# Forestry and economic growth in Ghana: evaluating the dynamics using the environmental Kuznets curve and adjusted net savings



Joseph Antwi Baafi and Kwame Acheampong
*Department of Economics Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana*
Michael Kwame Asiedu
*School of Business, Conestoga College, Kitchener, Canada, and*
Pearl Seyram Kumah
*Department of Accounting Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana*

Received 4 November 2024
Revised 21 January 2025
Accepted 25 April 2025

## Abstract

**Purpose** – This study investigates the link between economic growth, environmental sustainability and deforestation in Ghana, aiming to identify the economic drivers of deforestation and assess how sustainable economic practices can mitigate its rates.

**Design/methodology/approach** – The study used secondary data from 1980 to 2023. It applied quantitative techniques, including regression, vector error correction model and multiple Granger causality to examine the impact of GDP growth, adjusted net savings (ANS) and other control variables on Ghana's deforestation rate.

**Findings** – The analysis supports environmental Kuznets curve (EKC) hypothesis, indicating that deforestation initially rises with GDP but declines at higher levels. It finds a long-term relationship where economic growth correlates with reduced deforestation. ANS promotes sustainable growth, while FDI increases deforestation.

**Research limitations/implications** – The study supports the EKC hypothesis, indicating that economic growth initially increases deforestation but that ANS positively impacts long-term GDP growth. It emphasizes directing FDI toward sustainable sectors to mitigate deforestation. Overall, integrating environmental sustainability into economic planning is crucial for Ghana's growth.

**Practical implications** – To support sustainable economic development in Ghana, policies should integrate environmental sustainability into growth strategies and standardize adjusted net savings as a metric for evaluating resource-intensive projects. Directing FDI toward sustainable industries, along with stabilizing inflation, can help mitigate deforestation while promoting eco-friendly practices.

**Originality/value** – This study's originality lies in analyzing Ghana's forestry and economic growth through the EKC framework and adjusted net savings from 1980 to 2023. Unlike prior research, this paper addresses overlooked interactions between growth, environmental sustainability, population growth and FDI using more recent, stable data relevant to current policy decisions.

**Keywords** Environmental Kuznets curve (EKC), Deforestation, Economic growth, Adjusted net savings, Foreign direct investment and sustainability

**Paper type** Research paper



Forestry Economics Review
Vol. 7 No. 1, 2025
pp. 35-53
Emerald Publishing Limited
2631-3030
DOI 10.1108/FER-11-2024-0012

## 1. Introduction

Forests play a crucial role in supporting both economic growth and environmental sustainability, particularly in developing economies like Ghana (Ali *et al.*, 2021; Oduro *et al.*, 2015). The forest sector is vital for biodiversity conservation and carbon sequestration and contributes significantly to the livelihoods of rural communities by providing employment, raw materials and income (Asamoah *et al.*, 2023; Ao and Sadanandan, 2015; Pandey *et al.*, 2016; Shackleton *et al.*, 2007). Despite this, Ghana faces persistent challenges related to deforestation, land degradation and unsustainable forest management (Kyere-Boateng and Marek, 2021). These challenges raise critical questions about the interplay between forestry and economic growth: does Ghana's development lead to environmental degradation or foster sustainable management of forest resources?

This study aims to investigate the effects of forestry on economic growth in Ghana, utilizing two key economic concepts: the environmental Kuznets curve (EKC) hypothesis and sustainability metrics like adjusted net savings (ANS). The EKC suggests that as an economy grows, environmental degradation initially worsens but eventually improves as income levels rise, potentially leading to better forest conservation (Stern *et al.*, 1996). On the other hand, ANS provides a framework to assess whether economic activities, such as forestry, contribute to long-term welfare or are offset by environmental degradation (Food and Agricultural Organization, 2024). This study seeks to explore whether Ghana's economic growth aligns with the EKC hypothesis and whether the economic contributions of forestry are sustainable, as measured by ANS.

Ghana's development path has been accompanied by significant environmental concerns, particularly deforestation (Adom *et al.*, 2024; Asamoah *et al.*, 2023; Kumi *et al.*, 2024; Oduro *et al.*, 2015). According to the Global Forest Watch, Ghana's deforestation rate is among the highest in Africa, with an annual loss of approximately 3.4% of its forest cover between 2001 and 2023 (Global Forest Watch, 2024). Immediate economic benefits from forest exploitation, such as increased timber production and agricultural expansion (Rosenfeld *et al.*, 2024), have led to environmental degradation, habitat destruction and loss of biodiversity (Guptaa, 2024; Tari *et al.*, 2024). This raises significant concerns about whether the economic gains from forestry and related industries are sustainable in the long term.

Existing literature on forestry and economic growth in Ghana has largely focused on the economic value of timber and the drivers of deforestation (Abugre and Sackey, 2022; Acheampong *et al.*, 2019; Akomaning *et al.*, 2023; Asamoah *et al.*, 2023; Kyere-Boateng and Marek, 2021; Peprah, 2022; Peprah *et al.*, 2017). For instance, Acheampong *et al.* (2019) document high deforestation rates driven by agricultural expansion and illegal logging, while Akomaning *et al.* (2023) highlight the role of forestry in rural livelihoods and employment creation. However, few studies (Minlah *et al.*, 2021a) have applied the EKC framework to Ghana's forest management practices or used sustainability metrics like ANS to assess the long-term impact of forestry on economic welfare. This study aims to fill these gaps by offering a comprehensive analysis that integrates both the EKC hypothesis and ANS to evaluate forestry's role in Ghana's economic growth trajectory.

