Climate Action in Ghana

People, Policy, and Circular Solutions for a Resilient Future

Editors

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ISBN: 978-52-945-1

Typesetting: Mrs. Hellen Patsy Sunu
Printing:
Sundel Services, Accra, Ghana
E-mail: wilsundel@yahoo.com
Cellphone: +233-20 7703816

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List of abbreviations

Abbreviation	Meaning
ABM	Adaptation Benefits Mechanism
ACEP	Africa Centre for Energy Policy
ACCESS	Australian Community Climate and Earth System Simulator
ACEN	African Circular Economy Network
ACMAD	African Centre of Meteorological Applications for Development
ACRAP	Accra Compost and Recycling Plant
ADB	Asian Development Bank
ADRiFi	Africa Disaster Risk Financing Programme
AF	Adaptation Fund
AfDB	African Development Bank
AFOLU	Agriculture, Forestry, and Other Land Uses
AI	Artificial Intelligence
ASAP	Adaptation for Smallholder Agriculture Program
ASIF	Avoid, Shift, Improve and Fuel
ATK	Aviation Turbine Kerosene
AU	African Union
BAU	Business As Usual
BoG	Bank of Ghana
CAHOSCC	Committee of African Heads of State and Government on Climate Change
CBA	Community-Based Adaptation
CC DARE	Climate Change and Development – Adapting by Reducing Vulnerability
CCD	Climate Compatible Development
CCET	Centre Collaborating with UNEP on Environmental Technologies
CEAP	The Circular Economy Action Plan
CFSR	Climate Forecast System Reanalysis
CKD	Completely Knocked down
COP	Conference of Parties
COSMO	Consortium for Small-Scale Modelling
COTVET	Council for Technical and Vocational Education and Training
COVID	Coronavirus Disease
CPI	Climate Policy Initiative

Abbreviation	Meaning
CREW	Community Resilience through Early Warning
CWGPCC	CAHOSCC Women and Gender Programme on Climate Change
DFI	Development Finance Institution
EBRD	European Bank for Reconstruction and Development
ECMWF	European Centre for Medium-Range Weather Forecasts
EIB	European Investment Bank
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
ERA	ECMWF Re-Analysis
ESG	Environmental, Social and Governance
ETIP	Energy Transition and Investment Plan
EU	European Union
EV	Electric Vehicle
EWS	Early Warning System
FAO	Food and Agriculture Organization
GCF	Green Climate Fund
GCR	Ghana Carbon Registry
GDP	Gross Domestic Product
GES	Ghana Education Service
GHG	Green House Gas
GIPC	Ghana Investment Promotion Centre
GJ	Gigajoules
GMet	Ghana Meteorological Agency
GoG	Government of Ghana
GRA	Ghana Revenue Authority
GRB	Gender Responsive Budgeting
GSA	Ghana Standards Authority
GSGDA	Ghana Shared Growth and Development Agenda
GSS	Ghana Statistical Service
GT	Green Transport
GW	Gigawatts
HBM	Health Belief Model
HDPE	High-Density Polyethylene

Abbreviation	**Meaning**
IBRD	International Bank for Reconstruction and Development
ICEs	Internal Combustion Engines
ICMA	International Capital Market Association
ICON	Icosahedral Nonhydrostatic
IDA	International Development Association
IDB	Inter-American Development Bank
IDFC	International Development Finance Club
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual Property Rights
IRECOP	Integrated Recycling and Compost Plant
IRNSS	Indian Regional Navigation Satellite System
ISRO	Indian Space Research Organization
ISWM	Integrated Solid Waste Management
KPI	Key Performance Indicators
KSDP	Keta Sea Defence Project
LCA	Life Cycle Assessment
LDCF	Least Developed Countries Fund
LDPE	Low-Density Polyethylene
LEAP	Low Emissions Analysis Platform
LLDPE	Linear Low-Density Polyethylene
LPG	Liquified Petroleum Gas
LULUCF	Land Use, Land-Use Change, and Forestry
MA	Minimalist Approach
MBT	Mechanical biological treatment
MDTF	Multi-Donor Trust Fund
MEQ	Management of Environmental Quality
MEST	Ministry of the Environment, Science and Technology
MESTI	Ministry of the Environment, Science, Technology and Innovation
MLGRD	Ministry of Local Government and Rural Development
MMDA	Metropolitan, Municipal and District Assemblies
MoFA	Ministry of Food and Agriculture

Abbreviation	**Meaning**
MoGCSP	Ministry of Gender, Children and Social Protection
MoT	Ministry of Transport
MSW	Municipal Solid Waste
MTPD	Metric Tons Per Day
MW	Megawatt
NADMO	National Disaster Management Organization
NAPs	National Adaptation Plans
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organisation
NCCE	National Commission for Civic Education
NCCP	National Climate Change Policy
NDC	Nationally Determined Contributions
NGO	Non-Governmental Organisation
NMT	Non-Motorised Transport
NOAA	National Oceanic and Atmospheric Administration
NRDC	Natural Resources Defence Council
NSF	National Science Foundation
NWM	Numerical Wave Models
NWP	Numerical Weather Prediction
OEC	Observatory of Economic Complexity
PCTW	Post-Consumer Textile Waste
PET	Polyethylene terephthalate
PP	Polypropylene
PPCR	Pilot Program for Climate Resilience
PPP	Public-Private Partnerships
PTCW	Post-consumer Textile Waste
PV	Photovoltaic
RDF	Refuse-Derived Fuel
REDD	Reducing Emissions from Deforestation and Forest Degradation
RESCONREC	Resources, Conservation and Recycling
RFID	Radio Frequency Identification
RSER	Renewable and Sustainable Energy Reviews
SAIDI	System Average Interruption Duration Index

Abbreviation	Meaning
SAIFI	System Average Interruption Frequency Index
SCCF	Special Climate Change Fund
SDGs	Sustainable Development Goals
SIGA	State Interests and Governance Authority
SME	Small and Medium-scale Enterprises
SSA	Sub-Saharan African
STC	State Transport Corporation
SWAN	Simulating WAves Nearshore
TB	Terabyte
TPD	Tons Per Day
TRL	Technology Readiness Level
TVET	Technical and Vocational Education and Training
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	United States Dollar
WAM	Wave Model
WBG	World Bank Group
WHO	World Health Organisation
WMD	Waste Management Department

Foreword

I had never lived in Africa before. Today, as the Secretary General of the Climate Vulnerable Forum, which has its headquarters in Accra, this is home, and I love it here. The people are so friendly and hospitable, the food is good and the music amazing. As my days pass engaged in work, I am convinced that this is the African Century. The continent has many challenges arising from its brutal encounter with slavery and colonisation, and its history of contemporary governance issues is well-documented. However, Africa continues to hold immense promise, buoyed by considerable investment opportunities and resources, chief of which are its people, all of which can propel the continent to prosperity.

Africa is, however, one of the world's most climate-vulnerable continents. Though it contributes the least to global greenhouse gas emissions, it faces some of the most severe and far-reaching climate impacts. The Notre Dame Global Adaptation Initiative (ND-GAIN) Index has consistently shown many African countries rank among the least prepared to manage climate shocks. The reasons are layered: high exposure to climate hazards, dependence on climate-sensitive sectors like agriculture, inadequate infrastructure, limited adaptive capacity, and underinvestment in resilience-building. To this list, I would add the high cost of capital as well.

