IND, SER}. *Source*: Authors' calculations.

ecological footprint for consumption is expected to adjust by approximately −0.812, −0.845, and −0.903 units in the next period. The quick adjustment suggests that monitoring the ecological footprint for consumption and intervening early in response to deviations could be crucial.

Moreover, the diagnostic tests reported in Table 6 demonstrate that the models exhibit normal distribution, lack autocorrelation, and are free from specification errors and heteroskedasticity issues. In addition, stability tests reported in the Appendix, show the stability of the models over time.

4.2. Results

4.2.1. Impact of the agricultural sector on environmental quality

Table 5 presents the results of the NARDL model estimation, examining the impact of the agricultural sector on the ecological footprint for consumption. The results indicate that both short- and long-term asymmetric relationships exist between changes in agricultural sector value added and the ecological footprint, as confirmed by the Wald test.

The coefficient of positive changes in agricultural sector value added (AGR+) shows a significant negative impact on the ecological footprint for consumption. Specifically, a 1% increase in the agricultural sector value added reduces the ecological footprint by approximately 0.222%. This suggests that expanding the agricultural sector, while maintaining a constant share of the industrial and service sectors, contributes to improved environmental quality in the long term. Conversely, the coefficient of negative changes in agricultural sector value added (AGR-) indicates a positive but statistically insignificant effect on the ecological footprint. Although a decline in the agricultural sector value added may increase the ecological footprint, this effect is not robust in the long term. In the short run, the results show contrasting effects. Positive changes in agricultural sector value added (AGRI+) have a negative but nonsignificant impact, indicating that short-term increases in agriculture do not immediately affect the ecological footprint. However, negative changes in agriculture (AGRI-) have a positive and significant effect, meaning that a 1% reduction in agricultural sector value added increases the ecological footprint by 0.391% in the short term.

The results imply that a structural shift in favor of agriculture, i.e. increasing its share in GDP at the expense of other sectors (such as industry and services), may not lead to significant short-term improvements in environmental quality. However, in the long run, such a shift yields substantial environmental benefits, supporting policies that promote agricultural growth as a long-term strategy for enhancing environmental sustainability. On the other hand, a structural shift against the agricultural sector (i.e. reducing its share in favor of other sectors) has immediate negative consequences for environmental quality in the short run. This suggests that deprioritizing agriculture could worsen environmental outcomes in the short term, despite the long-term impact being negligible.

When comparing the results to other studies in the literature, Kwakwa et al. (2022) identify a U-shaped relationship between agricultural development and carbon emissions in Ghana. This underscores the importance for policymakers to promote widespread adoption of modern technology and environmentally sustainable agricultural practices. Ntim-Amo et al. (2022) show that agricultural value added has a significant positive impact on CO_2 emissions in Ghana, indicating environmental degradation. Consequently, they recommend a reduction in unsustainable agricultural practices. Khan et al. (2022) employ nonlinear analyses on a panel of developing and developed countries, revealing a positive impact of agriculture on carbon emissions of 15.16%. However, there is a negative influence of 2.92% on CO_2 emissions from using liquid fuels, contributing to more severe environmental deterioration. Furthermore, the study highlights detrimental consequences on the ecosystem in developing countries, specifically related to feed cropping, deforestation, biomass burning, and deep soil and cropping. Chowdhury et al. (2022) focusing on Bangladesh found that, in the long-run, production of cereals, other agricultural products, and land production, increased carbon emissions, and therefore negatively affect environmental quality. In contrast, agricultural production is found to decrease pollution in a panel of 26 Sub-Saharan African countries in a study conducted by Ali et al. (2023). Despite this negative impact, the author emphasized that the poorly mechanized nature of agriculture in those countries necessitates a holistic approach in policymaking, urging governments to consider future structural changes in the agricultural system to promote production without compromising environmental sustainability. The positive impact of agricultural sector value added on environmental quality supports the claims of Ali et al. (2020) regarding the importance of sector-specific dynamics. Unlike the work of Udemba (2021), which predominantly emphasizes negative environmental impacts from industrial growth, our results suggest that a balanced approach favoring agricultural development may counteract these adverse effects in the short term. Moreover, the findings align with the studies of Adebayo et al. (2021) and Awad (2021), where the link between economic sectors demonstrates significant variability in environmental outcomes. In contrast to Adebayo et al. (2021), who identified a positive correlation between service sector dominance and environmental quality, we find that while agriculture can yield long-term benefits, immediate impacts from negative shifts in this sector may exacerbate ecological footprint.

Figure A3 (see appendix) illustrates the cumulative dynamic multiplier asymmetry in the relationship between the agricultural sector and the ecological footprint for consumption. The solid black line depicts the impact on the ecological footprint for consumption following a positive change in the share of the agricultural sector in GDP, while the short-dashed black line represents the impact following a negative change. The short dotted red line represents the asymmetric curve, indicating the difference between positive and negative changes in the ecological footprint for consumption, along with its 95% confidence interval for statistical analysis. In Figure A3, it is observed that the zero line falls outside the upper and lower bounds of the 95% confidence interval, indicating that the asymmetric impact of the agricultural sector's share in GDP is statistically significant at the 5% level. This suggests that changes (positive and negative) in the agricultural sector's share have a discernible impact on the ecological footprint for consumption. A positive shock to the agricultural sector's share of GDP induces a negative response of the ecological footprint for consumption. This implies that an increase in the agricultural sector's contribution to GDP leads to an enhancement of environmental quality. Subsequently, this effect stabilizes over the long term, after five (5) years, persisting as a negative influence. It is noteworthy that the magnitude of the asymmetrical effect, following a positive shock, is more accentuated in the long term than in the short term. The response of the multipliers following a negative shock to the agricultural sector's share of GDP stabilizes over the long term after five (5) years.

