sustainability

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Green Building Practices: Fuzzy Synthetic Evaluation of the Drivers of Deforestation and Forest Degradation in a Developing Economy

Oluwayinka Seun Oke [1], John Ogbeleakhu Aliu [2,3,*], Ayodeji Emmanuel Oke [4,5], Damilola Ekundayo [6] and Oluwafemi Matthew Duduyegbe [5]

[1] Department of Forestry and Wood Technology, Federal University of Technology Akure, Akure 340110, Nigeria; osoke@futa.edu.ng
[2] Engineering Education Transformations Institute, College of Engineering, University of Georgia, Athens, GA 30602, USA
[3] CIDB Centre of Excellence, Faculty of Engineering and Built Environment, University of Johannesburg, Johannesburg 2092, South Africa
[4] Research Group on Sustainable Infrastructure Management plus (RG-SIM+), Department of Quantity Surveying, Federal University of Technology Akure, Akure 340110, Nigeria; aeoke@futa.edu.ng
[5] Department of Quantity Surveying, Federal University of Technology Akure, Akure 340110, Nigeria; duduyegbeqsv173922@futa.edu.ng
[6] School of Engineering and the Built Environment, Birmingham City University, Birmingham B4 7BD, UK; damilola.ekundayo@bcu.ac.uk
* Correspondence: john.aliu@uga.edu

Abstract: Since 1990, approximately 420 million hectares of forest have been lost worldwide due to land conversion for various uses, including agriculture, infrastructure development, urbanization, and other human activities. This study aims to investigate the critical drivers contributing to deforestation and forest degradation (DFD) in Ondo State, Nigeria, thereby identifying areas where REDD+ (Reducing Emissions from Deforestation and Forest Degradation) interventions could be most effective in reducing greenhouse gas emissions, particularly carbon dioxide (CO_2), which is released through forest loss and degradation. A questionnaire survey was used to obtain data from construction professionals such as architects, engineers, builders, quantity surveyors, and project managers. Collected data were analyzed using frequencies and percentages to report the background information of professionals, Mean Item Scores (MIS) to rank critical drivers of DFD, and Fuzzy Synthetic Evaluation (FSE) to identify the most critical drivers. FSE analysis revealed that DFD is primarily motivated by agricultural expansion (including cattle ranching and shifting cultivation) and infrastructure extension (particularly transportation networks and market and service infrastructure) among the proximate drivers. The analysis also identified demographic, economic, and policy and institutional factors as the most significant underlying drivers. The emphasis on agricultural expansion and infrastructure extension suggests that targeted interventions in these areas could significantly mitigate DFD in the study site under consideration. This may involve implementing stricter regulations and incentives to promote sustainable land use practices among farmers and landowners. Additionally, integrating environmental impact assessments into infrastructure projects can help minimize forest loss associated with road construction and urban expansion. This study introduces an innovative approach by applying the Geist and Lambin conceptual framework of 'proximate causes and underlying driving forces'. It is among the pioneering studies conducted in the study area to comprehensively analyze the drivers contributing to DFD using these frameworks. Although conducted in Ondo State, Nigeria, the findings can be extrapolated to similar regions facing similar challenges of DFD worldwide.

Academic Editor: Antonio Caggiano

Received: 28 December 2024
Revised: 2 February 2025
Accepted: 4 February 2025
Published: 13 February 2025

Citation: Oke, O.S.; Aliu, J.O.; Oke, A.E.; Ekundayo, D.; Duduyegbe, O.M. Green Building Practices: Fuzzy Synthetic Evaluation of the Drivers of Deforestation and Forest Degradation in a Developing Economy. *Sustainability* **2025**, *17*, 1538. https://doi.org/10.3390/su17041538

Keywords: construction projects; developing countries; environmental impact; resource conservation; sustainable building processes; sustainable construction

1. Introduction

According to the World Wildlife Fund, deforestation and forest degradation (DFD) accounted for roughly 10–15% of global greenhouse gas emissions in 2022 [1]. The UN Environment Programme's 2023 data indicate DFD is responsible for 11% of carbon emissions [2]. This alarming contribution to global warming was a key factor prompting the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. In response, the UNFCCC developed REDD+, an international approach to curbing emissions from DFD [3]. REDD+ offers financial compensation to tropical nations for reducing DFD, making it crucial to understand the various drivers of deforestation and degradation to ensure its effectiveness. Several researchers emphasize the need for a comprehensive analysis of all direct and indirect drivers of DFD in REDD+ countries. This systematic approach is essential for effectively reducing emissions and enhancing forest carbon stocks [4]. Understanding these drivers is also crucial for crafting effective national REDD+ policies and developing robust reference scenarios [5].

A key ongoing debate in REDD+ countries centers on identifying the primary culprit behind DFD: slash-and-burn agriculture or industrial logging. However, current arguments often lack empirical data and remain speculative. Therefore, more rigorous research is needed to solidify our understanding and guide future actions. Existing studies on DFD drivers have primarily relied on quantitative approaches, such as economic modeling [6], remote sensing techniques [7], and systematic literature reviews [8]. However, these approaches largely neglect the perspectives of construction stakeholders, the very actors who are often significant drivers of DFD through activities like infrastructure development. This gap between scientific analysis and the realities on the ground represents a missed opportunity. To achieve a more comprehensive understanding of DFD, it is increasingly relevant to integrate quantitative analysis that incorporates the opinions, knowledge, and perspectives of construction stakeholders.

In developing countries like Nigeria, where infrastructure development fuels economic growth, understanding the role of construction stakeholders in DFD is crucial. For instance, in southwestern Ondo State, a cocoa powerhouse, studies on construction-related DFD drivers are scarce. The state capital Akure has in recent times experienced increased flooding and rising temperatures caused by intense DFD in the surrounding areas [9–11]. However, no research has prioritized the specific DFD drivers that could inform policy responses tailored to this rapidly urbanizing region. Therefore, this study seeks to fill this gap by drawing upon the [12] conceptual framework of 'proximate causes and underlying driving forces'. This framework is particularly suitable for our study because it provides an ample approach to understanding the complex, multi-dimensional factors driving DFD. The framework distinguishes between proximate causes (immediate factors such as land use changes, agricultural expansion, and logging) and underlying driving forces (longer-term social, economic, and political factors like governance, policy, and economic incentives) that influence these processes. Moreover, the Geist and Lambin framework has been widely used in similar studies on DFD and has proven effective in guiding research into the multidimensional causes of environmental degradation. Using Fuzzy Synthetic Evaluation (FSE), the study will identify the most critical drivers of DFD in Akure from the perspective of construction stakeholders. This information is critical for curbing deforestation not only at the local level but also at the global, regional, and national scales. The following research questions underpin this study:

(1) What are the most critical proximate and underlying drivers of DFD in Akure from the perspective of construction stakeholders?
(2) Which strategies effectively address the identified drivers of DFD in Akure?