This research contributes to the discourse on economic development and environmental sustainability in several key ways. First, by applying the EKC hypothesis to Ghana, the study assesses how economic growth influences forest conservation over time. The period of 1980–2023 is selected as it reflects crucial economic and policy shifts, including the structural adjustment programs and liberalization policies of the 1980s that transformed Ghana's economic landscape and affected natural resources (Aidoo, 2019; World Bank Group, 2024a). These reforms, aimed at stabilizing the economy, enhancing productivity and promoting growth, also had unintended consequences, such as increased deforestation driven by agricultural expansion and timber demand (Ghana Statistical Service, 2022). Additionally, the endpoint of 2023 captures recent advancements in digital technology, sustainable finance and global environmental commitments, which provide a more holistic context for analyzing forestry's sustainability.

Secondly, the study introduces methodological innovations by employing advanced econometric techniques, such as the Toda and Yamamoto (1995) and Dolado and Lütkepohl (1996) multiple causality tests. These methods accommodate non-stationary time series data and provide robust insights into the long-term relationships between GDP growth, deforestation and FDI. Furthermore, the integration of ANS as a sustainability metric offers a more comprehensive framework for evaluating whether economic benefits from forestry are offset by natural capital depletion, addressing limitations of traditional approaches. Combining these two – the ANS metric with the EKC framework and leveraging recent data; this study fills significant research gaps and provides actionable understanding into the sustainability of Ghana's forestry sector within its broader development trajectory.

Despite its contributions, this study has several limitations. First, the availability and reliability of historical data on deforestation and economic indicators may affect the robustness of the analysis. Second, while the study integrates key economic concepts like the EKC and ANS, it does not fully account for other potential drivers of deforestation, such as governance quality and illegal activities, which may influence outcomes. Finally, the reliance on secondary data may limit the depth of insights compared to primary data collection. Addressing these limitations in future research could provide a more nuanced understanding of the relationship between forestry and economic growth.

The rest of the study is structured as follows: Section 2 reviews relevant literature on forestry and related issues. Section 3 discusses the methodology and data used. Sections 4 and 5 provide analysis and conclusions.

## 2. Literature review

This section explores the key theoretical frameworks, empirical findings and knowledge gaps that are relevant to the study of forestry and economic growth, particularly in light of the EKC hypothesis and sustainability metrics such as adjusted net savings.

### *2.1 Theoretical and conceptual review*

The EKC hypothesis posits that economic growth initially leads to increased environmental degradation, such as deforestation, as demand for resources and land conversion rises to support industrial and agricultural activities. However, as income levels continue to rise, environmental quality eventually improves due to factors like better regulations, technological advancements and increased public awareness, which foster investments in conservation and sustainable practices (Uchiyama, 2016). Economist Simon Kuznets introduced the concept behind the EKC in 1955 (Kuznets, 2019), focusing initially on income inequality. The EKC hypothesis was later formalized in the environmental context by Grossman and Krueger in 1995 (Grossman and Krueger, 1995).

The concept of ANS has emerged as a key metric for assessing the sustainability of economic growth, particularly in relation to natural resource depletion and environmental degradation (Hamilton and Clemens, 1999). ANS adjusts traditional measures of savings and investment by accounting for the depreciation of natural capital, including forests and environmental degradation. This metric helps to determine whether a country's economic growth is sustainable over the long term by factoring in the depletion of critical natural resources (Hamilton and Clemens, 1999). Hamilton and Clemens (1999) have applied ANS to broader contexts, emphasizing its importance in understanding the sustainability of economic development. Ever since its introduction, this concept has been used in other studies, such as Fakher *et al*. (2023), Güney (2019), Koirala and Pradhan (2020), Larissa *et al*. (2020), Zakari *et al*. (2022) to understand the concept of sustainable economic growth. However, its application in the case of Ghana is rare. While ANS has been widely used as a sustainability metric, its application to the forestry sector in Ghana remains underexplored. Most studies focus on the broader natural resource sectors, such as mining and agriculture (Adam *et al*., 2021; Adeyanju *et al*., 2021; Baafi, 2024; Hess, 2022), with limited attention to how forestry depletion specifically affects the country's long-term economic trajectory. This represents a significant gap in the literature; hence, including ANS in a study provides a better understanding of the sustainability of Ghana's forest management practices.

*2.2 Empirical review*

Empirical studies on the EKC hypothesis have been widely conducted across various countries and contexts. These studies could be grouped into country-specific, regional or sub-regional. Some country-specific studies that support the EKC include (Rasool *et al*., 2020; Sarkodie and Ozturk, 2020; Shahbaz *et al*., 2015). Regional or sub-regional studies that support the EKC also include Al-Mulali and Ozturk (2016), Apergis and Ozturk (2015), Erdogan (2024), Jahanger *et al*. (2022), Pablo-Romero *et al*. (2023), Shahbaz *et al*. (2016), Vo *et al*. (2021).