Increased droughts, unpredictable rainfall, rising sea levels, and extreme heat are already reshaping lives and livelihoods across the continent. Urban flooding, desertification, crop failures, and energy poverty are not theoretical risks but daily realities. These vulnerabilities make Africa's role in climate action not only necessary but urgent.

The Climate Vulnerable Forum (CVF), a coalition of nations highly exposed to climate change, has long emphasized two central pillars of climate justice, both standing on the principle of equity: first, that vulnerable countries have the right to develop through low-carbon, climate-resilient pathways; and second, that they must be supported, mainly by countries historically responsible for the climate crisis, including national and multilateral institutions they oversee, through meaningful global partnerships and equitable financing. The CVF has advocated for accelerated global action on mitigation to protect those most at risk, fair and accessible climate finance, and the recognition of loss and damage. We have championed tools like the CVF's Climate Prosperity Plans—strategic investment programs that chart a path toward low-emission development while unlocking economic and social dividends for vulnerable economies.

This book speaks directly to that vision. It brings together research and practice from Ghana, a country that reflects many of Africa's development and climate challenges, and demonstrates how local solutions can support global objectives. The contributions cut across key policy areas: clean energy, coastal resilience, sustainable waste management, data-driven adaptation strategies, and climate finance. These are the issues the CVF has persistently raised on global platforms, ensuring that vulnerable countries are not passive recipients of aid but active architects of their own futures.

This book blends scientific evidence with traditional ecological knowledge. This approach reinforces what many in the CVF already understand: that resilience is not only built in labs or boardrooms but in neighbourhoods and communities, in the fields and on the streets, through lived experiences, cultural systems, and indigenous wisdom.

While the examples in the book are Ghana-specific, the themes are continental in relevance. From climate-smart agriculture to gender-responsive policy, from renewable energy deployment to the circular economy, the chapters highlight issues that many African countries are grappling with. The recommendations are practical, grounded, and mindful of context. They signal a readiness not only to identify problems but to act with a greater sense of urgency and opportunity.

I applaud the Africa Centre for Energy Policy (ACEP) for leading this groundbreaking initiative. Over the years, ACEP has built a strong reputation for data-driven policy advocacy and pragmatic thought leadership. This publication is another step in advancing African voices and perspectives in the global climate conversation. It represents the kind of leadership, ambition, and evidence-based action that vulnerable nations should champion.

It is my sincere hope that this book inspires collaboration, implementation, and continuity. Let it be a reference for climate professionals, a guide for policymakers, and a prompt for more rigorous research and dialogue. I also hope to see additional volumes that explore even more areas, from climate finance tracking to nature-based solutions, from youth-led innovation to loss and damage mechanisms.

Climate action is a shared responsibility, but for vulnerable countries, it is also a lifeline—and an opportunity to build a better, more equitable future for all.

H.E. Mohamed Nasheed
Secretary-General, Climate Vulnerable Forum
Former President of the Republic of Maldives

Preface

It is with great pride that I introduce *"Climate Action in Ghana: People, Policy, and Circular Solutions for a Resilient Future"*—the first edited volume of its kind by the Africa Centre for Energy Policy (ACEP). This publication marks a significant milestone in our organisation's journey to deepen the discourse on climate action in Ghana and contribute meaningfully to the global climate agenda through locally grounded perspectives.

At ACEP, we recognise that addressing the climate crisis requires more than high-level commitments; it demands inclusive, evidence-based, and context-specific solutions. This book is born out of our commitment to galvanise multi-stakeholder efforts by drawing together research evidence and practical insights from academia, civil society, and industry professionals. Our goal is to bridge the gap between knowledge and action, creating a platform that promotes collaboration, learning, and shared responsibility.

A compelling feature of this volume is its deliberate blend of scientific analysis and traditional ecological knowledge. This fusion reflects our belief that climate solutions must be both innovative and rooted in the lived experiences of communities. Indigenous wisdom, passed down through generations, often offers time-tested approaches to environmental stewardship that are increasingly relevant in today's climate conversations.

Beyond this, the book highlights the transformative potential of technology and data-driven approaches in building climate resilience. From digital tools that enhance climate monitoring to innovations in clean energy and mobility, these contributions explore how Ghana can harness modern systems to address urgent environmental challenges. The role of policy is also foregrounded, with chapters offering thoughtful discussions on governance structures, regulatory frameworks, and strategic interventions to drive sustainable outcomes.

Financing climate action is a recurring theme throughout the book, and rightly so. Without robust, targeted, and sustained financing, many promising interventions will remain unrealised. The chapters underscore the importance of mobilising both public and private capital, while proposing models that can unlock greater investment for climate resilience and low-carbon development.

Each chapter is designed to serve a broad audience including academics, policymakers, and industry actors alike. More importantly, the contributions are not only analytical but action-oriented. They each provide clear recommendations, outlining the roles and responsibilities of various stakeholders in Ghana's climate transition.

Ultimately, this book is a call to action. Climate change is a shared challenge that requires our collective commitment and coordinated effort. We hope that this publication will inspire renewed urgency, foster collaboration, and serve as a valuable resource for anyone committed to building a sustainable and climate-resilient Ghana.

Let us act, together.

Benjamin Boakye
Executive Director
Africa Centre for Energy Policy (ACEP)

Acknowledgements

We acknowledge the generous support of Oxfam in Ghana, whose funding made this publication possible. We are grateful for their continued collaboration and longstanding support, which has enabled the Africa Centre for Energy Policy (ACEP) to contribute to climate action efforts in Ghana and beyond.

We extend our sincere thanks to the editors of this volume—Prof. Simon Bawakyillenuo of the Institute of Statistical, Social and Economic Research (ISSER), University of Ghana; Dr. Yaw Akyampon Boakye-Ansah of the University of Energy and Natural Resources (UENR); and Dr. Charles Gyamfi Ofori, Policy Lead for Climate Change and Energy Transition at ACEP. Each of them reviewed the chapters thoroughly and provided valuable feedback to the authors, helping to improve the overall quality of the work.

We also thank Ms. Gifty Asantewaa Nkrumah, who coordinated the project and ensured its smooth execution.

Our appreciation goes to all the authors who contributed chapters to this book. Their work forms the foundation of this publication, and we are thankful for their timely and thoughtful submissions.

Finally, we acknowledge all others who contributed in various ways to the development and completion of this book. Your support is appreciated.