The novelty of this study lies in identifying the most critical drivers contributing to DFD in the region from a construction sector approach. This prioritization is vital for several reasons. Firstly, it allows for targeted policy interventions, such as stricter logging regulations or incentives for sustainable construction practices. Secondly, by understanding stakeholder perspectives, collaborative solutions can be developed that address both construction needs and forest conservation. Thirdly, limited resources in developing countries necessitate focusing on the most impactful drivers, thereby maximizing environmental benefits per unit of investment. The findings of this study will be beneficial to policymakers at the national level by informing strategic policies to address forest loss. Additionally, the insights gained can support the development and implementation of national REDD+ strategies, ensuring that they are both effective and contextually relevant. This approach not only helps in mitigating climate change but also promotes sustainable development and resilience in the construction sector. Although this study was conducted in Akure, its findings can be extrapolated to other regions facing similar challenges with DFD. Lessons learned from this study can inform strategies in countries like Brazil, Guyana, Peru, Tanzania, and Indonesia. These countries, which have successfully secured REDD+ funding through bilateral agreements with developed countries like Norway, Germany, and the United Kingdom, can benefit from the insights gained from this study's approach to identifying and addressing DFD drivers.

This study supports the achievement of several United Nations Sustainable Development Goals (SDGs), including SDG 13 (Climate Action), SDG 15 (Life on Land), and SDG 9 (Industry, Innovation, and Infrastructure). By addressing the critical drivers of DFD and promoting sustainable practices, the study contributes to global efforts to combat climate change, preserve biodiversity, and foster innovation in sustainable construction.

2. Literature Review

2.1. The Situation of Deforestation and Forest Degradation (DFD) in Ondo State, Nigeria

Deforestation and forest degradation (DFD) are critical environmental issues globally, with significant impacts on biodiversity, climate change, and human livelihoods. In Akure, the capital of Ondo State, Nigeria, these issues have been a growing concern due to various anthropogenic activities. One of the primary causes is the expansion of settlements around the Akure Forest Reserve. As the population grows, the demand for land increases, leading to the clearing of forests for residential areas, infrastructure development, and other projects [13]. Additionally, agricultural activities, particularly the practice of shifting cultivation and the establishment of permanent farmlands, have led to the conversion of forest land into agricultural plots [14]. Another significant driver is the extraction of wood fuel. In many parts of Nigeria, including Akure, wood is a primary source of energy for cooking and heating. Unfortunately, the unsustainable harvesting of wood for fuel has led to forest degradation as trees are cut down faster than they can regenerate, impacting the overall health of the forest [9]. Both legal and illegal logging also contribute significantly to forest degradation in Akure. Timber is a valuable resource and the high demand for wood products has led to extensive logging activities [13]. While legal logging is regulated, illegal logging often goes unchecked, leading to unsustainable harvesting practices that severely deplete forest resources. As a result of these socio-economic and environmental factors, the Akure Forest Reserve has experienced significant DFD over the years. For instance, in

1986, undisturbed forests constituted over 63% of the land area. By 2017, this had shrunk to around 32%, translating to a loss of over 1.5 million hectares of primary forest in just under three decades [13]. Such data underscore the urgency of implementing effective measures to protect and restore forested areas. Programs, like Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Reducing Deforestation and Forest Degradation and Enhancing Environmental Services from Forests (REDDES), have been supported by organizations like the International Tropical Timber Organization (ITTO) to address DFD in Akure [14]. These initiatives offer hope for reversing the negative trends and promoting sustainable forest management.

2.2. Overview of the Geist and Lambin Conceptual Framework of DFD Drivers

Several frameworks on drivers influencing DFD exist. For instance, frameworks developed by the United Nations Food and Agriculture Organization (FAO) and the World Wildlife Fund (WWF) identify key factors like agricultural expansion, logging, infrastructure development, and policy and governance issues as primary drivers of DFD [1,15]. The Land Use Change Model (LUCM) is also a sought-after tool for analyzing and predicting the effects of various drivers on land use patterns. The tool helps understand how different factors, such as economic development, agricultural expansion, and policy changes, might lead to changes in land use, including DFD [16]. The Cascade Model, which explores the complex interactions between agricultural expansion and deforestation, emphasizes how changes in agricultural technologies and practices can drive DFD by altering land use dynamics [17]. However, the [12] conceptual framework offers a more comprehensive approach to understanding these drivers. This framework disaggregates the causes of deforestation and forest degradation into proximate causes and underlying driving forces, which are discussed next.

2.2.1. Proximate or Direct Driving Forces

According to [12], proximate causes include direct actions that result in DFD, such as agricultural expansion, wood extraction, and infrastructure expansion. Agricultural activities, particularly large-scale farming for crops like soybeans and palm oil and cattle grazing, are significant contributors to deforestation globally [1,15]. Studies by [18,19] have extensively documented how agricultural expansion leads to substantial forest loss, especially in tropical regions such as the Amazon and Southeast Asia. The expansion of agriculture often involves clearing land through methods like slash-and-burn agriculture or mechanized clearing, which directly impact forested areas. This process not only reduces forest cover but also fragments habitats and disrupts ecological balances, endangering biodiversity and ecosystem services [6]. Moreover, the conversion of forests to agricultural land alters local climate patterns, soil fertility, and water cycles, further exacerbating environmental degradation [5].

Logging for timber and fuelwood is a direct driver of DFD according to the [12] framework. According to them, unsustainable logging practices, such as selective logging and illegal logging, lead to the loss of valuable forest cover and biodiversity. Studies consistently show that these activities not only degrade forests but also contribute to habitat fragmentation, making ecosystems more vulnerable to invasive species and climate change impacts [3,20]. Selective logging targets specific high-value tree species, often leaving behind damaged forests and disrupting natural regeneration processes [9]. Illegal logging, driven by profit motives and weak law enforcement, further compounds these impacts, undermining conservation efforts and local livelihoods dependent on forest resources [6]. The cumulative effect of these activities is the loss of biodiversity, alteration of carbon storage capacities and degradation of ecosystem services vital for human well-being [19].