Moreover, the literature on the EKC hypothesis has seen extensive empirical studies across various countries and contexts, with mixed results (Purcel, 2020), provides new insights into the EKC hypothesis, particularly in developing and transition economies, highlighting the variability in environmental outcomes (Dinda, 2004; Mitić *et al*., 2019), offer comprehensive surveys of the EKC literature, emphasizing the diverse findings across different regions (Tietenberg and Lewis, 2019, 2023), along with (Hussen, 2012), discuss the theoretical underpinnings of environmental economics, including the EKC hypothesis (Seghezzo, 2009), review the concept of sustainable development, critical for understanding the EKC in the context of balancing economic growth and environmental health (Stoddart *et al*., 2020; Holden *et al*., 2014), further critique sustainable development practices, which are essential for evaluating the long-term implications of the EKC. Finally, the World Commission on Environment and Development's (ARE, 1987) lays the foundational framework for sustainable development, providing a backdrop for empirical investigations into the EKC hypothesis. These studies collectively enrich the discourse on the EKC by offering a broad perspective on the environmental impacts of economic growth and the importance of sustainable development. Other studies do not support the EKC hypothesis (Al-Mulali *et al*., 2015) while some show mixed results (Ahmed and Long, 2013; Azam and Khan, 2016; Ganda, 2019; Polomé and Trotignon, 2016):

In Ghana, studies such as (Minlah *et al*., 2021a, b; Nketiah *et al*., 2024; Ntim-Amo *et al*., 2022; Osayande and Omena, 2024) all show evidence of support or otherwise for the EKC hypothesis. These studies focus narrowly on $CO_2$ emissions as the primary indicator of environmental degradation, potentially overlooking other important pollutants such as deforestation, water pollution and biodiversity loss. This singular focus may not capture the full environmental impact of economic growth in Ghana, limiting the scope of the EKC analysis. Again, some of these studies have relatively longer period starting from 1960, which was marked by political instability and limited economic data, which weakens the reliability of earlier insights.

Ghana's forestry sector is characterized by a complex interplay between economic development and environmental degradation (Wiggins *et al*., 2004). The demand for agricultural land, timber and fuelwood has driven much of the deforestation observed in the country (Afele *et al*., 2022; Appiah *et al*., 2009; Kyere-Boateng and Marek, 2021; Mohammed *et al*., 2015; Nyarko *et al*., 2023; Peprah *et al*., 2017) noted that the country's dependence on forest resources for energy and construction materials has placed unsustainable pressure on forest ecosystems. Additionally, the agricultural sector, which is a key driver of Ghana's economy, has led to the large-scale conversion of forest land for cocoa, palm oil and rubber plantations. While these agricultural expansions have fueled economic growth, they have also significantly contributed to deforestation (Roth *et al*., 2017).

The forestry sector interacts with key variables such as population growth, foreign direct investment (FDI) and inflation, which significantly influence deforestation and economic outcomes. Population growth, for example, puts pressure on forest resources due to the demand for land for agriculture and settlements, with studies showing a strong link between higher population densities and increased deforestation rates in rural areas of Ghana (Amoah and Korle, 2020). Though FDI contributes to economic growth, it can have mixed effects on the forestry sector. While it can promote sustainable practices through industrial modernization, unchecked investments, particularly in extractive industries, often accelerate deforestation when environmental regulations are weak (Kindo and Paul Alagidede, 2023). Inflation, on the other hand, exacerbates deforestation by increasing the cost of living, driving dependence on forest resources for subsistence and reducing government capacity for effective forest management (Bau, 2016; Kideghesho, 2015). These dynamics emphasize the complexity of balancing economic growth with environmental sustainability in Ghana.

### *2.3 Literature gap*

The existing literature on the EKC hypothesis and sustainability metrics such as ANS in Ghana's forestry sector presents several deficiencies. Prior studies predominantly focus on $CO_2$ emissions as the sole indicator of environmental degradation, which overlooks other critical pollutants like deforestation, water pollution and biodiversity loss. This narrow scope limits the comprehensive understanding of environmental impacts. Additionally, many studies utilize data from periods marked by political instability, such as the 1960s, compromising the reliability of their findings due to inconsistent economic data. The application of ANS, a crucial sustainability metric, is also rare in the context of Ghana's forestry sector, with most research concentrating on broader natural resource sectors like mining and agriculture. Furthermore, previous research often fails to account for the complex interplay between forestry and socioeconomic variables such as population growth, foreign direct investment (FDI) and inflation, which significantly influence deforestation and economic outcomes.

This paper addresses these deficiencies by expanding the scope of environmental indicators beyond $CO_2$ emissions to include deforestation, providing a more holistic view of environmental impacts. It focuses on the period from 1980 to 2023, capturing significant economic and policy shifts relevant to understanding Ghana's current environmental challenges. Additionally, prior studies rely on data five years outdated, reducing relevance for current policy. Introducing ANS as a key sustainability metric, the paper evaluates the long-term economic impact of forestry depletion, which offers understanding into the sustainability of Ghana's forest management practices. Additionally, the paper examines the interplay between forestry and socioeconomic variables such as population growth, FDI and inflation, elucidating the dynamics that influence deforestation and economic outcomes. This comprehensive and multi-dimensional analysis significantly extends the existing literature, providing understanding and practical policy recommendations for balancing economic growth with environmental sustainability in Ghana. This study fills these gaps.