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1

An Introductory note on Ghana's Climate Action

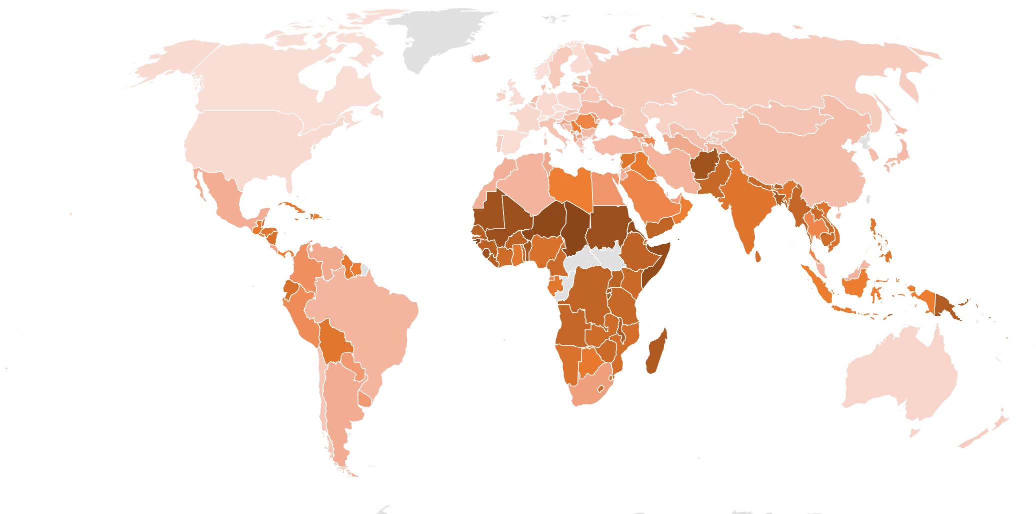
Gifty Asantewaa Nkrumah

Climate change remains an existential threat to the social, economic, and environmental well-being of populations worldwide. This threat is more acutely felt in Africa, where countries that have contributed relatively little to global greenhouse gas (GHG) emissions bear a disproportionate share of the consequences. As of 2021, Africa accounted for about 9% of global GHG emissions,[1] yet it remains among the world's most vulnerable to climate impacts. This pattern is illustrated in the Climate Vulnerability Index developed by the Notre Dame Global Adaptation Initiative (2024), where many African countries appear among the most at-risk globally (See Figure 1).

This vulnerability arises from a strong reliance on climate-sensitive sectors like agriculture and water resources, compounded by limited access to financial and technological resources, as well as existing socio-economic challenges such as poverty and weak institutional capacity. Climate impacts are evident in extreme weather events such as droughts, floods, coastal land loss among others, which

[1] Historical Greenhouse Gas Emissions from Climate Watch.

Figure 1: Climate vulnerabilities across the globe



Source: Notre Dame Global Adaptation Initiative

together disrupt livelihoods, compromise public health, increase cost of rehabilitation and further undermine socio-economic stability (NOAA, 2025; USGRP, 2017). Vulnerable communities, particularly those with limited adaptive capacity, are at a greater risk. As this book will explore, addressing these challenges demands context-specific solutions, especially in countries like Ghana, where climate resilience is critical for sustainable development.

Like many African countries, Ghana faces significant climate-related challenges that threaten its environment and economy. According to the World Bank, average temperatures in Ghana have risen by approximately 1°C since the 1960s, intensifying climate-related risks nationwide (World Bank, 2021). These rising temperatures have contributed to various severe impacts, including prolonged droughts in the northern regions, frequent flooding in urban centres, and accelerating coastal erosion, these situations worsened by the deforestation practices and building in swampy areas among other environmentally unfriendly practices. As a result, critical infrastructure, hydropower generation, food security, and the livelihoods of coastal and agricultural communities are increasingly under threat. This growing exposure to climate hazards is reflected in Ghana's global vulnerability ranking, where the country places 109th out of 187 countries (ND-GAIN, 2024).

In light of this stark reality, urgent and decisive climate action is imperative for Ghana's survival and long-term prosperity. Effective climate action must prioritise both mitigation and adaptation efforts. Mitigation efforts seek to reduce greenhouse gas emissions and slow the pace of global warming, not only to protect present generations but also to safeguard the future generations. Adaptation, meanwhile, involves strengthening the resilience of societies and ecosystems to withstand current and anticipated climate impact, thereby reducing exposure to and impact of risks and limiting potential losses.

The urgency of climate action has fuelled growing interest in developing sustainable and inclusive strategies for cultivating greener economies. Governments, businesses, and civil society increasingly prioritise renewable energy, climate-smart agriculture, circular economy models, and nature-based solutions to build resilience and reduce carbon footprints. In line with these global efforts, Ghana has made several key commitments to climate action. These include its Nationally Determined Contributions (NDCs) under the Paris Agreement and a range of national policies aligned with the agreement's objectives. Notable among these are the National Climate Policy, the National Adaptation Plan, the Energy Transition Framework, and the National Electric Vehicle Policy.

However, significant potential for growth remains as efforts to combat climate change continue. Challenges such as limited financial resources, technological deficits, and governance limitations persist, which impede mitigation and adaptation efforts. The financial gap, for example, is highlighted by an analysis of climate finance flows in Ghana, which tracked an annual average of US$ 830 million in 2019 and 2020, a mere 5%-9% of the estimated investment required (Climate Policy Institute, 2023). This situation emphasises the importance of designing practical and impactful technological solutions achievable within the current financial, governance and policy constraints and addressing the underlying barriers impeding progress under these climate challenges.

The pervasive impact of climate change necessitates a multifaceted response encompassing a variety of solutions and the active engagement of diverse stakeholders, including the academic and research community, policymakers, the private sector, Civil Society, local governance actors and the media. Climate action demands a consideration of diverse perspectives and approaches, encompassing traditional, modern, and hybrid methodologies. Such an inclusive approach is crucial to generating holistic, realistic and contextually relevant solutions. This book is grounded in that understanding. Its core objective is to curate practical, localised, and inclusive solutions that drive effective climate action in Ghana.

This book is structured into four thematic sections, beginning with grounded, community-level perspectives and gradually expanding toward broader systemic and technological approaches. The first section, **Traditional Knowledge and Community-Based Approaches,** lays the foundation by exploring locally relevant strategies within Ghanaian communities, emphasising integrating traditional ecological knowledge with scientific methods. It features two case studies: one from a coastal municipality demonstrating how Indigenous knowledge can be woven into scientific approaches to climate adaptation, and the other examining the intersection of gender, religion, and informal economies in shaping climate change communication. These chapters highlight the barriers and opportunities in leveraging culturally appropriate, community-driven strategies to build resilience and enhance climate literacy.

This book further transitions into the **Circular Economy and Waste Management** section, where climate vulnerability meets opportunity. The section traces the journey from waste as a problem to waste as a resource. The chapters highlight how circular economy principles and effective waste systems are central to reducing GHG emissions and enhancing adaptive capacity. The former chapter addresses the challenges of urban sanitation while the latter interrogates the dynamics of the informal recycling sector to the environmental costs of Ghana’s fast fashion culture. This section explores how rethinking material use and value chains can generate both environmental and economic benefits.

The third section, **Climate Policy, Sustainable Financing, and Business Models**, explores the critical enablers for climate action. This section initially interrogates current climate policy frameworks, financing structures, and business models, offering innovative ideas to transform long-standing concepts into practical solutions for Ghana’s climate agenda. Further, it advocates for a fundamental shift in governance, prioritising forward-thinking policies that facilitate impactful climate solutions.