The development of roads, dams, mining operations, and urban expansion is another significant proximate cause of DFD [12]. These infrastructure projects often necessitate the clearing of large tracts of forested land, leading to direct deforestation and habitat loss [4]

Roads, in particular, act as conduits for further human activities such as logging, agriculture, and settlement expansion, thereby intensifying deforestation pressures [21]. Infrastructure development also results in forest fragmentation, where remaining patches of forest become isolated, impacting wildlife populations and disrupting crucial migration routes [20]. This fragmentation reduces genetic diversity and resilience to environmental changes, further threatening biodiversity conservation efforts [12]. Moreover, the conversion of forests to infrastructure and urban areas alters local ecosystems and hydrological cycles. According to [22], land clearing for construction and subsequent development activities disrupts natural drainage patterns, leading to changes in water quality and availability downstream. These changes can have far-reaching consequences for both terrestrial and aquatic ecosystems, affecting biodiversity and human communities reliant on ecosystem services [6].

2.2.2. Indirect or Underlying Causes

According to [12], underlying causes encompass broader socio-economic, institutional, and policy factors that create conditions conducive to DFD. These causes influence and interact with proximate drivers, shaping patterns of land use change globally. According to [23], economic incentives play a pivotal role in driving DFD as industries seek profit from timber extraction, agriculture and land speculation, often prioritizing short-term gains over long-term environmental sustainability. Also, demand for commodities like palm oil, soybeans, and beef drives agricultural expansion into forested areas, pushing agricultural frontiers deeper into previously untouched landscapes [15]. Moreover, economic growth agendas often prioritize resource extraction and infrastructure development, intensifying pressure on forests and natural ecosystems [20]. In addition to market-driven incentives, economic factors also include subsidies and incentives that promote unsustainable practices. According to [24], government subsidies for agricultural expansion or infrastructure development that do not consider environmental impacts can inadvertently accelerate deforestation.

Weak governance, inadequate law enforcement, and unclear land tenure systems also contribute significantly to DFD as ineffective policies fail to regulate land use practices, leading to illegal logging, unsustainable agricultural practices, and land grabbing [12]. Corruption and lack of transparency exacerbate these issues, undermining conservation efforts and sustainable development goals [9]. Conversely, robust policy frameworks that enforce land use planning, promote sustainable practices, and empower local communities in natural resource management can effectively mitigate deforestation [3]. Effective governance also involves international agreements and cooperation to address transboundary issues such as illegal logging and trade in endangered timber species [17]. Multilateral agreements like the Convention on Biological Diversity and initiatives such as REDD+ aim to provide financial incentives for forest conservation and sustainable management practices, promoting global cooperation in combating deforestation [20].

Rapid population growth and urban expansion drive demand for housing, infrastructure, and resources, leading to land use changes that encroach upon forested areas [23]. Urban sprawl consumes valuable forest lands, fragmenting habitats and reducing biodiversity [16]. Urbanization also creates new markets for agricultural products and timber, intensifying pressure on forests as rural populations migrate to urban centers in search of economic opportunities [4]. Managing urban growth through compact city planning, green infrastructure development, and sustainable land use policies can help mitigate the impact of urbanization on forests [9]. Furthermore, traditional practices, cultural beliefs, and indigenous land tenure systems influence land use decisions and deforestation rates [12]. Indigenous communities often depend on forests for their livelihoods and cultural identity, practicing sustainable land management that preserves biodiversity [20]. However, external pressures, changes in land tenure, and globalization can undermine these practices, leading to forest degradation and loss of traditional knowledge [6]. Empowering indigenous and local communities in forest management through secure land tenure rights, participatory decision-making processes, and capacity building can enhance conservation efforts [11].

Technological advancements can both exacerbate and mitigate deforestation. According to [25], innovations in agriculture, such as mechanized farming equipment, genetically modified crops, and agrochemicals, have increased agricultural productivity but also facilitated large-scale land clearing and monoculture farming practices. Mechanized clearing techniques, including bulldozers and chainsaws, enable rapid land conversion for agriculture and infrastructure development, significantly impacting forest ecosystems [9]. Moreover, advancements in logging technologies have intensified timber extraction and fuelwood harvesting, leading to unsustainable logging practices [26]. High-capacity logging machinery and satellite-based monitoring systems have enabled more efficient exploitation of forest resources, often without adequate consideration for sustainable forest management practices [7]. However, technological innovations also offer opportunities for conservation and sustainable land use. Remote sensing technologies, such as satellite imagery and drones, facilitate the monitoring of deforestation trends, illegal logging activities, and land use changes in real time [6]. Geographic Information Systems (GIS) help in spatial analysis and planning for conservation efforts, identifying priority areas for protection and restoration [24]. Table 1 presents a summary of the drivers contributing to DFD using the conceptual framework by [12].

Table 1. Summary of critical drivers using conceptual framework of Geist and Lambin (2002).

Proximate (Direct) Causes	**Sources**
Agricultural expansion	[12]
Shifting cultivation	[6]
Permanent cultivation	[1,15]
Cattle ranching	[6]
Colonization and transmigration	[15]
Wood extraction	[12]
Commercial logging	[6]
Fuelwood gathering	[1,15]
Charcoal production	[1,15]
Polewood collection	[6]
Infrastructure extension	[12]
Transportation networks (roads, highways)	[5]
Human settlements	[1,15]
Market and service infrastructure	[9]
Underlying driving forces	[12]
Demographic factors	[12]
Population growth	[4,20]
Migration	[16,20]
Urbanization	[16,20]
Economic factors	[12]
Market growth and commercialization	[23,27]
Price changes	[23,24]
Economic structures and changes	[23,24]
Agricultural policies and subsidies	[23,24]

Table 1. *Cont.*

Proximate (Direct) Causes	Sources
Technological factors	[12]
Agricultural technologies and practices	[4,24]
Logging technologies	[9]
Infrastructure development technologies	[4,24]
Policy and institutional factors	[12]
Land tenure and property rights	[9]
Governance and political stability	[11,24]
Policy frameworks and enforcement	[11,24]
Cultural and socio-political factors	[12]
Social conflicts and wars	[9,11]
Attitudes and beliefs towards forests	[9,11]
Cultural and social norms	[11,24]

Source: Tables created by authors.

3. Research Methodology

3.1. Study Area

This study aimed to inform the implementation of Reducing Emissions from Deforestation and Forest Degradation (REDD+) in Akure, Ondo State, Nigeria. By investigating the critical drivers contributing to deforestation and forest degradation (DFD) in the region, the research sought to identify areas where REDD+ interventions could be most effective. A questionnaire survey was used to gather data from a targeted population of construction professionals practicing in Akure. This group included architects, engineers, builders, quantity surveyors, and project managers, whose professional activities can significantly influence forest resource use. Due to the ease of administration and its design for quick and easy completion by busy construction professionals, a well-structured questionnaire was chosen as the primary data collection method [28].