## 3. Methodology

This study focuses on the quantitative assessment of the relationship between forestry and economic growth in Ghana using time-series data from 1980 to 2023. This period covers significant economic changes in Ghana, including structural adjustments, forest management reforms and industrialization efforts that may impact the relationship between forestry and economic growth.

### *3.1 Data sources and variables*

The main data sources include the World Bank's World Development Indicators. The key variables for this study are categorized into dependent, independent and control variables. The dependent variable is deforestation rate (DEF). This is calculated as the annual percentage decrease in forest area (Minlah and Zhang, 2021; World Bank Group, 2024b). The independent variables include GDP growth rate and GDP growth rate squared ($GDP^2$) – this term captures the potential nonlinear relationship hypothesized by the EKC. The sustainability metric variable is ANS, which measures sustainable development by adjusting gross national savings (GNS) for factors such as fixed capital depreciation, natural resource depletion, environmental damage and investments in human capital (World Bank Group, 2024b). It starts with GNS, subtracting fixed capital depreciation and natural resource depletion (e.g. from oil, gas and forests) and adding education expenditure as a proxy for human capital investment. Environmental damage, particularly $CO_2$ emissions, is monetized using the social cost of carbon to reflect pollution costs. ANS, typically expressed as a percentage of gross national income (GNI), evaluates whether economic activities deplete a country's capital or contribute to long-term welfare (World Bank, 2024).

The control variables include population growth (POP), foreign direct investment (FDI) and inflation (INF).

### *3.2 Econometric approach*

*3.2.1 Diagnostic tests.* The analysis begins by testing the stationarity of time-series data using unit root tests, as non-stationary data can lead to misleading regression results. The augmented Dickey–Fuller (ADF) (Damodar and Dawn, 2021) and Phillips–Perron (PP) (Phillips, 1988) tests were used to check for stationarity at the level of the variables, with differencing applied where necessary. To mitigate the issue of pre-testing bias, the alternative approach suggested by Toda and Yamamoto (1995), Dolado and Lütkepohl (1996) was used in this study, incorporating a TYDL model alongside the conventional testing methods.

To ensure the robustness of the vector error correction (VEC) model, four diagnostic tests, namely, the Johansen cointegration test (Johansen, 2009), VEC residual serial correlation LM test, the VEC stability check using autoregressive (AR) root table, and the VEC lag exclusion Wald test, were performed in addition to the initial stationarity test.

*3.2.2 The EKC estimation.* To test the EKC hypothesis, the estimated regression equation was:

$$DEF_t = \beta_0 + \beta_1 GDP_t + \beta_2 GDP_t^2 + \in_t \quad (1)$$

Where $\beta_1$ captures the initial positive effect of economic growth on deforestation, $\beta_2$ captures the subsequent negative effect of economic growth on deforestation, indicating forest conservation at higher income levels. If $\beta_1 > 0$ and $\beta_2 < 0$, the EKC hypothesis is supported.

*3.2.3 Cointegration analysis.* Where the variables were found to be integrated of the same order, cointegration tests were performed to determine whether there was a long-term equilibrium relationship between deforestation and GDP growth rate using the Johansen cointegration test. The presence of cointegration suggests that the variables share a common trend, despite short-term deviations. The VAR model was chosen to examine the dynamic interactions between deforestation and economic growth in Ghana. VAR was suitable for capturing the interdependencies among the variables without imposing strong theoretical restrictions on the direction of causality (Canova, 1995). The general form of the VAR model was written as:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \ldots + A_p Y_{t-p} + \in_t \quad (2)$$

Where $Y_t$ is a vector of the variables, including DEF, GDP, $GDP^2$ and ANS and other controls, $A_1, A_2, \ldots A_p$ are matrices of coefficients for lagged values of the variables and $\in_t$ represents the error term. The optimal number of lags was determined using the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC). Building on the VAR model, the VEC model was introduced to account for long-run equilibrium relationships through the inclusion of error correction terms (Lutkepohl, 2004).

Assuming time series for each variable is $X_t = [DEF_t, GDP_t, GDP_t^2, ANS_t, POP_t, FDI_t, INF_t]$ and given the existence of cointegration, the general form of a VECM model is given as:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-1} + \varepsilon_t \tag{3}$$

Where $X_t$ is a vector of the variables in the system, $\Delta X_t$ represents the differenced terms of the variables to achieve stationarity, $\Pi X_{t-1}$ is the long-run relationship between the variables (cointegration term), $\Pi$ represents the matrix of cointegrating vectors, $\Gamma_i$ are the short-run coefficient matrices, $\varepsilon_t$ is the vector of white noise error terms and $k$ is the lag length selected for the model. If there are $r$ cointegrating vectors, $\Pi$ can be decomposed as:

$$\Pi = \alpha\beta' \tag{4}$$

Where $\alpha$ is the adjustment matrix, which indicates the speed of adjustment toward the long-run equilibrium, and $\beta'$ contains the cointegrating vectors. The cointegrating equation therefore looks like:

$$DEF_t = \beta_0 + \beta_1 GDP_t + \beta_2 GDP_t^2 + \beta_3 ANS_t + \beta_4 POP_t + \beta_5 FDI_t + \beta_6 INF_t + \varepsilon_t \tag{5}$$