Table 6. Diagnostic tests.

Tests	« SC = AGR» model	« SC = IND» model	« SC = SER» model
R-squared	0.619	0.544	0.522
Adjusted R-squared	0.575	0.491	0.467
F-statistic	14.105***	10.326***	9.456***
Jarque Bera Normality Test	1.281	1.181	1.766
	[0.527]	[0.554]	[0.414]
Breusch-Godfrey Serial Correlation LM Test	0.625	1.199	0.628
	[0.539]	[0.310]	[0.538]
Breusch-Pagan-Godfrey Heteroskedasticity Test	0.714	0.436	1.539
	[0.719]	[0.931]	[0.149]
Ramsey RESET test	0.095	0.935	0.498
	[0.759]	[0.339]	[0.484]
F-Bounds Test	7.086	6.233	6.162
	5% Lower Bound : 2.62	5% Lower Bound : 2.62	5% Lower Bound : 2.62
	5% Upper Bound : 3.79	5% Upper Bound : 3.79	5% Upper Bound : 3.79
t-Bounds Test	−6.234	−5.919	−5.829
	5% Lower Bound : −2.86	5% Lower Bound : −2.86	5% Lower Bound : −2.86
	5% Upper Bound : −4.19	5% Upper Bound : −4.19	5% Upper Bound : −4.19
Long-run asymmetry test (Wald test)	42.132***	102.605***	97.012***
Short-run asymmetry test (Wald test)	17.151***	2.663	3.227*

Note. *, **, *** denotes significance at 10%, 5% and 1%, respectively. Values in parentheses [] are p-values. SC = {AGR, IND, SER}. *Source*: Authors' calculations.

4.2.2. Impact of industrial sector on environmental quality

Table 5 presents the results of the NARDL model estimation, examining the effect of the industrial sector on the ecological footprint for consumption. The Wald test results indicate the presence of a significant long-term asymmetric relationship between changes in the industrial sector value added and the ecological footprint, at the 1% significance level. However, no short-term asymmetric effects were observed, meaning that changes in industrial sector activity do not have an immediate and statistically significant impact on the ecological footprint in the short run.

The coefficient for positive changes in the industrial sector's share in GDP (IND+) is −0.178, which is both statistically significant and indicates that a 1% increase in industrial sector value added reduces the ecological footprint by 0.178% in the long term. This suggests that as the industrial sector grows, it can have a positive effect on environmental quality. This seems to align with the notion that industrial growth, when accompanied by sustainable practices and technological advancements, can contribute to improved environmental quality. Interestingly, the results also show that a negative change in the industrial sector's share (IND-) has a nonsignificant impact on the ecological footprint. The coefficient for IND- is -0.052, indicating that a decrease in the industrial sector's contribution to GDP does not lead to a substantial improvement in environmental quality. This contrasts with the expectation that reducing industrial activity would automatically result in environmental benefits. This observation suggests that a reduction in industrial activity alone may not guarantee a substantial improvement in environmental quality. Additional factors, such as the nature of industrial processes, environmental regulations, and technological advancements, may influence the overall impact on environmental outcomes.

Let us compare the results to the existing literature. Ahmed et al. (2022) demonstrate a statistically significant but moderately sized increase in environmental degradation associated with industrialization across fifty-five (55) Asia-Pacific countries, utilizing proxies such as carbon emissions, methane, greenhouse gas (GHG), and nitrous oxide emissions. The authors underscore the imperative of fostering environmentally friendly industries. Guivis et al. (2023) derive a threshold effect in the relationship between industrialization and the environment. They show that industrialization, measured by the value added of industry and the value added of manufacturing significantly deteriorates the quality of the environment. However, the introduction of the environmental policy stringency variable as a transmission channel produces a detrimental effect of industrialization on carbon emissions up to thresholds of 37.33% and 37% for the industrial sector and the manufacturing sector, respectively. For environmental policy stringency above these thresholds, industrialization significantly reduces CO_2 emissions. Nkemgha et al. (2023) identify a threshold effect in the relationship between industrialization and the environment, demonstrating that industrialization, measured by industry and manufacturing value added, significantly degrades environmental quality. However, the inclusion of the environmental policy stringency variable as a transmission channel reveals a negative impact of industrialization on carbon emissions up to thresholds of 37.33% and 37% for the industrial and manufacturing sectors, respectively. Beyond these thresholds of environmental policy stringency, industrialization leads to a significant reduction in carbon emissions. Utilizing the ecological footprint as a proxy for environmental degradation, Musah and Yakubu (2023) demonstrate that industrialization exerts a negative and significant influence on the ecological footprint, indicating that industrialization contributes to environmental sustainability in Ghana. This finding was explained by the fact that despite Ghana's intensified focus on industrialization, particularly in manufacturing, the implemented environmental policies by the country aimed at pollution reduction are praiseworthy. While existing literature, such as that of Guivis et al. (2023), suggests a straightforward detrimental impact of reduced industrial activity on environmental quality, our results imply that a simplistic reduction in industrial activity may not yield the expected environmental benefits.