3.2. Questionnaire Design

The questionnaire itself was divided into two sections. The first section aimed to identify the characteristics of the respondents to ensure their suitability for the study and provided context for their responses in the second section. The second section then focused on the critical drivers of DFD in the Akure region. Here, respondents were asked about their experiences and observations regarding factors contributing to forest loss and degradation. To gauge the perceived significance of each factor, respondents used a five-point Likert scale where 1 = very low importance, 2 = low importance, 3 = neutral, 4 = high importance, and 5 = very high importance. This allowed respondents to indicate the extent to which they believe each factor contributes to DFD. In Akure, recruiting participants for this study presented a challenge due to the decentralized nature of professional registration bodies and the difficulty in obtaining a comprehensive, up-to-date list of construction professionals. To overcome these limitations, a combined sampling approach (purposive and snowball sampling) was employed [29]. Purposive sampling allowed the researchers to directly identify and recruit participants with specific qualifications and experience in the construction sector. This approach was chosen to gather in-depth, specialized insights aligned with the study's objectives. Then, snowball sampling complemented this by utilizing referrals from initial participants to expand the pool of potential subjects while maintaining relevance to the research focus. This method is particularly helpful when studying niche populations or those who may be difficult to locate through traditional means [30]. To mitigate potential biases associated with snowball sampling, several strategies were employed, including selecting initial participants from diverse construction roles to ensure a balanced range of perspectives. Additionally, clear eligibility criteria were applied to all referred participants, thereby enhancing the robustness and validity of the findings.

3.3. Questionnaire Refinement

To refine the instrument and ensure its clarity, validity, and reliability [31], a pilot study was conducted. This pilot involved administering the questionnaire to a carefully selected group (purposive sample) of 12 industry professionals with relevant expertise in forestry, ecology, environmental policy, and construction-related areas. Their feedback on the questionnaire's clarity and understandability was instrumental in refining the final version, ensuring it could generate accurate and reliable data. The value of pilot studies in construction research is well-supported by other [24,32]. The feedback gathered from the pilot study focused on three main aspects: question clarity and wording, questionnaire structure and flow, and question relevance and completeness. Regarding clarity and wording, participants highlighted instances where technical terminology related to deforestation and forest degradation (DFD) could be simplified to improve comprehension. Based on this feedback, several items were reworded to reduce ambiguity, ensuring greater clarity for a broader audience. In terms of structure and flow, respondents suggested a more logical progression for sections addressing policy influences and construction practices. These sections were reorganized to enhance readability and ensure a more natural flow of topics. Lastly, with regard to relevance and completeness, participants recommended adding items related to community engagement and regulatory frameworks. These suggestions were incorporated into the final instrument to capture a more comprehensive view of DFD drivers and mitigation strategies.

3.4. Dissemination of Questionnaire

Google Forms was used to administer the questionnaire to the participants between September and November 2024. The purposive–snowballing sampling approach yielded a sample of 224 construction professionals. Of these, 143 responded to the questionnaire, resulting in a 64% response rate. Frequency and percentages analysis was used to explore the background characteristics of the respondents, such as years of experience and areas of specialization. The 27 drivers identified through the literature review were grouped according to the [12] conceptual framework of 'proximate causes and underlying driving forces'. To rank these critical drivers of DFD, Mean Item Scores (MIS) were calculated. Drivers with the highest MIS were prioritized, followed by those with progressively lower scores within each group. Cronbach's alpha (α) with a 0.7 cut-off point was used to assess the reliability of data from the questionnaire's second section. This analysis yielded an α-value of 0.819, indicating good internal consistency of the data.

3.5. Analysis of Data

To address any possible uncertainties regarding the inherent subjectivity of human responses in surveys and further refine the understanding of critical drivers, Fuzzy Set Theory (FST) was adopted. FST offers a valuable approach for dealing with ambiguous, subjective and imprecise judgments that arise in complex problems [33]. Its strength lies in the use of linguistic variables, which introduce a degree of imprecision that reflects the inherent ambiguity of human reasoning. This allows for a more precise and objective explanation and quantification of information that may not be perfectly defined [34]. FST's application, particularly through the use of mathematical operators in a fuzzy domain, has been shown to reveal preferences within individual or group decision-making processes [35]. One key application of FST is Fuzzy Synthetic Evaluation (FSE) which assesses decision-making scenarios involving multiple criteria [36]. Hence, to mitigate inherent subjectivity in responses, this study utilized FSE to assess the critical drivers of DFD within

Akure. This method accommodates the fuzzy decision environment characterized by multiple criteria.

The FSE was conducted with appropriate weightings (W) assigned to the respective categories of the [12] framework. Equation (1) provided the calculation of the respective W.

$$W_i = \frac{M_j}{\sum_{i=1}^{5} M_j} \tag{1}$$

where

W_i = Each group or variable's weight;

M_j = Each group or variable's mean rating;

$\sum M_j$ = Total of the mean ratings for all groups or variables.

The next step involves selecting appropriate models for analysis within a fuzzy environment. Equation (2), as proposed by [34], offers a suitable approach for this type of scenario. According to [34], this equation is particularly well-suited when dealing with a large number of variables with minimal differences in their weightings. This aligns well with the current study, which explores 27 drivers categorized into eight groups. The minimal difference in weightings might be because the FSE methodology itself assigns weights based on relative importance within the chosen framework.

$$M(\cdot, \oplus), bj = \min\left(1, \sum_{i=1}^{m} wi \times rij\right) \forall bj \in B \tag{2}$$

where

w_i = Drivers' weightings;

r_{ij} = Membership Function (MF) of the drivers;

$\oplus$ = Total product of weighting and membership function.

Beyond the weightings and MFLs, Equation (3) is employed to determine a quantitative measure of overall driver impact.

$$\text{Overall impart} = \sum_{k=1}^{5} (W \times R_k) \times L \tag{3}$$

where

W = Weighting calculated earlier;

R = Membership function degree;

L = Linguistic variable.