This equation represents the long-run equilibrium relationship between deforestation and economic growth, considering sustainability and control variables. The short-run equation for the change in deforestation can be represented as:

$$\Delta DEF_t = \alpha_1 \big( DEF_{t-1} - \beta_1 GDP_{t-1} - \beta_2 GDP_{t-1}^2 - \beta_3 ANS_{t-1} - \beta_4 POP_{t-1} - \beta_5 FDI_{t-1} - \beta_6 INF_{t-1} \big) + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-1} + \varepsilon_{1,t} \tag{6}$$

We adopt Toda-Yamamoto causality test (TY) for causality analysis. This test offers several advantages. First, it doesn't require pre-testing for the stationarity or cointegration of the variables. Secondly, this method works in levels, meaning it can handle variables even if they are integrated of different orders (e.g. *I(1), I(0)* or *I(2))*. Again, this method is ideal for handling non-stationary data, which is likely the case with variables such as GDP, $GDP^2$ and deforestation rates. Lastly, the TY test is more robust against model misspecification, particularly regarding lag length and unit root testing. Using GDP and DEF variables the traditional VAR model in its basic form can be written as

$$GDP_t = \alpha_1 + \sum_{i=1}^{k} \beta_{1i} GDP_{t-1} + \sum_{i=1}^{k} \varphi_{1i} DEF_{t-1} + \varepsilon_{1t} \tag{7}$$

$$DEF_t = \alpha_2 + \sum_{i=1}^{k} \beta_{2i} GDP_{t-1} + \sum_{i=1}^{k} \varphi_{2i} DEF_{t-1} + \varepsilon_{2t} \tag{8}$$

Where k = optimal lag length and other variables are already defined. The Toda-Yamamoto method augments the VAR model by adding extra lags to account for non-stationarity. Suppose $d_{max}$ is the maximum order of integration of the variables, which could be *I(1), I(2),* etc. The augmented model becomes:

$$GDP_t = \alpha_1 + \sum_{i=1}^{k+d_{max}} \beta_{1i} GDP_{t-1} + \sum_{i=1}^{k+d_{max}} \varphi_{1i} DEF_{t-1} + \varepsilon_{1t} \quad (9)$$

$$DEF_t = \alpha_2 + \sum_{i=1}^{k+d_{max}} \beta_{2i} GDP_{t-1} + \sum_{i=1}^{k+d_{max}} \varphi_{2i} DEF_{t-1} + \varepsilon_{1t} \quad (10)$$

Where $d_{max}$ is the maximum integration order, added as extra lags to the VAR.

The hypothesis test for causality between DEF and GDP and GDP and DEF is as follows

$H_0$: $\varphi_{11} = \varphi_{12} = \ldots = \varphi_{1k} = 0$, this means that the lagged values of DEF do not significantly influence GDP, implying no Granger causality from deforestation to GDP growth.

$H_0$: $\beta_{21} = \beta_{22} = \ldots = \beta_{2k} = 0$, this means that the lagged values of GDP do not Granger-cause DEF.

Once the augmented VAR model is estimated, the Wald test is used to check for causality. The Wald statistic follows a $\chi^2$ distribution. The Wald test for causality is conducted as follows:

$$W = (b - b_o)'.\left(\Sigma^{-1}\right).(b - b_0) \quad (11)$$

Where $b$ is the vector of coefficients of the lagged independent variables (GDP and DEF), $b_0$ represents the null hypothesis (typically a vector of zeros), and Σ is the variance-covariance matrix of the coefficients. If the Wald test statistic exceeds the critical value from the $\chi^2$ distribution, we reject the null hypothesis and conclude that there is causality. Otherwise, we fail to reject the null hypothesis, implying no causality. Again, we proceed to use the Toda and Yamamoto (1995) to conduct a multiple causality test between deforestation and other control variables.

## 4. Results and discussion

Table 1 shows unit root test results from the ADF and PP methods for GDP and $GDP^2$, which are stationary at levels (I(0)). Differencing GDP (D(GDP,1)) makes it highly stationary, with ADF and PP $p$-values of 0.0001 and 0.0000, respectively. DEF is non-stationary at levels but becomes stationary after second differencing (I(2)). ANS and FDI are non-stationary at levels but become I(1) after first differencing, as does POP. INF is stationary at levels (I(0), $p$-value 0.0000).

**Table 1.** Stationarity test

| Variables | ADF (Levels) | PP (Levels) | Differenced variables | ADF (Differenced) | PP (Differenced) |
|---|---|---|---|---|---|
| GDP | 0.0117* | 0.0243* | D(GDP,1) | 0.0001*** | 0.0000*** |
| $GDP^2$ | 0.0009*** | 0.0009**** | | | |
| DEF | 0.2177 | 0.0101* | D(DEF,2) | 0.0001*** | 0.0001*** |
| ANS | 0.2315 | 0.2315 | D(DEF,1) | 0.0000*** | 0.0000*** |
| FDI | 0.4590 | 0.4590 | D(FDI,1) | 0.0000*** | 0.0000*** |
| POP | 0.3707 | 0.5578 | D(POP,1) | 0.0001*** | 0.0035** |
| INF | 0.0000*** | 0.0000**** | | | |

**Note(s):** *** (1% significance level), ** (5% significance level) and * (10% significance level)
**Source(s):** Authors' own creation

Given the mix of variables with different integration orders – I(0), I(1) and I(2) – the VECM as already mentioned, is appropriate for capturing both short-term dynamics and long-term relationships.