Figure A6 (see appendix) illustrates the cumulative dynamic multiplier asymmetry in the relationship between the industrial sector and the ecological footprint for consumption. Figure A6 shows that the zero line falls within the upper and lower bounds of the 95% confidence interval during the first two (2) years, indicating that the asymmetric impact of the agricultural sector's share in GDP is not statistically significant at the 5% level in the short term. This suggests that immediate changes (either positive or negative) in the industrial sector's share do not lead to a significant difference in the ecological footprint for consumption during this short-term period. However, starting from year 3, the zero line falls outside the upper and lower bounds of the 95% confidence interval suggesting that the asymmetric impact of the agricultural sector's share in GDP is statistically significant at the 5% level in the long term. Starting from year 3, both positive and negative shocks to the agricultural sector's share of GDP induce a negative response of the ecological footprint for consumption. It is noteworthy that the absolute magnitude of the asymmetrical effect following a positive shock is more accentuated than the absolute magnitude of the asymmetrical effect following a negative shock. This suggests that, in the long term, increases in the industrial sector's share in GDP have a more substantial negative impact on the ecological footprint for consumption, therefore enhancing environmental quality compared to decreases in the industrial sector's share. In addition, it takes about five (5) years for the multipliers to reach a stable impact, indicating that the full effect of changes in the industrial sector's share on the ecological footprint for consumption becomes apparent and stabilizes after a relatively extended period.

4.2.3. Impact of the service sector on environmental quality

Table 5 presents the results of the NARDL model estimation for the influence of the service sector on the ecological footprint for consumption. The Wald test reveals a significant long-term asymmetric relationship at the 1% significance level, with a short-term asymmetric effect observed at the 10% level.

The coefficient for positive changes in the service sector's share in GDP (SERV+) is -0.368, and this is statistically significant at the 1% level. This indicates that a 1% increase in the service sector's value-added leads to a 0.368% reduction in the ecological footprint for consumption in Côte d'Ivoire over the long term. This suggests that, under other factors being constant, an increase in the contribution of the service sector to the GDP corresponds to an improvement in environmental quality, as measured by the ecological footprint for consumption. This can be attributed to the relatively lower environmental impact of service-oriented activities compared to industrial or agricultural sectors, as well as potential shifts towards less resource-intensive economic activities.

Conversely, the coefficient for negative changes in the service sector's share (SERV-) is −0.008 and statistically nonsignificant, indicating that a reduction in the service sector's share does not have a notable impact on the ecological footprint over the long term. This suggests that downsizing the service sector may not be an effective strategy for improving environmental quality. This result suggests that, a reduction in the service sector's share in GDP may not be a robust strategy for achieving long-term improvements in environmental outcomes. The nature of the variable used to measure the service sector's value added can also explain this result. Indeed, the service sector's value added includes value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services.

With regard to the short-term effects, a one percent positive change in the share of the service sector in GDP is associated with a statistically significant 0.288% reduction in the ecological footprint for consumption in the short term. This result suggests that, in the short term, an increase in the contribution of the service sector to GDP is linked to an improvement in environmental quality, as measured by the ecological footprint for consumption. A one percent negative change (reduction) in the share of the service sector in GDP is associated with a 0.127% increase in the ecological footprint for consumption in the short term. However, this result is not statistically significant, implying uncertainty about the observed effect, particularly given the noted significance level of the Wald test for short-run asymmetry.

When comparing the results to a few studies from the literature, Wang et al. (2020) report that the service sector in China is a notable emitter of embodied CO_2. Ali et al. (2017) demonstrate that structural shifts in Malaysia, transitioning from predominantly industrial activities to a greater focus on the services sector, result in a reduction in the concentration of CO_2 emissions. Such findings support the argument presented by Luukkanen et al. (2015) that service-oriented growth can yield positive environmental benefits. Alam (2014) shows that the contribution of service value added to GDP have a positively significant impact on CO_2 emissions in four South Asian countries. The short-term dynamic supports the findings of Yassin and Aralas (2017), where they identified that the transition from an agricultural to an industrial economy increased pollution, but the shift towards a service-based economy correlated with reduced environmental pollution. Similar to Adebayo et al. (2023), the results from this study indicate long-term asymmetric relationships between sectoral contributions (agriculture, industry, services) and the ecological footprint. In addition, the findings align with Ali et al. (2022) in noting that different economic sectors in Africa have varying impacts on environmental quality, with the service sector showing a particularly positive influence. Our study and Ali and Gniniguè (2022) confirm the U-inverted relationship between economic activity (via global value chains or sectoral value chains) and environmental pollution in Africa, suggesting that initial economic growth may lead to environmental degradation until a certain threshold is met. Another similarity between the findings of this study and the existing literature can be found in Sahoo and Sethi (2022) which emphasize that economic growth and industrialization increase the ecological footprint, while the service sector has a positive influence on environmental quality.

Figure A9 (see appendix) presents the cumulative dynamic multiplier asymmetry in the relationship between the service sector and the ecological footprint for consumption. The zero line falls outside the upper and lower bounds of the 95% confidence interval suggesting that the asymmetric impact of the service sector's share in GDP is statistically significant at the 5% level. This implies that there is a discernible difference in how the ecological footprint responds to positive and negative shocks in the service sector. The ecological footprint's response to a positive or negative shock in the service sector's value added stabilizes starting from the fourth year. Nevertheless, the absolute magnitude of the asymmetrical effect resulting from a positive shock is more pronounced than the absolute magnitude of the asymmetrical effect resulting from a negative shock. It is important to highlight that the cumulative effects of a positive shock on the service sector's share in GDP are negative, in contrast to the effects of a negative shock, which are negative up to the third year but then turn positive (albeit close to zero) from the fourth year onward.

Table 7. Verification of research hypotheses.