The concluding section of the book focuses on **Technological Innovations and Data-Driven Solutions** with the potential to scale up climate resilience and decarbonisation efforts. The chapters describe advanced early warning systems designed to safeguard coastal communities, practical strategies for solar photovoltaic adoption and transport decarbonisation. This section therefore offers a vision of climate-smart infrastructure and demonstrates that Ghana's climate future can be proactively shaped through informed policy decisions, and strategic investment in data acquisition.

Together, these contributions present a compelling, intersectional, and solution-oriented narrative. The book moves beyond diagnostics to offer pathways – rooted in local realities, informed by data, and driven by equity – for how Ghana can build resilience and thrive in a changing climate.

References

Climate Policy Initiative. (2023, December 18). *Climate finance in Ghana*. https://www.climatepolicyinitiative.org/publication/climate-finance-in-ghana/

Climate Risk Profile: Ghana. (2021). The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15857-WB_Ghana%20Country%20Profile-WEB.pdf

National Oceanic and Atmospheric Administration. (2025, April 2). *Climate change impacts*. https://www.noaa.gov/education/resource-collections/climate/climate-change-impacts

NOAA National Centres for Environmental Information. (2025, April). *Climate at a glance: Global time series*. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series

Notre Dame Global Adaptation Initiative. (2024, August). *Country index*. Retrieved April 16, 2025, from https://gain.nd.edu/our-work/country-index/

U.S. Global Change Research Program (USGCRP). (2017). *Climate science special report: Fourth National Climate Assessment, Volume I* (D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, & T. K. Maycock, Eds.). https://doi.org/10.7930/J0J964J6

Traditional Knowledge and Community-Based Approaches

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Evaluating the Comprehension of Climate Change Communication Among Market Women in Ghana

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Abstract

Climate change represents a global challenge with far-reaching implications for communities and ecosystems, with particular emphasis on women. However, women have been perceived to lack critical knowledge about climate change and may engage in activities that worsen its effects. Drawing on the Health Belief Model, this study utilises a qualitative methodology to critically examine market women's awareness and conceptualisation of climate change and the efficacy of existing communication strategies. It employs a case study of one of the largest markets in Ghana. Convenience sampling was used to select 25 participants, and interviews were used to gather data. Content and cross-sectional analytical approaches were utilised for the analyses. The findings revealed the limited knowledge of participants of climate change and the biblical underpinnings of participants' conceptualisation, perceptions, and ways of mitigating climate change. We conclude that there will be limited achievement in climate change mitigation and adoption without key emphasis on the roles of religion and the media. There is also the need for effective ways of communication to enhance women's understanding of climate change mitigation and adoption. The study also proposes communication strategies such as clear and concise language, storytelling and narratives, visual aids including videos and images, social media, mobile games and apps and arts-based communication.

Keywords: Climate Change, mitigation and adaptation, Market Women**,** Communication strategies**,** Health Belief Model

Introduction

Climate change represents a global challenge with far-reaching implications for communities and ecosystems. Some negative impacts include flooding, droughts, increased extreme weather conditions, heat waves and gradual changes, such as biodiversity loss or a reduction in the groundwater level. Indirect effects are also associated with changes in local food productivity and water and vector-borne diseases. These affect poverty reduction and food security (Jalloh *et al*., 2013; NASA, 2022). While all people are exposed to the dangers of climate change, women have been argued to be more vulnerable and susceptible to experiencing more harmful effects (Bob & Babugura, 2014; Owusu *et al*., 2019).

Extant research has also revealed that women have limited knowledge about climate change compared to males (Ali *et al*., 2021; Bede-Ojimadu and Orisakwe, 2020; Owusu *et al.*, 2019). Several empirical studies have highlighted reasons underlying women's limited knowledge of climate change awareness and related issues. Most women, particularly in low-income countries, often face restrictions in accessing climate-related information due to existing social and economic inequalities. In many communities, traditional roles mean women have limited participation in decision-making and access to educational resources, which restricts their ability to understand climate issues compared to men (UN Women, 2023).

Women in agriculture, including market women, are particularly susceptible to the impacts of climate change due to their heavy reliance on natural resources and limited access to adaptive resources (FAO, 2018). The magnitude of the adverse effects of climate change is such that it could gradually but firmly erode gains made toward gender equality (Owusu *et al.*, 2019). Additionally, women's activities can significantly impact climate change and people's health. For example, consistent exposure to wood smoke has been linked to respiratory diseases, including acute respiratory illness, lung cancer and impaired lung functions, which have been identified as major causes of disability and premature death in women (Ali *et al*., Bede-Ojimadu and Orisakwe, 2020). Although there have been some contestations, 'wood emits more carbon dioxide per kilowatt-hour than coal – and far more than other fossil fuels.' (Sterman *et al*. 2022, p. 128).

Subsequently, much research and strategies have been done to enhance awareness and mitigate the negative impact of climate change. However, these studies have mainly focused on farmers (e.g., Antwi-Agyei, 2021; Assan *et al*., 2018; Wrigley-Asante, 2019). Nevertheless, a significant group in the agriculture and food value chain is the market women. With their pivotal roles in commerce and community life, market women represent a unique lens through which one can explore the dynamics of climate change awareness and comprehension at the grassroots level. However, there is a dearth of studies exploring market women's awareness, understanding, and perception of climate change. The limited research negatively affects the development of targeted and effective communication strategies to enhance sustainable practices (Amoako & Agyei-Ohemeng, 2016; Mensah & Acheampong, 2017; Adu-Gyamfi & Owusu-Ansah, 2018; Darkwah & Agyeman, 2020).

Building resilient communities and raising linguistic and communicative knowledge on climate change among marginalised groups like market women is equally in line with the global demand for inclusive and sustainable development (UNDP, 2015). This chapter presents a study that examines climate change knowledge, comprehension and strategies for mitigation and adaptation among market women in Techiman. It also presents the communication channels used to convey climate change information to market women in Ghana and their effectiveness. We recommend effective communicative strategies to enhance coping and adaptation to the changing climate.

The chapter is structured in six sections after the introduction. Following the introduction, the second section reviews relevant literature, the third presents the methodology, and the fourth presents the findings and discussions. The fifth and sixth chapters present the conclusions and recommendations, respectively.

Literature Review

Climate change is a global phenomenon marked by long-term alterations in temperature, precipitation, and atmospheric conditions, driven by both natural and human factors, particularly greenhouse gas emissions (Abbass *et al*., 2022; IPCC, 2023). It transcends geographical boundaries, affecting ecosystems and communities worldwide (Urry, 2015). While some perceive it as divine intervention or a sign of biblical prophecies (Golo and Yaro, 2013), scientific consensus identifies human activities, including unsustainable energy use, deforestation, and fossil fuel exploitation, as the primary drivers (IPCC, 2013; Noya *et al*., 2019). This trend significantly impacts the Earth's climate systems and global warming, with surface temperatures already 1.1°C higher than pre-industrial levels (IPCC, 2023).