4. Results

4.1. Background Information

The survey attracted a diverse group of construction professionals, with varying academic qualifications and experience levels. Over 40% (61 respondents) held a Bachelor's degree, while Master's degrees were attained by 31.4% (45 respondents) and PhDs by 5.6% (8 respondents). In terms of professional backgrounds, engineers formed the largest group (30.1%, 43 respondents), followed by architects (23.1%, 33 respondents) and project managers (15.4%, 22 respondents). Builders comprised 17.4% (25 respondents) of the sample. Experience levels also varied, with a significant number of respondents possessing substantial experience in the field. The largest group (42 respondents, 29.4%) had 11–15 years of experience, closely followed by those with 16–20 years (39 respondents, 27.3%). While there were individuals with less experience (29 respondents, 20.3% with 1–5 years and 15 respondents, 10.5% with 6–10 years), a good portion (18 respondents, 12.5%) boasted over 20 years of experience. This blend of academic qualifications and practical experience positions the respondents to provide valuable insights into the critical drivers of DFD.

4.2. Critical Drivers Contributing to Deforestation and Forest Degradation (DFD)

Table 2 ranks the critical drivers contributing to DFD, structured according to the conceptual framework by [12]. Direct actions like agricultural and infrastructure expansion emerge as significant contributors. In the agricultural expansion dimension, activities such as cattle ranching and shifting cultivation (MIS = 3.55 and MIS = 3.53 respectively) require land clearing for pastures or temporary fields. This disrupts natural habitats and alters forest ecosystems entirely. Similarly, within the infrastructure extension category, the development of transportation networks (roads, highways) and market infrastructure (averaging a MIS = 3.47) creates easier access to previously remote forested areas. While this increased accessibility can be important for economic development, it also opens the door for further agricultural expansion, logging and human settlements. Looking beyond the immediate causes, Table 2 also reveals the underlying driving forces that fuel deforestation trends. Demographic factors such as population growth (MIS = 3.77) and migration (MIS = 3.51) create a growing demand for land and resources. This often leads to increased pressure on forested areas to meet these needs. Economic factors also play a significant role with market growth and commercialization (MIS = 3.57) ranking as one of the most critical, alongside price changes (MIS = 3.41), influencing land use decisions. This is because the pursuit of economic growth can sometimes come at the expense of forests, as these factors incentivize activities that contribute to deforestation. Land tenure and property rights (MIS = 3.46) and governance and political stability (MIS = 3.41) emerge as critical factors under the policy and institutional dimension according to Table 2. Unclear or weak property rights can create uncertainty and incentivize short-term deforestation for gain. Similarly, political instability or lack of enforcement of environmental regulations can hinder effective forest conservation effort.

Table 2. Weightings of critical drivers contributing to DFD.

Critical Drivers	MIS	R	*W*	Total MIS	Total *W*
Proximate (direct) causes					
Agricultural expansion					
Shifting cultivation	3.53	2	0.21	14.05	0.51
Permanent cultivation	3.50	3	0.19		
Cattle ranching	3.55	1	0.18		
Colonization and transmigration	3.47	4	0.14		
Wood extraction					
Commercial logging	3.11	2	0.17	11.70	0.31
Fuelwood gathering	3.18	1	0.18		
Charcoal production	2.98	3	0.11		
Polewood collection	2.43	4	0.10		
Infrastructure extension					
Transportation networks (roads, highways)	3.47	1	0.18	10.27	0.43
Human settlements	3.34	3	0.14		
Market and service infrastructure	3.46	2	0.15		
Underlying driving forces					
Demographic factors					
Population growth	3.77	1	0.19	10.71	0.42
Migration	3.51	2	0.21		
Urbanization	3.43	3	0.22		

Table 2. *Cont.*

Critical Drivers	MIS	R	*W*	Total MIS	Total *W*
Economic factors					
Market growth and commercialization	3.57	1	0.19	13.66	0.39
Price changes	3.41	2	0.17		
Economic structures and changes	3.32	4	0.16		
Agricultural policies and subsidies	3.36	3	0.14		
Technological factors					
Agricultural technologies and practices	3.10	1	0.16	8.52	0.37
Logging technologies	2.57	3	0.14		
Infrastructure development technologies	2.85	2	0.15		
Policy and institutional factors					
Land tenure and property rights	3.46	1	0.16	10.09	0.33
Governance and political stability	3.41	2	0.13		
Policy frameworks and enforcement	3.22	3	0.12		
Cultural and socio-political factors					
Social conflicts and wars	2.76	3	0.15	8.84	0.29
Attitudes and beliefs towards forests	2.98	2	0.14		
Cultural and social norms	3.10	1	0.17		

NB: MIS = rank, R = rank, *W* = weights.

Next, the FSE analysis probes deeper than just assigning weights to different categories within the [12] framework. It incorporates a concept called 'membership functions level (MFL)' to assess the criticality of various factors contributing to DFD. These membership functions essentially measure how strongly a group of variables aligns with a specific level of importance in driving deforestation. The FSE methodology employs three distinct membership function levels (MFLs): MFL3, MFL2, and MFL1. These levels operate in a hierarchical structure, with MFL3 providing the most granular detail and MFL1 offering the most general overview as shown in Table 3. The 27 drivers are denoted as $d = \{d1, d2, d3, \ldots, d27\}$, following the notation suggested in [37]. The five-point Likert scale ($e = \{1, 2, 3, 4, 5\}$) allows respondents to rate each driver's importance on a spectrum ranging from 1 = very low importance, 2 = low importance, 3 = neutral, 4 = high importance, and 5 = very high importance. Table 3 further illustrates the application of these concepts. For instance, consider the first driver within the first group. The table reveals that respondents rated this driver with varying degrees of importance: 28% rated it 'low' (2), 35% rated it 'neutral' (3), 14% rated it 'high' (4), and 12% rated it 'very high' (5). This distribution of ratings translates to the MFL3 membership function for this specific driver, which can be expressed as (0.00, 0.28, 0.35, 0.14, 0.12), as shown in Table 3. The first value (0.00) represents 'very low importance' (which received no ratings in this case), and the subsequent values correspond to the percentages of respondents who assigned each level of importance on the Likert scale.

The MFL1, representing the overall index of driver criticality, can be determined using Equation (2). After the calculation, the MFL1 can be expressed as (0.00, 0.31, 0.24, 0.26, 0.03), as shown in Table 3.

$$(0.40 \times 0.00 + 0.34 \times 0.00 + 0.26 \times 0.00) = (0.00)$$

$$(0.40 \times 0.29 + 0.34 \times 0.32 + 0.26 \times 0.34) = (0.31)$$

$$(0.40 \times 0.22 + 0.34 \times 0.24 + 0.26 \times 0.28) = (0.34)$$

$$(0.40 \times 0.36 + 0.34 \times 0.31 + 0.26 \times 0.25) = (0.36)$$

$$(0.40 \times 0.08 + 0.34 \times 0.11 + 0.26 \times 0.02) = (0.03)$$

Table 3. Membership function of critical drivers contributing to DFD.