Hypotheses	Decision
H1: Positive structural transformation in Côte d'Ivoire's agricultural sector reduces the ecological footprint in the long term, while negative structural shifts increase environmental degradation in the short term.	**Verified.** The results indicate that a positive change in the agricultural sector's value-added leads to a significant long-term decrease in the ecological footprint. Negative changes lead to an increase in the ecological footprint.
H2: Structural changes in Côte d'Ivoire's industrial sector, specifically increased industrialization, contribute to a long-term reduction in the ecological footprint, with insignificant short-term impacts of negative shocks.	**Verified.** The findings demonstrate that a positive change in the industrial sector's share results in a statistically significant long-term reduction in the ecological footprint. Furthermore, negative changes do not show a significant immediate impact on environmental quality.
H3: Growth in Côte d'Ivoire's service sector significantly reduces the ecological footprint in both the short and long term.	**Verified.** The results indicate that a positive change in the service sector's share leads to a significant reduction in the ecological footprint in both the short term and the long term.

Source: Authors' calculation.

In Table 7, we verify whether the three (3) hypotheses formulated in the Introduction section are validated or not.

4.2.4. Impact of control variables on environmental quality

The results from Table 3 suggest that, on average, an increase in GDP per capita in Côte d'Ivoire is associated with an increase in the ecological footprint for consumption, and this relationship holds in both the short and long run. The estimated coefficients are statistically significant, ranging from 0.279 to 0.451 for the long run estimates and from 0.387 to 0.483 for the short run estimates. This suggests that as the economic prosperity of the country improves (reflected by higher GDP per capita), there is an accompanying rise in the ecological footprint. This could be attributed to increased consumption patterns, resource utilization, and potentially a higher demand for goods and services. In addition, the slightly higher short-run coefficients imply a more immediate impact compared to the longer-term dynamics. This could be due to immediate adjustments in consumption patterns or production practices. Overall, the results emphasize the need for Côte d'Ivoire to be attentive to the environmental consequences of economic growth. Similar results were obtained in the literature by authors such as: Hassan et al. (2019) for the case of Pakistan, Beşe and Swint Friday (2022) for the case of Turkey, Shahbaz et al. (2023) for the top 10 world's emitter countries, Magazzino (2023) for the case of China, and Onifade (2023) for oil-exporting African countries.

Regarding the effects of energy use on environmental quality, the long-run coefficients are 0.526, 0.409, and 0.533, indicating that, on average, an increase in energy use is associated with an increase in the ecological footprint for consumption. This suggests that as energy use in Côte d'Ivoire increases, there is a corresponding rise in the ecological footprint, implying that higher energy consumption may contribute to environmental degradation and increased resource utilization. However, in the short run, only the coefficient for the 'AGRI' model is positive and statistically significant. The results imply that addressing the environmental impact of energy use is crucial for sustainable development in Côte d'Ivoire. Nathaniel et al. (2019) found a different result for South Africa where long-term environmental quality is enhanced by energy use in the long run. Meanwhile, Sun et al. (2023), employing nonlinear techniques, such as the quantile-on-quantile approach, show that energy consumption positively influences the ecological footprint across a majority of quantiles, while in South Africa, a negative impact is observed at most quantiles.

Internet usage is found to have a nonsignificant impact on the ecological footprint for consumption in Côte d'Ivoire, meaning that changes in internet usage are associated with changes in the ecological footprint. This finding contrasts with the findings of Mamadou et al. (2022), who indicated that internet penetration contributes to environmental sustainability in Sub-Saharan Africa. It is noteworthy that Mamadou et al. (2022) utilized carbon emissions as a metric for environmental sustainability, and this divergence in measurement criteria may explain the observed differences in results.

4.3. Discussion and implications

The results highlight both short-term and long-term asymmetric relationships, indicating that sectoral shifts significantly influence environmental outcomes.

The analysis shows that an increase in the agricultural sector's contribution to GDP is associated with improved environmental quality over the long term. However, the short-term effects suggest that rapid agricultural expansion can lead to negative environmental impacts due to intensified activities. In the context of a structural change toward the agricultural sector, these findings may be explained as follows. In the short term, when the agricultural sector's share in GDP increases, it may imply intensified agricultural activities, potentially involving land use changes, which can have immediate, albeit not significant, negative environmental effects, such as deforestation or soil degradation. However, over time, the positive impact on environmental quality may become evident. Sustainable agricultural practices, technological advancements, and reforestation efforts associated with increased agricultural focus could contribute to improved environmental conditions. In the case of a structural change toward other sectors, in the short term, a reduction in the agricultural sector's share of GDP might be linked to rapid industrialization or a shift toward other economic activities. This shift could bring short-term negative impacts, such as increased pollution due to industrial expansion. On the other hand, the diminished effect in the long term suggests that as industrial and service sectors mature, environmental regulations and sustainable practices may be implemented, mitigating the negative impact seen in the short term. These findings have particular significance in the context of Côte d'Ivoire's current agricultural landscape. As outlined in the National Development Plan 2021–2025, the agricultural sector stands as a cornerstone of the Ivorian economy. Côte d'Ivoire possesses substantial natural agricultural resources, showcasing notable achievements in agricultural development that position it among the global and African leaders, especially in the production of key export commodities. The country holds the top position globally in cocoa and cashew nut production, ranks as the world's fifth-largest palm oil producer (second largest in Africa), holds the fifth position globally in natural rubber production (top in Africa), and secures the third position in Africa for cotton production. Additionally, Côte d'Ivoire leads in banana production on the continent and stands as Africa's foremost banana exporter. The government's strategic vision for 2021–2025 aims to reinforce the pivotal role of agriculture in the country's economic dynamics and enhance its potential by 2025.