The impacts of climate change are vast and multifaceted, affecting living organisms, ecosystems, and human systems globally (Noya *et al*., 2019). Rising sea levels, extreme weather events, and declining agricultural productivity threaten food security and intensify poverty and inequality, particularly among vulnerable populations (Jalloh *et al*., 2013; Abbass *et al*., 2022). Climate variations contribute to the spread of vector-borne diseases and antimicrobial resistance, with flooding and extreme weather events facilitating the dissemination of resistant pathogens through water, soil, and air (Asweto and Onyango, 2023; Magnano *et al*., 2023; Salgueiro *et al*., 2024). Mental health challenges linked to trauma from extreme events and loss of livelihoods further compound the human cost of climate change (Palinkas and Wong, 2020). Additionally, the tourism industry faces disruptions as environmental degradation diminishes destination appeal and alters tourism flows, reducing economic value and visitor well-being (Sifolo and Henama, 2017; Gomez-Martins, 2014).

Climate change also exacerbates societal inequalities, disproportionately affecting the poor and marginalised groups such as women and indigenous communities (FAO, 2014). Limited access to infrastructure, adaptation opportunities, and financial resources compounds their vulnerability. Extreme weather events and natural disasters cause disproportionate asset losses among the poor, as seen during Ethiopia's 1999–2000 drought, where the poorest lost 60–80% of their assets, compared to just 6% among the wealthiest (Hallegatte and Rozenberg, 2017). These cascading impacts, including poverty, morbidity, and mental health challenges, highlight the urgent need for equitable climate adaptation strategies to reduce vulnerability and address the systemic challenges posed by climate change (FAO, 2019; Ali *et al*., 2021; Bede-Ojimadu and Orisakwe, 2020).

Market Women's Activities and Environmental Impact

Due to their unique community roles, women can be key agents in combating climate change. They often play crucial roles in managing natural resources, agriculture, and household energy consumption, which positions them well to drive climate adaptation and mitigation efforts (UN Women, 2018). On the other hand, socioeconomic factors, including poverty, frequently enhance the vulnerability of women, particularly in developing nations (Owusu *et al.,* 2019; Akponikpe *et al*., 2019). Owusu *et al*. (2019) revealed in their study comprising women in some slum areas in Ghana that while climate change poses serious environmental hazards to all individuals, their perceptions and knowledge of them are differentiated by gender, age, educational status, and place-based variables.

The agriculture sector has a complex value chain spanning input companies, farmers, traders, food companies and retailers, all of whom are important and must ultimately be involved to ensure a sustainable environment. Consequently, the activities of traders and market women are key to climate action. While the economic contributions of market women are significant to national economic growth, their activities may unintentionally contribute to climate change through energy consumption, waste generation, and unsustainable agricultural practices (Owusu *et al*., 2019; FAO, 2016).

The expansion of market activities is often associated with rapid urbanisation, which increases energy consumption and greenhouse gas emissions (IPCC, 2014). Urban markets' heightened infrastructure, transportation, and energy demand contribute to environmental stress. Understanding the scale and nature of these emissions is crucial for developing sustainable urbanisation strategies.

In market settings, particularly in informal markets, traditional cooking practices often involving open fires contribute to air pollution. The combustion of biomass for cooking releases pollutants that degrade air quality and have implications for human health and climate change (IEA, 2019). Understanding these dynamics is essential for designing interventions that promote cleaner cooking technologies and reduce environmental impact.

While market activities drive economic development, the literature highlights the necessity of adopting sustainable practices to mitigate environmental consequences. Integrating eco-friendly technologies, promoting sustainable waste management, and encouraging responsible agricultural practices are identified as pathways toward achieving a balance between economic growth and environmental sustainability (IPCC, 2014; Owusu *et al*., 2019).

Notably, rapid urbanisation linked to market expansion can increase energy consumption and greenhouse gas emissions (IPCC, 2014). Disposal of organic and non-organic waste generated by market activities, including packaging materials and food waste, may contribute to environmental degradation and emissions (Owusu *et al*., 2019). Additionally, traditional cooking methods for food preparation, such as open fires, can release pollutants that contribute to air quality deterioration and climate change (IEA, 2019).

A significant body of literature emphasises the vulnerability of women in developing countries to the impacts of climate change (Akponikpe *et al*., 2019). Socioeconomic factors, including limited access to resources and decision-making power, often exacerbate women's challenges in adapting to changing environmental conditions. The relevance of this vulnerability is underscored by the pivotal roles that women, particularly market women, play in local economies (Adger *et al*., 2007; Akponikpe *et al*., 2019; Owusu *et al*., 2019).

Cultural norms and societal expectations also significantly shape women's vulnerability to climate change impacts. Traditional gender roles may confine women to specific work sectors and limit their mobility, hindering their ability to adapt to environmental changes effectively (Akponikpe *et al*., 2019). Additionally, women's responsibilities for caregiving and household activities can increase their exposure to climate-related risks, particularly when these tasks become more arduous due to environmental stressors.

Coping and Adaptation Strategies

Adaptation and mitigation are two main strategies for addressing climate change (Gomez-Martins, 2014). Adaptation is “adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities” (IPCC, 2007; p. 6). It involves monitoring and anticipating change and undertaking actions to avoid negative consequences or take advantage of the potential benefits of those changes. Adaptation to adverse impacts of climate change is imperative because failure to adapt could lead to dire consequences such as loss of livelihood, social conflicts, and displacement, and even death. Adaptation measures are meant to reduce individuals' vulnerabilities to adverse impacts of climate change while ensuring sustainability. Effective adaptation among farmers, for instance, requires changes in processes, practices, and structures to achieve sustainable development.

Adapting to climate change involves a range of strategies, including policy and management interventions to reduce vulnerability, manage risks, and build resilience in ecological and production systems (McEvoy *et al*., 2013). Effective climate policies, when paired with social protection measures, can benefit people with low incomes by strengthening scalable, well-targeted safety nets and fostering community-led initiatives, such as building solar panels or sustainable farming systems, which promote ownership and commitment (Hallegatte and Rozenberg, 2017; Hügel and Davies, 2020). Cooperatives also play a critical role in reducing vulnerability, particularly among rural populations, by enhancing coherence and coordination, aligning with frameworks like the Paris Agreement and the Sendai Framework (Lafont *et al*., 2023; FAO, 2019). Migration is a coping mechanism in areas experiencing severe climate impacts, such as Kenya and Ethiopia, where it mitigates risks from rangeland degradation and food insecurity (Filho *et al*., 2023; Berlemann & Steinhardt, 2017).

Communication channels are crucial in conveying climate change information to diverse audiences. The effectiveness of communication channels in reaching and engaging specific demographic groups, such as market women, is a critical consideration (Ostrom, 2009). According to Darkwah and Agyeman (2020), misconceptions and a lack of comprehensive knowledge about climate change hinder effective adaptation strategies. The role of accessible and culturally sensitive communication strategies in enhancing understanding cannot be underestimated (Amoako and Agyei-Ohemeng, 2016).

A comprehensive approach to climate change communication involves utilising various channels to reach different demographic groups (Ostrom, 2009). The literature emphasises the importance of employing a mix of traditional and modern communication channels to ensure broad coverage and accessibility, acknowledging the diverse preferences and information-seeking behaviours of different audience segments.

Theoretical Framework - The Health Belief Model

The Health Belief Model (HBM) was traditionally used to explain and predict health behaviours and can be applied to environmental behaviours by treating climate change as a health threat that requires preventive action (Griffin, 2012; Scarinci *et al*., 2012). The components of the HBM are perceived susceptibility, perceived severity, perceived benefits, perceived barriers, cues of action and self-efficacy (Champion & Skinner, 2008; Rosenstock, 1974).