Critical Drivers	MFL 3	MFL2	MFL1
Proximate (direct) causes			
Agricultural expansion			
Shifting cultivation	(0.00, 0.28, 0.35, 0.12, 0.10)	(0.00, 0.29, 0.25, 0.38, 0.08)	(0.00, 0.31, 0.34, 0.36, 0.03)
Permanent cultivation	(0.00, 0.30, 0.33, 0.14, 0.12)		
Cattle ranching	(0.00, 0.27, 0.34, 0.15, 0.01)		
Colonization and transmigration	(0.00, 0.29, 0.32, 0.16, 0.11)		
Wood extraction			
Commercial logging	(0.00, 0.31, 0.30, 0.13, 0.12)	(0.00, 0.31, 0.22, 0.38, 0.09)	
Fuelwood gathering	(0.00, 0.26, 0.34, 0.12, 0.05)		
Charcoal production	(0.00, 0.25, 0.32, 0.15, 0.11)		
Polewood collection	(0.00, 0.28, 0.31, 0.14, 0.14)		
Infrastructure extension			
Transportation networks (roads, highways)	(0.00, 0.32, 0.29, 0.13, 0.14)	(0.00, 0.30, 0.33, 0.42, 0.11)	
Human settlements	(0.00, 0.29, 0.28, 0.14, 0.04)		
Market and service infrastructure	(0.00, 0.27, 0.31, 0.11, 0.13)		
Underlying driving forces			
Demographic factors			
Population growth	(0.00, 0.30, 0.33, 0.12, 0.11)	(0.00, 0.31, 0.33, 0.22, 0.22)	
Migration	(0.00, 0.31, 0.32, 0.11, 0.13)		
Urbanization	(0.00, 0.28, 0.30, 0.14, 0.12		
Economic factors			
Market growth and commercialization	(0.00, 0.33, 0.29, 0.12, 0.14)	(0.00, 0.33, 0.33, 0.37, 0.12)	
Price changes	(0.00, 0.26, 0.34, 0.13, 0.12)		
Economic structures and changes	(0.00, 0.30, 0.28, 0.12, 0.13)		
Agricultural policies and subsidies	(0.00, 0.32, 0.27, 0.15, 0.05)		
Technological factors			
Agricultural technologies and practices	(0.00, 0.29, 0.31, 0.12, 0.17)	(0.00, 0.22, 0.23, 0.22, 0.11)	
Logging technologies	(0.00, 0.34, 0.26, 0.14, 0.13)		
Infrastructure development technologies	(0.00, 0.30, 0.33, 0.13, 0.02)		
Policy and institutional factors			
Land tenure and property rights	(0.00, 0.27, 0.35, 0.13, 0.11)	(0.00, 0.31, 0.34, 0.12, 0.10)	
Governance and political stability	(0.00, 0.31, 0.29, 0.14, 0.11)		
Policy frameworks and enforcement	(0.00, 0.28, 0.34, 0.13, 0.13)		
Cultural and socio-political factors			
Social conflicts and wars	(0.00, 0.29, 0.30, 0.15, 0.10)	(0.00, 0.26, 0.23, 0.12, 0.11)	
Attitudes and beliefs towards forests	(0.00, 0.32, 0.28, 0.12, 0.05)		
Cultural and social norms	(0.00, 0.30, 0.31, 0.14, 0.14)		

Employing Equation (3), the analysis yielded an overall impact score of 3.23 ($0.00 \times 1 + 0.31 \times 2 + 0.34 \times 3 + 0.36 \times 4 + 0.03 \times 5$). Given the Likert scale (1–5, with 3 representing average impact), this score suggests an influence on DFD. While no single driver may be dominant, the combined effect of these factors poses a noteworthy threat to forest ecosystems. Figure 1 provides a diagrammatic representation of the most significant drivers based on the MIS and their respective *W*.

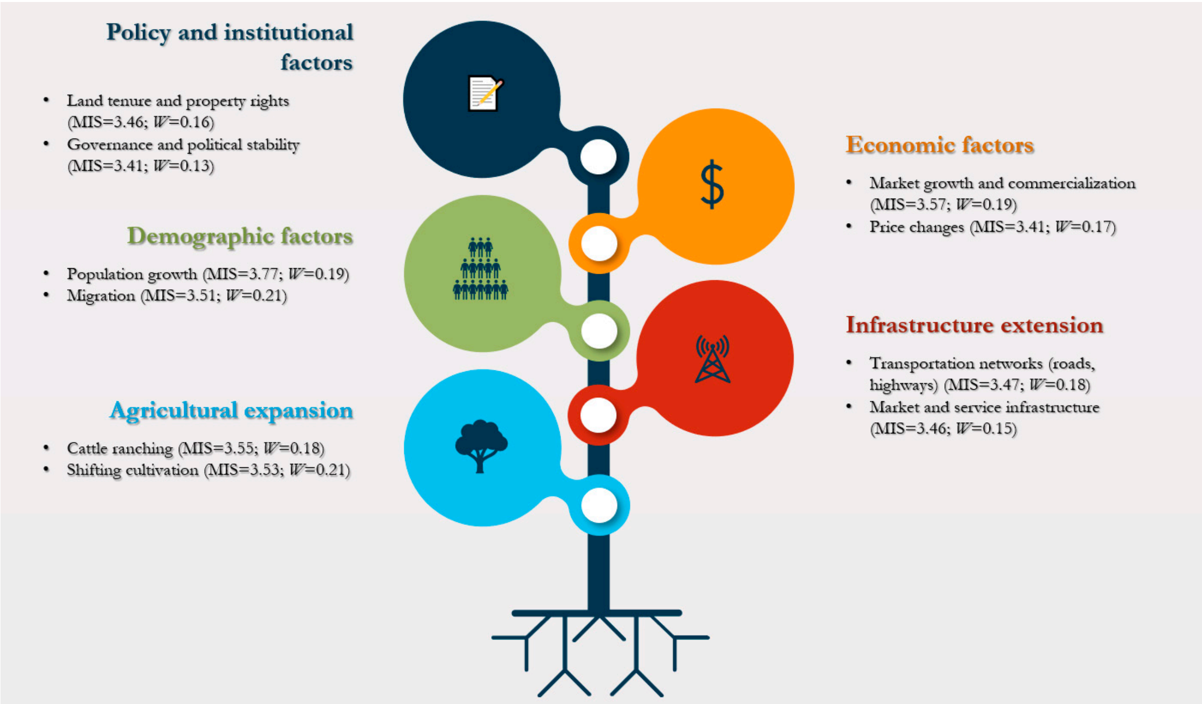

Figure 1. Critical drivers contributing to DFD.