Over the period 2021–2025, the government aims to act simultaneously on three (03) strategic axes, which, by nature, have environmental impacts: (1) improvement of agricultural production, (2) growth of local processing, and (3) agro-industry integration into global markets. First, through the improvement of agricultural production, the government is dedicated to enhancing agricultural production by rapidly improving productivity across all stages, including seeds, irrigation, mechanization, cultivation techniques, fertilization, transport, storage, and product quality control. Second, through the growth of local processing, the government aims to foster the growth of local processing by developing a national primary and secondary processing industry across all relevant sectors, necessitating support for the implementation of a system to ensure compliance with progressively stringent quality and environmental standards. Third, the country aims to ensure the integration of the agro-industry into global distribution and marketing circuits, enabling the acquisition of export market share through efficient and secure outlets in Europe, America, and Asia, while capitalizing on market opportunities within West Africa.

In the industrial sector, the significant long-term negative impact on the ecological footprint suggests that sustainable industrial practices can lead to improved environmental quality. The absence of a strong significant short-term effect implies that immediate environmental changes in response to a decrease in industrial sector value added are not pronounced. It suggests that environmental outcomes may take time to manifest, and policies targeting the industrial sector in Côte d'Ivoire may need to be assessed with a focus on long-term effects. It is worth recalling that the industrial sector plays a key role in accelerating the structural transformation of Côte d'Ivoire. To significantly enhance the productivity and competitiveness of industrial companies, industrialization policy emphasizes strengthening the country's industrial base, optimizing the capabilities of extractive industries and growth drivers, fostering the development of industrial clusters, and leveraging the country's competitive advantages. According to the National Development Plan 2021–2025, this approach involves the establishment of industrial infrastructures, particularly Integrated Industrial Zones adhering to international standards, strategically distributed nationwide based on local economic potential, with a special focus on water resource availability. These actions are anticipated to be implemented by monitoring environmental impacts. The findings for the service sector reveal a significant long-term negative effect on environmental quality, aligning with the idea that a growing service sector, if accompanied by sustainable practices and efficient resource use, can contribute to a decrease in the ecological footprint, reflecting positive environmental outcomes. With regard to the short-term effects, the positive impact on environmental quality could stem from the nature of services, which often have a lower direct environmental impact compared to industrial activities, especially if they are oriented towards sustainability.

In terms of policy implications, based on the findings of this study and the sector-specific nuances in their influence on environmental quality, the following set of policy recommendations is suggested.

First, since the results indicate that positive changes in agricultural value-added reduce the ecological footprint in the long term, the government of Côte d'Ivoire should implement policies promoting sustainable farming practices, especially given that agriculture accounted for 28% of GDP (average 1961–2021) and about 69% of export receipts, employing two-thirds of the population. This can include organic farming, agroecology, and agroforestry, which can enhance productivity while minimizing environmental degradation. It is also suggested to further implement initiatives to process agricultural products like cocoa, cashews, and rubber within the country to reduce environmental costs linked to raw exports, create value-added jobs, and increase export revenues.

Second, Côte d'Ivoire has a relatively large industrial sector: mining and quarrying; food processing and tobacco; textiles and leather; wood and furniture; paper, cardboard, publishing and printing; oil, chemicals, rubber and plastics; glass, ceramics and building materials; metalworking; manufacture of all types of machinery and equipment; electricity, gas and water. Given that industrial sector growth can have a positive effect on environmental quality in the long run, the industrial sector, which includes activities like oil, chemicals, rubber and plastics and mining and quarrying, could benefit significantly from policies that incentivize greener technologies. For example, stricter environmental regulations and tax incentives could encourage companies in these sectors to transition to cleaner production methods, helping reduce pollution and conserve resources. Given the global shift toward sustainable development, these industries could position themselves as leaders in environmentally conscious production, ensuring long-term viability and alignment with international environmental standards. With industries like food processing and textiles and leather, Côte d'Ivoire can further develop industries that focus on the processing of domestic agricultural products. This strategy aligns with the country's strengths in agriculture (such as cocoa, coffee, and cashew nuts) and helps reduce reliance on exporting raw materials. Encouraging investment in value-added processing industries can create jobs, stimulate economic growth, and promote sustainable industrialization, while also contributing to environmental sustainability by reducing the carbon footprint associated with raw exports. The wood and furniture, paper, cardboard, publishing and printing, and metalworking sectors can particularly benefit from policies that introduce stricter regulations on waste management, resource use, and emissions. These measures would not only improve environmental quality but also encourage these industries to innovate and adopt more sustainable practices, helping to future-proof them against the growing demand for eco-friendly products and services.

Third, since the expansion of the service sector contributes to environmental quality improvement, both in the short and long term, the government should foster the growth of green services, such as eco-tourism, renewable energy consulting, and sustainable finance. These industries not only contribute to GDP but also promote environmental sustainability.

Fourth, given the study's findings that sectoral shifts influence environmental quality, we suggest the government of Côte d'Ivoire to develop an overarching green growth strategy that promotes sustainable practices across all sectors. This strategy should align agricultural, industrial, and service sector policies to achieve long-term environmental sustainability. The development of infrastructure projects—especially in transport and digital sectors—should prioritize sustainability, given the rising demand for energy and transport services and Côte d'Ivoire's regional economic hub role.