Perceived susceptibility refers to how vulnerable individuals or communities feel about the effects of climate change. It addresses, for instance, the extent to which people believe that they or their community are at risk from the effects of climate change. Perceived severity concerns individuals' perception of the seriousness of climate change's impacts. Thus, it identifies whether individuals believe climate change's consequences are severe enough to demand action. Perceived benefits focus on the perceived advantages of taking action to mitigate climate change. For instance, it addresses whether people believe adopting renewable energy, reducing carbon footprint, or supporting climate policies will lead to positive outcomes like improved public health, economic savings, or environmental protection.

Perceived barriers focus on obstacles or costs associated with acting. It measures financial, social, or logistical challenges that might prevent individuals from engaging in climate change mitigation behaviours. For example, the cost of installing solar panels or the inconvenience of reducing car usage. Cues to action refer to the triggers that prompt individuals to act. In the context of climate change, cues could include media coverage, extreme weather events, public health warnings, or campaigns that raise awareness about the importance of reducing carbon emissions. Self-efficacy points to individuals' confidence in their ability to take effective action. It addresses individuals' belief in their capacity to change their behaviour, contributing to climate action.

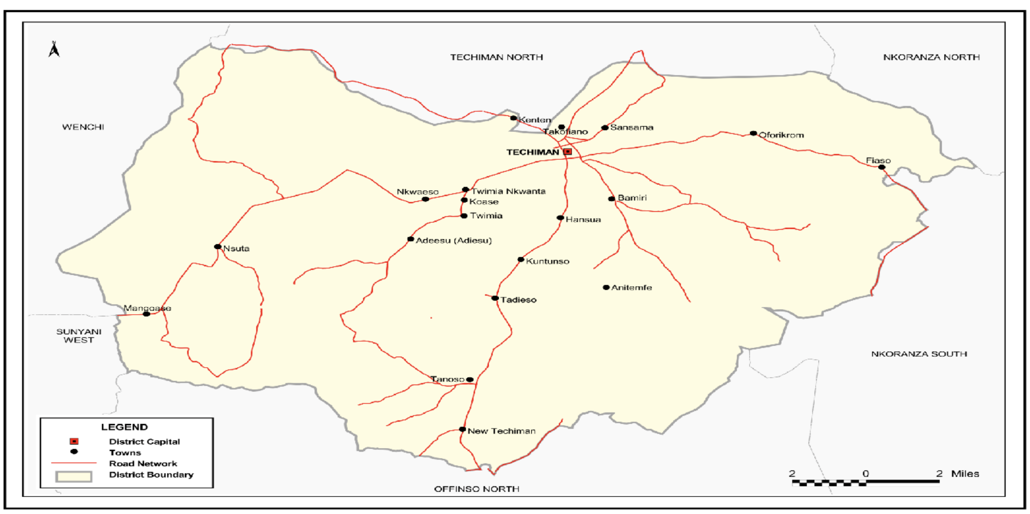
The model can help identify which factors most strongly influence individuals' willingness to engage in climate-friendly behaviours and what might be done to overcome barriers. This HBM could provide valuable insights into how to effectively promote climate change mitigation efforts by addressing the psychological and social factors that influence behaviour.

Methodology

This study employed a qualitative approach to delve into the lived experiences of market women, offering deep insights into their perceptions and experiences of climate change and communication. It allowed participants to express their feelings, understandings and perceptions about the conceptualisation and rationalisation of climate change, the communication strategies, the challenges of communicating climate-related issues and how they are being addressed. One of the greatest strengths of qualitative research is its ability to generate richness and depth of explorations and descriptions (Myers and Avison, 2002) and to capture the complex, nuanced, and context-specific dimensions of this multifaceted process.

The research was conducted in the Techiman Market in the Bono East Region of Ghana. Techiman Market is one of the country's largest and most diverse traditional markets, attracting traders and buyers from various regions. This setting provides a rich context for capturing multiple market activities and contextual elements, ensuring that the findings reflect the diverse experiences and practices of market women. The focus on Techiman Market allows for in-depth insights into the specific challenges and opportunities market women face in this significant commercial hub (Marshall & Rossman, 2016).

Figure 1: Map of Techiman Municipality



Source: Ghana Statistical Service

Convenience and purposive sampling methods were used to select 25 market women between 25 and 60 years. The convenience method was used because it allowed us to choose available participants and offer to participate in the interview. Two queen mothers were purposively selected to provide vital information about participants' perspectives on climate change and effective communication channels. Interviews were the primary method of gathering the data. The interviews involved both individual face-to-face and group interviews. The queen mothers were interviewed individually, while other participants were interviewed in groups. The groups' interviews were made up of between three and five individuals. In-depth interviews helped to provide richer insights into participants' perspectives, experiences, and challenges regarding climate change. Participants were interviewed about the perceptions, causes, and impacts of climate change. They were also interviewed on the effectiveness of channels and processes in communicating information about climate change.

The data was transcribed and coded manually. Thematic and cross-sectional analysis were employed to identify recurring themes and patterns in the qualitative data. Coding and categorisation were carried out to get insight into market women's complex experiences and viewpoints on climate change.

The ethical considerations involved informed consent, confidentiality and anonymity, cultural sensitivity, and power dynamics. We stayed close to the data and did not impose our ideas on participants. No participant was forced or coerced to participate, and they were informed of the purpose of the data gathered. The women were interviewed in both the Twi and English languages. Those who could not speak the English language fluently were interviewed in Twi. The Twi language was interpreted carefully to ensure accuracy, cultural sensitivity, and ethical integrity. We ensured that the concepts and ideas conveyed in the local language were accurately represented in English, considering cultural nuances and context. We also worked closely with participants to interpret the data. Their input helped to clarify meanings that might be ambiguous or context-dependent.

Results and Discussion

This section presents the findings and discussions on how participants conceptualise climate change. It focuses on the perception, causes, impact, and strategies to combat climate change.

Perception of climate change

Most participants explained that they had not heard anything about 'climate change' as a concept. About 38.4% of respondents indicated that they have heard about the concept but do not know much about it. However, most participants, accounting for 61.6% of respondents, perceived climate change as changes in the weather.

> "I have heard something about it. The weather has changed" (Respondent A).

> "For me, I think it is seasonal. We have dry and wet seasons. The weather conditions are about seasons, and each has its characteristics. But it looks like the dry season has extended. We are to experience rainfall this August" (Millie Respondent C)

> "It is August, and it is supposed to rain, but there is no trace." (Respondent D)

The findings highlight the respondents' limited but emerging awareness of climate change. Awareness is primarily framed by their lived experiences with changing weather patterns. Their perspectives suggest that weather or seasonal variability, such as extended dry seasons and unpredictable rainfall, shapes their understanding of climate change. These findings suggest that their knowledge is largely shaped by observable short-term variations rather than scientific or policy-driven explanations of long-term climate trends.