5. Discussion of Results

Findings from this study reveal that of the three proximate and five underlying driving forces from the conceptual framework by [12], deforestation and forest degradation (DFD) is primarily motivated by agricultural expansion and infrastructure extension among the proximate drivers. These findings align with [38], which pointed to agricultural expansion as a critical driver, particularly in regions where there is a high demand for arable land to meet food production needs. According to [25], the conversion of forests into agricultural lands is prevalent in developing countries where subsistence farming is common. This process often leads to significant loss of biodiversity and disruption of ecosystems. The need to produce more food to support growing populations and the push for cash crops such as palm oil, soybeans, and rubber have further accelerated the rate of agricultural expansion, making it a critical factor in DFD [38]. Agricultural activities replace forest cover with monocultures or mixed cropping systems, which not only deplete the soil but also reduce the habitat available for wildlife, leading to ecological imbalances [39]. Infrastructure extension, on the other hand, is another significant proximate driver, as noted by [40]. According to them, the development of roads, urban areas and industrial zones facilitates access to previously remote forested regions, promoting further land conversion for agricultural and commercial purposes. Ref. [22] highlight that infrastructure projects often lead to habitat fragmentation, increased human encroachment and unsustainable exploitation of forest resources. Moreover, the construction of infrastructure, while essential for economic development, poses substantial risks to forest conservation by opening up forests to logging, mining, and agricultural activities [41].

Among the underlying driving forces, demographic factors, economic factors, and policy and institutional factors are the most significant. Demographic factors such as population growth and migration are often intertwined, as increasing populations drive the need for more land and resources, while migration, particularly from rural to urban areas, places additional pressure on forested regions [23,38]. These demographic shifts often lead to the expansion of agricultural activities and the development of infrastructure, further driving DFD. Additionally, as urban areas expand, they encroach on surrounding forested land, leading to habitat fragmentation and increased human–wildlife conflicts [39]. In cases of population booms, there is a heightened demand for housing, which often results in the clearing of forests for residential and commercial purposes. This urban sprawl not only reduces the forest cover but also disrupts ecosystems and reduces biodiversity [25]. Economic factors have also been regarded as significant drivers, especially in developing regions. According to [42], economic growth and increasing market demands for agricultural products and timber often drive expansion into forested areas as countries seek to capitalize on lucrative markets. Moreover, market growth and commercialization stimulate agricultural expansion as farmers respond to higher prices and increased demand for commodities like palm oil, soybeans, and timber products [43]. This expansion frequently leads to the conversion of forests into agricultural land, contributing to DFD. Likewise, fluctuations in prices for agricultural goods and timber can influence land use decisions, encouraging intensified production or deforestation during periods of high prices [12]. In developing regions particularly, where economic growth is often prioritized to alleviate poverty and promote development, the pressure to exploit natural resources, including forests, can be substantial [39]. Policies aimed at stimulating economic growth may inadvertently lead to increased deforestation if environmental considerations are not adequately integrated [25].

Policy and institutional factors, such as land tenure systems, agricultural policies, and environmental regulations, play a critical role in either mitigating or exacerbating DFD. According to [20,44], weak governance, inadequate enforcement of environmental laws, and policies that prioritize agricultural expansion over forest conservation can significantly contribute to DFD. Clear land tenure systems, as highlighted by these studies, can prevent illegal logging and land grabs, ensuring that forest resources are managed responsibly. Conversely, policies that prioritize rapid economic growth without adequate environmental safeguards often lead to deforestation. According to [25], economic development goals can drive the exploitation of natural resources, including forests, to meet increasing demands for agricultural products, timber, and infrastructure development. In such contexts, the balance between economic prosperity and environmental sustainability becomes critical. Thus, addressing policy and institutional drivers requires comprehensive approaches that integrate environmental considerations into development strategies. This includes promoting sustainable land use practices, ensuring equitable land tenure systems, and strengthening enforcement mechanisms for environmental laws [20,45].

Based on the findings of this study, the following recommendations are made:

***Addressing proximate drivers*:**

- ○ Promote sustainable agricultural practices such as cocoa agroforestry, cassava crop rotation, and improved fallows with native trees.
- ○ Explore and encourage alternative livelihoods that reduce pressure on forest lands, such as ecotourism or sustainable forestry practices.
- ○ Implement stricter environmental impact assessments (EIAs) for infrastructure projects to minimize deforestation.
- ○ Prioritize the development of sustainable transportation networks, such as public transportation systems and improved road maintenance, to reduce reliance on new roads through forested areas.
- ○ Encourage the development of green infrastructure that integrates natural elements into urban planning, reducing sprawl and pressure on forest ecosystems.

***Addressing underlying drivers*:**

- ○ Implement family planning initiatives and educational programs to address population growth.
- ○ Encourage urban planning strategies that promote compact and sustainable cities, reducing urban sprawl and its encroachment on forests.

- Promote sustainable agricultural products through certification schemes and consumer education campaigns.
- Encourage responsible infrastructure development practices that minimize environmental impact.
- Explore economic diversification initiatives to reduce dependence on resource extraction and deforestation-driven sectors.
- Strengthen land tenure systems to provide clear ownership rights and discourage illegal logging and land grabs.
- Improve environmental governance by strengthening law enforcement and promoting transparency in environmental decision-making.
- Foster political stability to create an environment conducive to long-term environmental planning and sustainable development.

Findings from this study hold significant implications for recent international efforts to curb tropical forest loss, including initiatives like Reducing Emissions from Deforestation and Forest Degradation (REDD+), The Rainforest Protection Pact, UN-REDD Programme, and National REDD+ Strategy [21]. While these initiatives aim to halt and reverse forest loss, our analysis suggests that drivers like agricultural expansion and infrastructure extension will likely continue to degrade Akure's forests in the coming years. This necessitates a re-examination of the technical approaches employed in these international efforts. For them to be effective, these approaches must be adapted to the specific context of Akure. Additionally, policies should prioritize promoting sustainable agricultural practices. This could involve providing incentives for farmers to adopt land use practices that conserve forest areas. Also, infrastructure development plans should integrate environmental impact assessments to minimize negative consequences on forest ecosystems.