Finally, over the past few years, Côte d'Ivoire has maintained strong public investment and attracted private investment, which is important for developing sustainable infrastructure. Therefore, Public-Private Partnerships (PPPs) can be instrumental in scaling up investments in renewable energy, eco-friendly transport, and waste management systems. Supporting projects that align with the country's National Development Plan (NDP) 2021–2025, especially in digital and transport infrastructure will help Côte d'Ivoire achieve its structural transformation, green growth objectives and improve competitiveness in regional and global markets.

The analysis in this study is concentrated on Côte d'Ivoire and its specific economic structure, while other studies include broader African or global contexts. This specificity could limit the generalizability of the findings to other regions with different economic dynamics or levels of industrialization, as highlighted in Sahoo and Sethi (2022), which deals with Newly Industrialized Countries and their unique challenges.

5. Conclusion

The study's main research question focuses on understanding how structural change influences environmental quality in Côte d'Ivoire. To address this, the study employs the Nonlinear Autoregressive Distributed Lag (NARDL) cointegration approach, aiming to quantify sector-specific (agriculture, industry, and service) impacts on environmental degradation and assess short- and long-term predictions, considering both positive and negative shocks in the context of asymmetric dynamic multipliers. Environmental quality is measured by the ecological footprint for consumption. The study utilizes data from diverse sources, spanning the period 1961 to 2021, sourced from the World Bank's World Development Indicators (WDI) database and the National Footprint and Biocapacity Accounts (NFA) public data for ecological footprint.

The results show that the adjustment coefficients for models examining the impact of the agricultural, industrial, and service sectors on the ecological footprint for consumption are all negative and statistically significant, suggesting a relatively faster adjustment mechanism. The rapid adjustment implies that timely monitoring of the ecological footprint for consumption and early intervention in response to deviations might be essential.

Examining the impact of the agricultural sector, both short-term and long-term asymmetric relationships are identified. In the long term, an increase in the agricultural sector's share in GDP is associated with a significant reduction in the ecological footprint, indicating improved environmental quality. Conversely, a reduction in the agricultural sector's share leads to a short-term increase in the ecological footprint, but this effect diminishes in the long term. The findings suggest that time is a crucial factor in realizing the positive impact of a structural change toward the agricultural sector on environmental quality. The results of the asymmetric dynamic multipliers show that changes in the agricultural sector's share significantly impact the ecological footprint for consumption, with a positive shock leading to a long-term enhancement of environmental quality. The asymmetrical effect is more pronounced in the long term, persisting as a negative influence after five years, while the response to negative shocks stabilizes over the same period.

For the industrial sector, a significant long-term asymmetric relationship is observed, indicating that an increase in its share of GDP is linked to a substantial reduction in the ecological footprint. However, changes in industrial sector value added do not have an immediate and statistically significant impact on the ecological footprint in the short term. The absence of a significant short-term effect implies that policies targeting the industrial sector in Côte d'Ivoire may need to be assessed with a focus on long-term effects. The dynamic multipliers reveal that the industrial sector's immediate changes do not significantly impact the ecological footprint for consumption in the short term during the first two years. However, from year 3 onward, both positive and negative shocks lead to a long-term negative response, with an increased industrial sector share having a more substantial negative impact on ecological footprint, stabilizing after approximately five years.

The service sector demonstrates both short-term and long-term asymmetric relationships. However, the short-term asymmetric relationship is weak. An increase in the service sector's share in GDP is associated with a significant reduction in the ecological footprint over the long term, aligning with positive environmental outcomes. However, a reduction in the service sector's share in GDP does not significantly impact the ecological footprint in the long term. In the short term, an increase in the service sector's share is linked to improved environmental quality, while a decrease does not have a significant short-term effect. The results from the dynamic multipliers show that the cumulative effects of a positive shock from the service sector on GDP are consistently negative, while the effects of a negative shock, although initially negative, turn positive (albeit close to zero) starting from the fourth year onward, indicating a nuanced relationship between the service sector and environmental outcomes.

This study contributes to the growing body of literature by providing empirical evidence on the sector-specific dynamics that influence environmental quality in Côte d'Ivoire, highlighting the importance of structural transformation in achieving sustainable development goals. The findings suggest that policymakers should prioritize sustainable practices in agriculture and industry while fostering the growth of the service sector to enhance environmental outcomes.

The study has some limitations that must be acknowledged. The research relies heavily on historical data spanning from 1961 to 2021, which may not capture recent changes or emerging trends in structural transformation and environmental quality. Moreover, while the nonlinear autoregressive distributed lag (NARDL) model is well-suited for capturing asymmetries, it may not fully account for all the complexities and interdependencies within the data, such as potential external shocks or socio-economic factors that influence both economic activities and environmental outcomes.

While this study identifies critical insights into the sector-specific dynamics affecting environmental quality in Côte d'Ivoire, future research directions could benefit from greater specificity and alignment with the findings of this study. For instance, subsequent investigations could explore how specific agricultural practices impact the ecological footprint. Furthermore, it would be interesting to assess the long-term effects of industrial policies on environmental degradation, particularly regarding the adoption of cleaner technologies and practices. Moreover, further studies could evaluate the link between service sector expansion and environmental sustainability, particularly in sectors such as eco-tourism and renewable energy. Finally, future studies could assess policy effectiveness over various time horizons to adapt strategies according to the evolving structural changes and their environmental impacts.