*4.1 The EKC estimation*

The results of the EKC estimation in Table 2 illustrate the relationships among GDP, $GDP^2$ and DEF. Further details of the results are shown in Appendix Table A. The coefficient for GDP is 0.261, indicating a positive but statistically insignificant relationship. Conversely, the coefficient for $GDP^2$ is −0.040, indicating negative statistically significant relation, suggesting that while deforestation initially increases with rising GDP, it may decline at higher levels of GDP. The significant negative relationship between $GDP^2$ and deforestation supports the EKC hypothesis, which is in line with Minlah *et al.* (2021a), Ntim-Amo *et al.* (2022).

For an economy like Ghana's, these EKC findings suggest that deforestation initially increases with economic growth, as the country prioritizes development over environmental sustainability through urbanization, industrialization and agriculture. However, the significant negative coefficient for $GDP^2$ indicates a potential turning point where continued growth could reduce deforestation, aligning with Sustainable Development Goal (SDG) 15, which promotes sustainable land use and combating deforestation. This highlights the need to integrate sustainable practices into economic planning to balance development with environmental conservation for future generations.

*4.2 Cointergration test*

Before conducting the cointegration analysis, it is essential to verify the cointegration relations among the variables, as shown in Appendix Table B. The unrestricted cointegration rank test (trace test) was performed. All variables were included with lags set from 1 to 2 in first differences. The trace test results indicate one cointegrating equation at the 0.05 level, rejecting the null hypothesis of no cointegration. The eigenvalue for the "*None*" hypothesis was 0.973706, yielding a trace statistic of 145.2471, exceeding the critical value of 95.7536, with a *p*-value of 0.0000. The hypothesis of at most one cointegrating relationship was not supported, with a trace statistic of 47.0101 falling below the critical value of 69.8188 and a *p*-value of 0.7605. The maximum eigenvalue test also indicates one cointegrating equation at the 0.05 level, with the same eigenvalue and a maximum eigenvalue statistic of 98.2369, surpassing the critical value of 40.0775 and a *p*-value of 0.0000. Testing for at most one cointegrating relationship yielded a statistic of 22.4637, which did not exceed the critical value of 33.8768 and had a *p*-value of 0.5717.

The unrestricted cointegrating coefficients normalized by the condition indicate significant relationships among the variables. The first normalized cointegrating equation shows notable coefficients, such as −2.7921 for *DEF* and 0.2481 for *D_GDP*, reflecting how the variables adjust to deviations from long-run equilibrium. Subsequent cointegrating equations reveal

**Table 2.** The EKC estimation

| Variable | Coefficient | Standard error | *t*-value | *p*-value |
|---|---|---|---|---|
| GDP | 0.261 | 0.209 | 1.250 | 0.221 |
| $GDP^2$ | −0.040 | 0.160 | −2.500 | 0.018** |
| Constant | 39.000 | 0.732 | 53.30 | 0.000*** |

**Note(s):** *** (1% significance level) and ** (5% significance level)
Dependent variable: Deforestation
**Source(s):** Authors' own creation

complex interactions among the variables, with varying coefficients and adjustment coefficients. The log likelihood values across equations suggest robustness, supporting the existence of a long-run equilibrium relationship among the variables.

*4.3 Cointegration analysis*

The results of both long and short run relationships are shown in Appendix Table C.

*4.3.1 Long run relationships.* First, the coefficient of GDP (−0.0889) is negative and statistically significant, suggesting that economic growth reduces deforestation in the long run. This is in line with Ahmed *et al*. (2015). In the Ghanaian context, this result implies that higher levels of GDP should be associated with efforts to protect the environment, possibly through stricter environmental policies or a shift toward less resource-intensive industries.

The ANS is a crucial sustainability metric that incorporates the costs of environmental degradation into the measurement of sustainable economic growth. The positive and significant coefficient of 0.3246 suggests that sustainable growth, as captured by ANS, positively influences Ghana's overall economic growth – a finding further supported by Qin *et al*. (2024). This indicates that factoring in environmental costs, such as forest depletion and biodiversity loss, into economic policies enhances long-term growth prospects. The result underscores the need for policies that promote sustainable resource management, particularly in forestry, to support both economic and environmental sustainability; hence the justification for introducing ANS.

Similarly, FDI has a positive, statistically significant impact on deforestation, with a 0.4242 coefficient, suggesting that increased FDI contributes to deforestation, likely through resource-intensive sectors like logging, agriculture and infrastructure. This underscores the need for policies in Ghana that redirect FDI to sustainable industries, balancing economic growth with environmental conservation.

The results show that population growth has a positive (0.4583) but statistically insignificant relationship with deforestation. This implies that GDP and FDI may have more impact. Urbanization, where most population growth occurs, reduces direct forest pressure on forested areas, while effective land use policies and sustainable practices further mitigate deforestation. Additionally, Ghana's transition to a service-based economy and increased education lessen reliance on resource-intensive industries. This, together with rural-to-urban migration, reduces deforestation pressures.