The study also reveals that demographic pressures and economic incentives substantially contribute to deforestation. Curbing deforestation in Akure will likely require addressing underlying demographic factors such as population growth and migration patterns. This finding aligns with the work of [38] who found that population growth, particularly in developing regions, leads to increased demand for land and resources. This demand drives agricultural expansion into forested areas, contributing to deforestation. Similarly, Ref. [25] highlight how economic factors, such as the need to produce more food and the push for cash crops, incentivize deforestation for agricultural purposes. Therefore, policies aimed at controlling population growth and managing migration patterns should be incorporated into broader environmental conservation strategies. The authors of this research opine that economic policies should strive for a balance between development goals and forest conservation. Mechanisms like payment for ecosystem services (PES) can provide financial incentives to local communities for preserving forested areas. Policy and institutional reforms are also critical in light of this study's findings. As highlighted earlier, strengthening land tenure systems can prevent illegal logging and land grabs, ensuring sustainable forest management. Finally, government authorities in Akure must ensure the National REDD+ Strategy is implemented and upheld in both letter and practice.

Financial sustainability remains a critical hurdle for policymakers seeking to curb deforestation and preserve Akure's forests. Countries like Brazil, Guyana, Peru, Tanzania, and Indonesia have successfully secured REDD+ funding through bilateral agreements with Germany, Norway, Japan, and other developed nations [46]. However, Nigeria, and specifically Akure, has struggled to secure similar commitments. This lack of financial support poses a significant challenge. To bridge this gap, policymakers in Akure could explore alternative funding mechanisms, such as public–private partnerships or carbon offset initiatives. Additionally, strengthening their proposals to better align with REDD+ donor priorities could improve their chances of attracting investments. Beyond the challenge of economic viability, another critical issue requiring attention is the underutilization of Akure's forest reserves. While the state boasts 16 reserves, only the Osse and Akure Forest Reserves currently serve as pilot sites, with plans for future expansion. These two reserves have a logging moratorium in place, enforced by a joint task force [47]. However, a more comprehensive strategy is necessary to unlock the full potential of all 16 reserves. This could encompass developing management plans for each reserve, outlining sustainable forestry practices alongside potential revenue-generating activities like eco-tourism or harvesting non-timber forest products (NTFPs). Additionally, investments in infrastructure within the reserves, such as access roads and visitor facilities, could enhance accessibility and attractiveness for sustainable uses. Finally, strengthening enforcement capabilities is crucial to prevent illegal logging and encroachment across all reserves. By addressing both economic viability and reserve underutilization, policymakers in Akure can create a more robust and sustainable approach to deforestation reduction and forest preservation.

Overall, the categorization of the various proximate and underlying driving forces and allowing respondents to prioritize them can be useful for formulating targeted interventions and policy adjustments. A good entry point, for example, could be the development of regional action plans that specifically address the predominant drivers identified in this study. By tailoring strategies to combat agricultural expansion and manage infrastructure development sustainably, policymakers can effectively mitigate the impacts of DFD in Akure and similar regions. Likewise, leveraging the insights from this study can guide the allocation of resources towards initiatives that promote sustainable land use practices and conservation efforts. For instance, integrating ecological considerations into urban planning processes and infrastructure projects can help minimize habitat fragmentation and biodiversity loss associated with DFD. Similarly, investing in education and awareness campaigns targeted at local communities and stakeholders can foster a culture of environmental stewardship and support for conservation initiatives. Also, by fostering dialogue and cooperation among diverse stakeholders, such as local communities, NGOs, private sector entities, and international organizations, policymakers can enhance the effectiveness and sustainability of efforts to preserve forest ecosystems and promote resilience against future environmental challenges.

6. Conclusions

Across both developed and developing countries, the issue of deforestation and forest degradation (DFD) persists as a critical environmental challenge. With climate change exacerbating its impacts, understanding the drivers of DFD becomes increasingly urgent for effective environmental stewardship and sustainable development. This study quantitatively assessed the critical drivers contributing to DFD in Akure, Nigeria, using the [12] conceptual framework of 'proximate causes and underlying driving forces'. To obtain quantitative data, a well-structured questionnaire was developed and disseminated to construction professionals such as architects, engineers, builders, quantity surveyors, and project managers. Findings indicate that DFD is primarily motivated by agricultural expansion (including cattle ranching and shifting cultivation) and infrastructure extension (particularly transportation networks and market and service infrastructure) among the proximate drivers. The Fuzzy Synthetic Evaluation (FSE) analysis also identified demographic, economic, and policy and institutional factors as the most significant underlying drivers. Population growth and migration emerged as the primary drivers within demographic factors, while market growth, commercialization, and price changes were highlighted under economic factors. Furthermore, land tenure, property rights, governance, and political stability were recognized as key policy and institutional factors driving DFD in Akure.

Despite the contributions of this study, a few limitations are acknowledged. Firstly, the study was restricted to the context of Akure and might not be reflective of other cities or regions in Nigeria. Future studies might want to expand their scope to include multiple regions across the country to generalize findings more broadly. Secondly, this study only solicited responses from construction professionals, potentially limiting the perspectives from other stakeholders such as local communities, government officials, and environmental NGOs. Future studies might want to incorporate a more diverse range of participants to obtain a comprehensive understanding of the drivers of DFD. Also, future studies could employ mixed-method approaches to complement the questionnaire-based data collection used in this study. Integrating qualitative methods such as interviews, focus groups, and case studies could provide deeper insights into the socio-cultural, economic, and political dynamics influencing DFD. This approach would enhance the richness and contextual understanding of the drivers identified, offering a more comprehensive basis for effective policy recommendations and interventions. Finally, this study did not conduct statistical tests to assess the significance of the drivers' impacts. Future research could employ inferential statistical techniques to determine the strength and significance of relationships between identified drivers and DFD, thereby enhancing the robustness of the findings.

Author Contributions: Conceptualization, O.S.O. and A.E.O.; Methodology, J.O.A., D.E. and O.M.D.; Software, O.M.D.; Validation, J.O.A., A.E.O., D.E. and O.M.D.; Formal analysis, O.S.O., D.E. and O.M.D.; Investigation, O.S.O., J.O.A., A.E.O., D.E. and O.M.D.; Resources, A.E.O., D.E. and O.M.D.; Data curation, O.S.O., J.O.A., A.E.O. and D.E.; Writing—original draft, O.S.O. and A.E.O.; Writing—review & editing, J.O.A. and O.M.D.; Visualization, J.O.A.; Supervision, A.E.O.; Project administration, D.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Requested information is not available.

Conflicts of Interest: The authors declare no conflict of interest.

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