Notes

1. Global hectares (Gha) are the accounting unit for the Ecological Footprint and Biocapacity accounts. A global hectare is a biologically productive hectare with world average biological productivity for a given year.
2. Ecological reserve/deficit represents the difference between the biocapacity and the ecological footprint of a region or country. An ecological deficit is observed when the ecological footprint of a population exceeds the biocapacity of the area available to that population. An ecological reserve occurs when the biocapacity of a region exceeds its population's ecological footprint.
3. Includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production (Based on the WDI definition).
4. Includes manufacturing. It comprises value added in mining, manufacturing, construction, electricity, water, and gas (Based on the WDI definition).
5. Includes value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services (Based on the WDI definition).

Authors' contributions

Writing, data collection, analysis, interpretation, and discussions on the results were performed by Jeffrey Kouton, Johan Didier Kakou, and Yann Muriel Okoua. All authors read and approved the final manuscript.

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Data availability statement

Data available on reasonable request from the corresponding author.

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Appendix

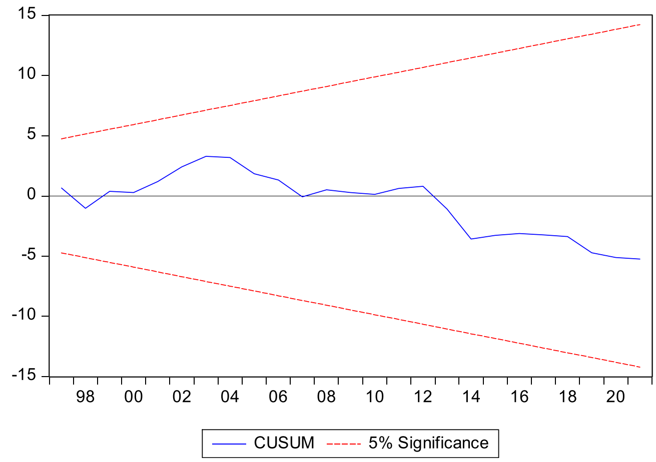

Figure A1. CUSUM graph at 5% significance for the 'AGR' model.

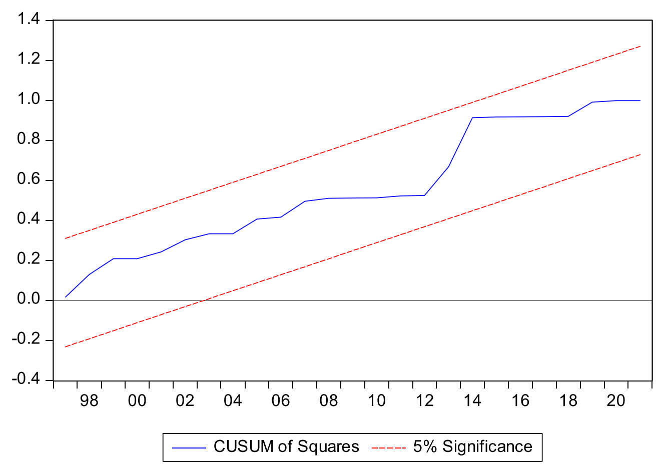

Figure A2. CUSUMSQ graph at 5% significance for the 'AGR' model.

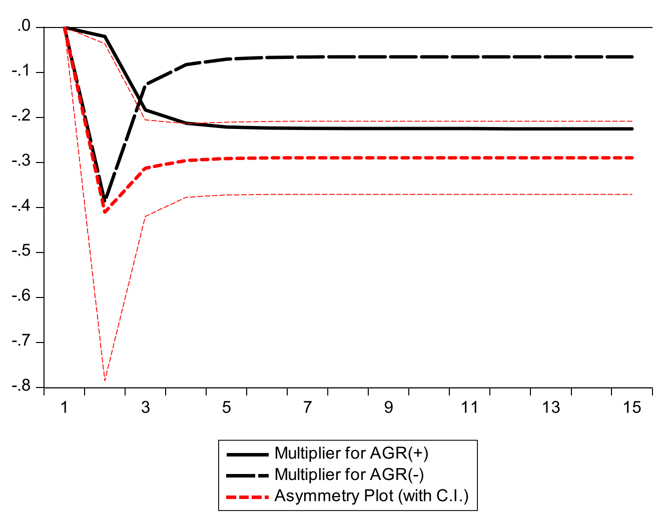

Figure A3. Dynamic multiplier; agricultural sector share in GDP on ecological footprint for consumption.

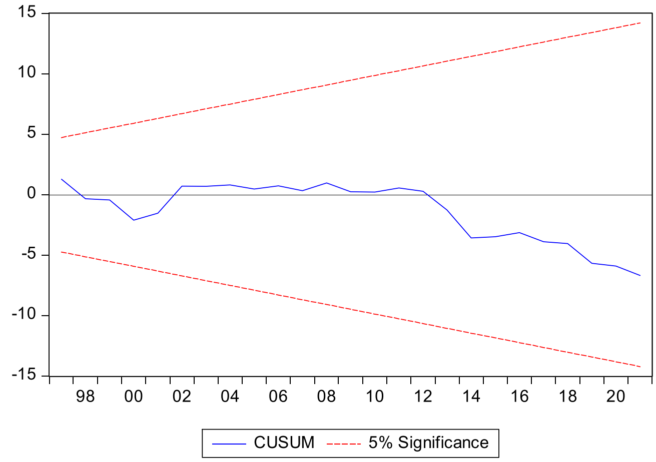

Figure A4. CUSUM graph at 5% significance for the 'IND' model.