Finally, the coefficient for INF is negative (−0.0364) and statistically significant, indicating that higher inflation rates are associated with reduced deforestation in the long run. Increased inflation may raise the costs of economic activities that drive deforestation, such as resource extraction and agricultural expansion, thereby discouraging these practices. For Ghana, persistent inflation could potentially help curb deforestation, although it may also present broader economic challenges. However, this finding is not supported by Mujahid and Minhaj (2020) who identified a positive relationship between inflation and growth. This may stem from the differing contexts and focus of the studies. Mujahid and Minhaj explored the broader relationship between inflation and economic growth, a macroeconomic perspective, while this study focuses specifically on deforestation, a micro-level environmental issue. This divergence highlights the importance of context. Ghana's unique economic, environmental and institutional characteristics could mediate the inflation-deforestation relationship differently than in other regions.

*4.3.2 Short run relationships.* The error correction term for deforestation is −0.0066, which is negative but statistically insignificant, indicating minimal adjustment toward long-run equilibrium following system shocks. This suggests that short-run policies may not substantially impact deforestation, as changes are more likely driven by external factors rather than a return to a long-term trend. The volatility in deforestation rates, as indicated by the lack of predictive power in past deforestation trends, further emphasizes the challenge of implementing effective short-term measures.

The first difference of GDP has a coefficient of −0.0154, indicating a slight but statistically insignificant reduction in deforestation with short-term GDP growth. In contrast, the second lag of GDP is −0.0247 and statistically significant, suggesting that while economic growth has minimal immediate impact on deforestation, it may reduce deforestation over time.

The ANS shows mixed effects. The first lag of ANS has a very small coefficient of 0.0001, which is statistically insignificant, suggesting that incorporating environmental degradation costs into savings does not have a clear short-term impact on deforestation. Similarly, the second lag of ANS is positive but also statistically insignificant, indicating a lack of immediate influence. Whereas ANS is valuable for assessing sustainability, its impact on forest conservation is long-term.

In the case of FDI, the first lag of FDI shows a positive but insignificant effect on deforestation (0.0009), while the second lag is negative (−0.0119) and also insignificant. This suggests that FDI's impact on deforestation may strengthen over time. Although short-term effects are minimal, the negative second lag implies potential long-term deforestation reduction through sustainable investments and technology transfers. However, the statistical insignificance highlights the need for caution in relying on FDI for environmental sustainability.

Population growth's effect on deforestation is reflected in two negative coefficients: the first lag at −0.3046 and the second lag at −0.6074. Both coefficients are statistically insignificant, indicating that short-run population changes do not have a clear immediate effect on deforestation. Lastly, inflation's first lag shows a negative coefficient of −0.0015, which is statistically insignificant, and the second lag is similarly insignificant at −0.0015, suggesting that inflation has no short-term effect on deforestation.

*4.3.3 Further test.* 4.3.3.1 VEC stability condition check. Appendix Table D presents the stability condition check for the VECM, which analyzes the interactions among the variables. The identification of five-unit roots in the system indicates non-stationarity, a common issue in time series data that can lead to misleading regression outcomes if not addressed. This non-stationary behavior justifies the use of the VECM, which effectively manages co-integrated variables that share long-term equilibrium relationships (Chen, 2022). Stability within the model was assessed by examining the roots and their moduli, where stability is indicated by moduli less than 0.5. However, some roots have moduli equal to or exceeding 0.5, suggesting potential instability. This is confirmed in Appendix Figure E. This indicates that shocks to the system could produce lasting effects. Despite the model's utility, overall stability was uncertain due to unit roots. Economically, this emphasizes the need for policies that mitigate lasting impacts, particularly in forestry, where unregulated FDI in extractive industries could hinder sustainable resource management.

Nonetheless, some aspects of the system exhibits dampening oscillatory behavior, indicating that certain variables stabilize after initial fluctuations, reflecting economic cycles and environmental impacts. The VECM effectively captures long-run equilibrium relationships despite unit root instability. These cyclical dynamics show that variables like GDP growth, FDI, and deforestation may eventually stabilize aftershocks, emphasizing sustainable policies' role in buffering long-term instability. For environmental planning, sustainable forestry practices could mitigate the effects of economic volatility on deforestation.

4.3.3.2 VEC lag exclusion Wald test. The results of the lag exclusion test are shown in Appendix Table F. The results provide insights into which lags are crucial for explaining the dynamics of the variables under study. For the first lag, the test shows that it is highly significant for GDP and FDI, with *p*-values of 0.0108 and 0.0000, respectively. This indicates that the first lag plays a crucial role for these variables and cannot be excluded from the model. For the other variables, the *p*-values are higher than the conventional thresholds of 0.05 or 0.01, suggesting that the first lag might be less important for them. However, INF has a borderline significance with a *p*-value of 0.0757, meaning it could still have some influence.

In the case of the second lag, it is significant for FDI ($p$-value of 0.0001) and INF ($p$-value of 0.0339), implying that the second lag should also be retained for these variables. For the other variables, the $p$-values are relatively high, indicating that the second lag may not be as critical and could potentially be excluded for these variables. The joint test, which evaluates the overall significance of the lags across all variables, reveals highly significant results for both lag 1 and lag 2, with $p$-values of 0.0000. Thus, when considered together, the lags are essential for explaining the system's dynamics and excluding them would result in model misspecification.