According to Coulibaly *et al*. (2015), weather and climate are traditionally understood through seasonality in many parts of Africa. People expect certain weather patterns during specific times of the year, and any deviation, such as an extended dry season, may be perceived as unusual but not necessarily linked to broader climate change. However, weather change is a key sign of climate change that has caused widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere**.** As some studies indicate, local people are ignorant of climate change simply 'because they cannot explain the phenomenon as a trained scientist can, but they can perceive the change and offer explanations and causal factors in their way' (Awuah-Nyamekye, 2019).

When participants were asked about their perception of climate change, there were two main responses. Typified by the responses below, whilst some participants were eager to know about it, others were not too keen on it:

"I have not sought any information about it or practiced any action to adapt or mitigate it" (Respondent E).

"I would like to know more about it. I want to know everything about climate change" (Respondent F).

"I know nothing about climate change and don't intend to seek any information" (Respondent G).

The range of responses highlights varying levels of interest and engagement with climate change among respondents. For example, there are **uninterested** individuals who do not know the term and have no intention of seeking more information. There are also **eager learners** who are curious and willing to learn about climate change. As will be pointed out later in the next section, many participants remained adamant and neutral in its mitigation and adaptation because they believed climate change is an occurrence that is beyond them to question or comprehend.

Perceived Causes of Climate Change

Participants attributed various reasons for the changes in weather. It spans from uncertainty to an act of God. On the basis of uncertainty, about 76.4% of participants, constituting the majority, indicated they did not know the causes of climate change or 'changes in the weather.

"I am not very aware of climate change. I don't even know the causes" (Respondent H).

"I don't know the causes of climate change, so please, you, the experts, should educate us to become aware. We only need to pray hard" (Respondent I).

"I don't know the cause of this change in weather. Only God can answer this problem" (Respondent J).

Almost all participants linked the changes in weather to an act of God. These changes were based on three main things: firstly, as a fulfilment of Biblical prophecy, and secondly, as God's punishment for the sins; and lastly, disobedience of the human race:

"I have been in this business for one year now. I attended a vocational school. I hear a lot of people complaining about the delay in rainfall. For three months now, there has been no rainfall. I don't know the cause. It is only best known to God. Apart from God, who else can explain this crisis?" (Respondent D)

> "I believe this climate change is happening because the world is ending. Imagine how rain does not fall in its season. Only prayers can atone for our sins, and God will have mercy on us so we can go to normal climate conditions" (Respondent F).

> "Sin, of course, is a major cause of this climate change. I believe so much on this. Sometimes, we pray for a change in the climate in my church" (Respondent M).

Other participants asserted the weather variations are a result of a gruesome murder case which happened in 2021. The case involved a man who identified himself as a footballer and a draughtsman who murdered two boys and kept their body parts in a refrigerator in *Alaska*, a suburb of *Abesim* near Sunyani in the Bono Region. The case is being heard in court, and a final verdict has yet to be made.

Some participants, forming about 2.1%, argued against attributing the change in weather to God.

> "I don't believe the climate change is because Jesus is coming. I can't say that nor know what is causing the climate crisis" (Respondent F).

It could be realised that the majority of respondents, representing about 97.4%, attribute climate change to an act of God. This concern is mainly due to the country's religious inclination. Constitutionally, Ghana is a secular country, but the majority are religious. According to the 2021 Population and Housing Census by the Ghana Statistical Service, about 71% of Ghanaians identify as Christian, whereas about 20% identify as Muslim. Most personal, social, economic, and political occurrences are attributed to Biblical prophecies and teachings. With this overwhelmingly Christian population, and although the country leans more towards religious pluralism, Christian practices dominate public institutions and celebrations. In this case, individuals are socialised at home, in the church and educational settings to believe in God and attribute almost every occurrence to God.

Colonial legacies can also be connected to these Christian beliefs. Historically, European merchants embarking on trade expeditions, notably Roman Catholic missionaries who accompanied Portuguese traders, introduced Christianity to Ghana during the late 15th century. Colonisation made missionary activities more pronounced (Nyinevi and Amasah, 2015). As emphasised by Okon (2008), 'Christianity became the religion of civilisation and development' (p.1).

Other respondents described other causes, such as poor sanitation, leadership, and deforestation. Related to the poor leadership is the lack of trust in political leaders and the capacity of agencies like the Ghana Meteorological Agency.

> "I don't even know if the weather forecasters are fake or not. They should learn to predict accurately. There are no weather predictions they have made that have come true. Sometimes, they expect it will be sunny all day, but the sun will not even appear in the sky. I don't know if they learned things well or not. They are just playing with our minds and must be serious about their work. They should stop deceiving us" (Respondent N).

Most participants, who point to God as the ultimate cause of weather variation, may be unaware or pay limited attention to the human-induced causes of climate change, which have been perceived as the greatest cause of global warming. Subsequently, participants may engage in activities that compound climate change issues without awareness. Rapid urbanisation, increased waste generation, and unsustainable agricultural practices associated with market activities can exacerbate environmental challenges.

Market women may use wood fuels to smoke fish, cook or do other things that affect climate change. Wood, for example, has been identified to emit more carbon dioxide per kilowatt-hour than coal – and far more than other fossil fuels (Sterman, Siegel, & Rooney-Varga, 2018), which worsens climate change. Forest regrowth might eventually remove that extra carbon dioxide from the atmosphere, but regrowth is uncertain and takes time – decades to a century or more, depending on forest composition and climatic zone – time we do not have to cut emissions enough to avoid the worst harms from climate change (Sterman *et al*., 2022). The set of identified climatic hazards aligns with the existing literature and the IPCC reports.

Sources of information on climate change

The church plays a key role in Ghana's personal, social, economic, cultural, and political dimensions. Interestingly, the church has taken over educating its members on climate change. Almost all participants attributed their knowledge about climate change to the church.

> "We only hear about climate change from our pastors, who constantly ask us to pray for the world as we near the end of time" (Respondent, Q).

> "We rarely hear information about climate change on radio, television, or newspapers. We rarely listen to the radio or watch television. We don't even know what causes climate change. We have not practised anything to adapt or mitigate climate change" (Respondent, A).
>
> "I rarely hear the radio, TV, or anyone creating awareness of climate change and how we can adapt or mitigate this crisis" (Respondent, D).
>
> "I have heard that when you burn things, and the smoke goes up to the sky, it can cause rain to fall. I don't know if burning fossil can cause a climate crisis. But if this is true, we would have enough rainfall because we burn a lot here in the markets and even our homes" (Respondent, O).

The findings highlight the significant influence of religious organisations (e.g., churches) in shaping public perceptions of climate change in Ghana. Given that many participants attribute their climate knowledge solely to religious teachings, and traditional media (radio, TV, newspapers) appears to play a limited role, churches can serve as a crucial platform for climate education. Religious leaders must be equipped with accurate climate knowledge through training and tailored faith-based messages to strengthen the church's role in climate education. Integrating climate discussions into sermons and religious media can enhance awareness, while partnerships with climate organisations, government agencies, and faith-based NGOs can provide resources and credibility.

Perceived impact of climate change

Most participants attested to some main impacts of variations in the weather, including hunger, high prices, low business activities and low health. Many participants expressed fear about impending hunger and the effect on prices.