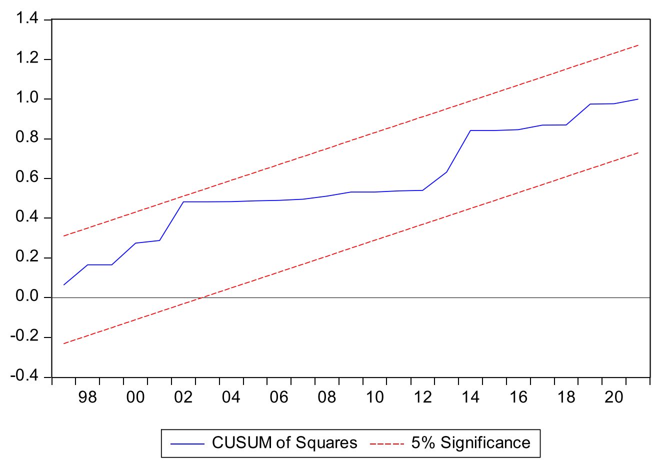

Figure A5. CUSUMSQ graph at 5% significance for the 'IND' model.

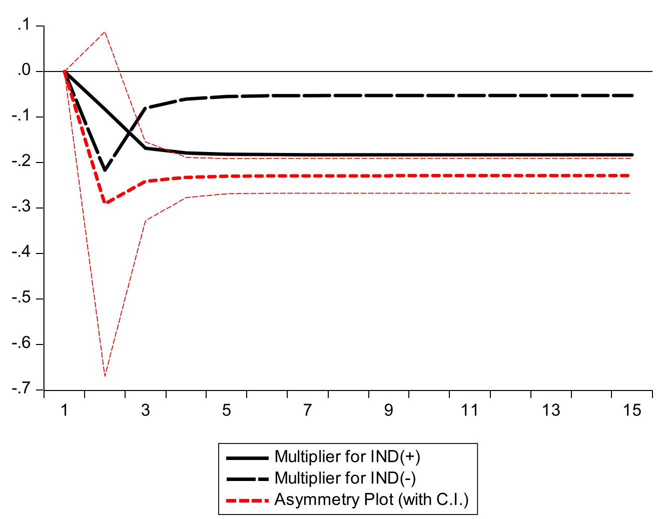

Figure A6. Dynamic multiplier; industrial sector share in GDP on ecological footprint for consumption.

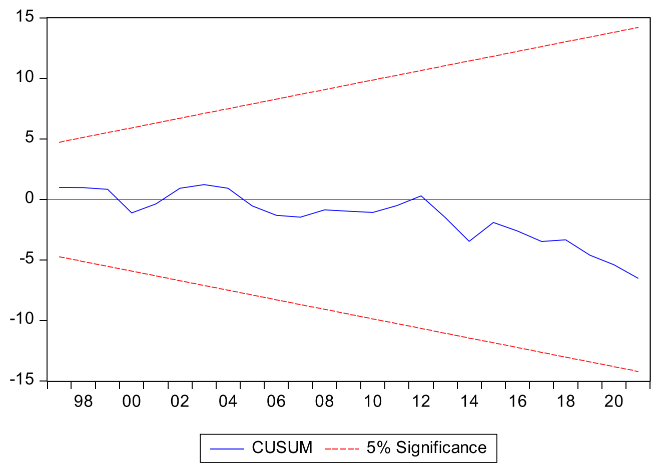

Figure A7. CUSUM graph at 5% significance for the 'SER' model.

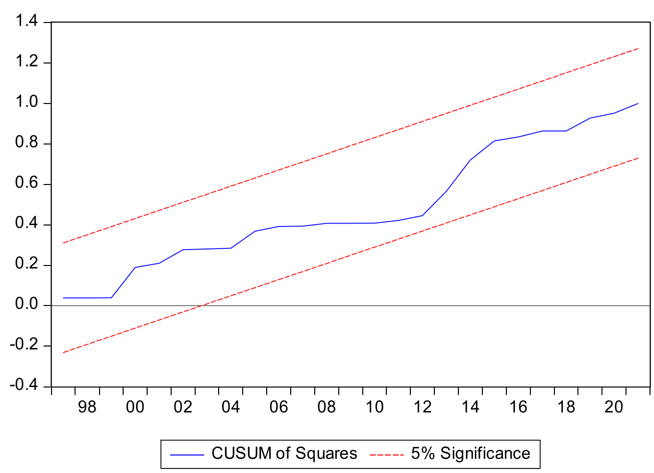

Figure A8. CUSUMSQ graph at 5% significance for the 'SER' model.

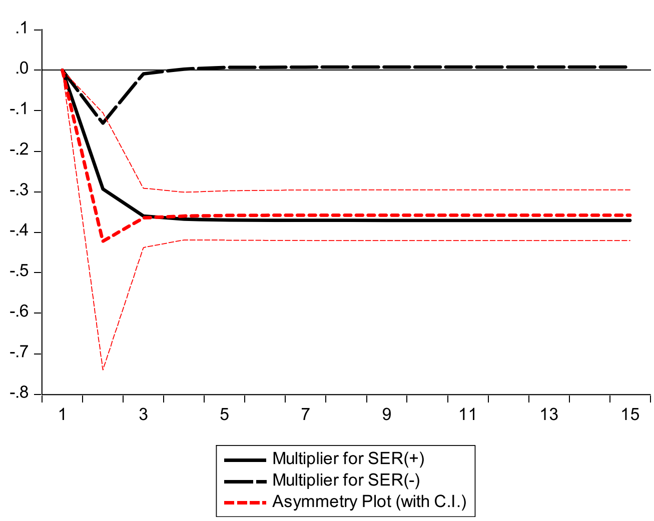

Figure A9. Dynamic multiplier; service sector share in GDP on ecological footprint for consumption.