4.3.3.3 VEC residual serial correlation. The result is shown in Appendix Table G. The VEC residual serial correlation LM test results indicate that there is no significant serial correlation in the residuals of the VEC model across different lag orders. The results show that for lags 1, 2 and 3 the LM statistic is 39.2580, 46.2047 and 31.5404 with a corresponding probability values of 0.3260, 0.1187 and 0.6806, respectively. This $p$-value is significantly higher than the common significance levels (0.05 or 0.01), suggesting that we do not reject the null hypothesis of no serial correlation at this lag. Stated differently, high $p$-values across all lags imply that there is no significant evidence of serial correlation in the residuals of the VEC model, which is a positive outcome. This suggests that the model adequately captures the dynamics of the data without leaving behind autocorrelated residuals.

### *4.4 Causality test*

Next, we proceed to the causality test for deforestation and its relationship with other variables. The results are displayed in Appendix Table H. The evidence is weak regarding GDP potentially Granger-causing deforestation, indicated by a Chi-squared statistic of 5.5558 and a $p$-value of 0.0622. This suggests that while economic growth might influence environmental degradation, the effect is not strong enough to be statistically significant. This result differs slightly from Minlah *et al*. (2021b) who found no causality between GDP and deforestation. The difference between our findings and those of Minlah *et al*. (2021b) may arise from variations in methodology, data sources and time periods analyzed. Our study included additional control variables, such as population growth, that mediate the GDP–deforestation relationship. Again, temporal factors, such as shifts in Ghana's economic structure or changes in environmental policies, could also influence the results. The analysis, however, shows no significant evidence that deforestation Granger-causes GDP, with a Chi-squared value of 1.9777 and a $p$-value of 0.3720. This indicates that changes in deforestation rates do not predict GDP fluctuations, though it poses long-term risks to resource availability and resilience. Deforestation Granger-causes FDI, suggesting that increased deforestation may attract foreign investment, particularly in resource-exploiting industries. Additionally, there is a strong causal relationship between GDP and FDI, shown by a Chi-squared value of 17.2288 and a $p$-value of 0.0002, with other factors like ANS, POP and inflation significantly influencing FDI.

## 5. Conclusion and policy recommendations

This study explored the connections between economic growth, environmental sustainability and deforestation in Ghana, testing the EKC hypothesis. The results support the EKC hypothesis in Ghana. This trend suggests that as Ghana advances economically, a shift toward sustainable practices and environmental policies occurs, leading to reduced deforestation.

Further, the study reveals that ANS positively impacts long-term GDP growth. This highlights the need for environmental considerations in economic planning, ensuring that growth does not compromise natural resources. FDI in resource-intensive sectors was found to increase deforestation, underscoring the importance of directing investment toward sustainable areas. Population growth had a weaker association with deforestation yet still emphasizes the pressure on land. Lastly, the study noted that inflation reduces deforestation in the long term, suggesting that economic costs influence resource-intensive activities. Overall, these findings suggest that while economic growth is crucial for Ghana, it must be managed carefully to ensure that environmental sustainability is integrated at every stage.

To foster sustainable economic development in Ghana, the following policy recommendations, drawn from the study's findings, are proposed. Firstly, integrating environmental sustainability into national economic growth strategies is crucial. This approach ensures that development is pursued in harmony with natural resources rather than at their expense. Enhancing the use of adjusted net savings (ANS) as a key metric in policy evaluation is essential. The positive relationship between ANS and long-term GDP growth underscores its importance in guiding sustainable development. By making ANS a standard measure, especially for large-scale projects in resource-intensive sectors, Ghana can ensure that economic growth does not lead to environmental degradation.

Another key recommendation is to direct foreign direct investment (FDI) toward sustainable industries. Currently, FDI has driven deforestation, particularly in sectors reliant on natural resources. By offering incentives for investment in renewable energy, technology, and sustainable agriculture, Ghana can leverage the benefits of FDI while protecting its forests. Additionally, maintaining stable inflation rates is vital for promoting sustainability, as high inflation increases costs associated with resource-intensive activities. Stability in inflation helps limit resource extraction and encourages sustainable industry practices.

Further supporting sustainability, several innovative policy measures should be considered. Integrating natural capital accounting into national economic indicators such as GDP allows for a more holistic assessment of economic development, factoring in environmental costs like deforestation and pollution. Institutionalizing natural capital accounting ensures economic decisions align with sustainability goals, fostering long-term ecological and economic stability. Establishing green investment funds to incentivize green investments is another promising policy. These funds would provide concessional financing and tax incentives for businesses adopting sustainable practices, such as renewable energy, waste recycling and resource-efficient production processes. Linking these incentives to measurable environmental outcomes encourages private sector innovation and reduces environmental degradation.

Another critical policy is promoting community-based natural resource management (CBNRM). This model empowers local communities to manage and co-manage natural resources like forests and water bodies. By linking sustainable resource management with economic benefits through revenue-sharing mechanisms, CBNRM can reduce exploitation, enhance local livelihoods and promote conservation. Finally, utilizing ANS metrics in budget allocations provides a practical framework for aligning fiscal decisions with sustainability. Regions or sectors demonstrating higher adjusted net savings and better resource management practices could be rewarded with increased funding. This policy ensures that economic development is balanced with environmental preservation and encourages policymakers to prioritize sustainability in their decision-making processes.

Suggested areas for further studies include sectoral contributions to deforestation, climate change impacts and the effectiveness of environmental policies.

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**Supplementary material**
The supplementary material for this article can be found online.

**Corresponding author**
Joseph Antwi Baafi can be contacted at: jobash5@hotmail.com, jbantwi@aamusted.edu.gh