> "I suspect severe hunger will be in 2025" (Respondent, O).
>
> "I know for sure that the climate will affect cashew production this year. I am wondering about the hunger that will arise in the ensuing year. The climate is affecting the maturity of food crops" (Respondent C).
>
> "We are feeling the impact on our business because prices of commodities are high, and people cannot buy. We are not even getting the produce from the farmers because it is not raining" (Respondent E).

> "I have worked in this market for over 10 years. Climate change is affecting sales in the market. That's all I can say, and I don't know the causes of climate change" (Respondent J).

> "The market is not good at all. People are not buying. You can open your store all day and make a small sale" (Respondent O).

Participants perceived the seriousness of climate change, its impacts, and the need to mitigate it. Their concerns about looming hunger, low sales, and limited profitability were highly expressed. However, the responses also suggest gaps in climate awareness, especially regarding climate change's broader health and environmental consequences. Beyond economic concerns, market women are less informed about climate-related health risks, such as foodborne diseases, water contamination, and vector-borne illnesses. As climate variability increases, these risks threaten their businesses and personal well-being.

Interestingly, participants did not mention any impact of climate change on women. Whilst climate change poses multifaceted challenges globally and within the developing world, women are often identified as a particularly vulnerable demographic facing heightened risks and impacts (Akponikpe *et al*., 2019). This vulnerability stems from a complex interplay of socioeconomic, cultural, and environmental factors, reinforcing the need for targeted research and interventions to address the unique challenges faced by women in the context of climate change.

The pivotal role of women in agrarian economies, where they are often engaged in subsistence farming and natural resource-dependent activities, exposes them to direct impacts of climate variability (Adger *et al*., 2007). Changes in precipitation patterns, temperature extremes, and the frequency of weather-related events can disrupt agricultural practices, jeopardising food security and exacerbating existing vulnerabilities among women in these regions. Historically, while demand tends to be relatively smooth and predictable, supply continues to be much more erratic due mainly to the weather (KPMG, 2021)

Perceived barriers to climate education and coping strategies

This study examined some barriers respondents faced in accessing climate education and their strategies to cope with them. While many participants recognise the importance of learning about climate change, their ability to do so was hindered by factors such as limited access to information (mainly through media), conditions of the market, and competing business priorities. In explaining the point on limited access to information, some participants pointed out that traditional sources of information, such as television and radio, rarely provide dedicated climate education beyond weather forecasts.

> "I don't have a TV set in my house. And on the radio, they only do adverts. Radio stations rarely discuss and create awareness of climate change except by giving weather forecasts" (Respondent H).

The ineffectiveness of market information centres in disseminating climate education further limits engagement with climate information. A respondent outlined two key issues: first, the noise from the markets makes it difficult to hear or focus on messages from public information centres. Secondly, market women are constantly engaged in transactions, so they may not have the time or attention to actively listen to general announcements.

> "Can you hear the information centre in the market from where we are now? It is not clear because there is noise all over. The information centre may not be as effective as meeting groups, which is more effective and efficient. We may be busy transacting business, so our attention may not be focused on the information they share. Now you have my attention because you are with me in person. So, I believe group meetings will be more appropriate. We can also use our various groups to educate people on climate change" (Respondent K).

The concerns from the respondents raise questions about the effectiveness of passive communication methods, such as loudspeaker announcements, in capturing the attention of market women. Secondly, the results emphasise the challenge of integrating climate education into the busy routines of women in the market. Lastly, the results reveal the failure of the mass media to use their broader reach to provide adequate education on climate change to the general public. Despite these obstacles, they have identified alternative ways to receive climate education, such as group meetings and community-based learning approaches, which they believe are more effective in their context.

The adaptation practices offered by the majority of participants were prayers. This is not unexpected since the conceptualisation, perceptions and causes were all mainly attributed to God. It is, therefore, expected that problems will be addressed through prayers. Since God is perceived to be the cause, it is unsurprising that participants have not done much about it. Others also indicated that they had done little about it since there was very little they could do.

> "We can do nothing as market women except pray to God for forgiveness" (Respondent B).
>
> "I have not practiced any action to address this crisis" (Respondent P).
>
> "I have not done any practice to adapt or mitigate it. I don't even know anything about it" (Respondent Q).
>
> "What can market women do to solve this climate change? Show me. We have nothing to do to change this reverse" (Respondent D).

Some participants preferred some ways to mitigate climate change. Approximately 89.8% emphasised education and training individually and at the group level.

> "It will indeed be essential to have much information about climate change through civic education, focus group meetings, training and workshops, radio and TV programs, and one-on-one engagements" (Respondent R).

It appears participants were not sure of the ways to tackle the problems due to their limited knowledge of the subject. They believe in God's intervention to mitigate the challenges. Many authors have underscored the impact of religion on climate change. The perspective of participants in perceiving climate change as resulting from divine decrees serves as a great challenge in mitigating climate change. This means that some religious organisations may not encourage their members to engage in human activities that will positively impact the climate; instead, they should be encouraged to pray and desist from sin to combat climate change. Golo and Yaro (2013) argue that the main solution '*lies in obeying God'*. Some studies have also highlighted how Christianity, for instance, condemns traditional practices that could be used to preserve the waters and river bodies by labelling them as evil practices (Awuah-Nyamekye, 2019).

Participants mention less the need for changes in human activities or right policies to ensure improved health, economic interventions, or environmental protection. Most participants also hardly mentioned the financial, social, or logistical challenges that might prevent individuals from engaging in climate change mitigation behaviours. Their perceived barriers, as indicated above, were mainly about limited resources, which were mentioned by a few. There were also minimal cues or activities to trigger and prompt individuals to take action. These include limited media coverage, public health warnings, or campaigns that raise awareness about the importance of reducing carbon emissions.

The data showed less self-efficacy among participants. Participants were less confident about their ability to take any effective action, which can be contributed by their limited knowledge and reliance on divine intervention. They felt less capable of changing their behaviour, contributing to climate change mitigation, reducing energy consumption, or advocating for policy changes.

Conclusions and policy recommendations

This study highlights the critical need for more effective communication strategies to raise awareness about climate change among market women. The findings demonstrate that participants possess limited knowledge, and religious beliefs often influence their understanding of climate change. It underscores the importance of tailoring communication efforts to bridge these knowledge gaps while respecting cultural and religious contexts. The study highlights that reliance on divine intervention can be leveraged to strengthen the role of religious institutions in climate education. Through the Health Belief Model, the study emphasises that enhancing awareness and promoting more scientifically grounded perceptions of climate change are essential for fostering better adaptation strategies within vulnerable communities.

The Health Belief Model (HBM) posits that messages will achieve optimal behaviour change if they successfully target perceived barriers, benefits, self-efficacy, and threats (Jones *et al*. 2015). The model pointed out the participants' deep fear of weather variations and their impact. It also brought out the desire of participants to know more about climate change and their willingness to adopt changes that will bring variations. It could also be perceived from the findings that religion plays a key role in climate change conceptualisation and mitigation. The following recommendations will enhance climate change mitigation:

1. **Enhance localised climate education policies**: The government must develop and implement climate change education policies and training programmes that are accessible to all. These materials should use plain, non-technical language and be translated into major local languages. This will ensure wider understanding and engagement across different demographic groups, especially at the community level.
2. **Use engaging and jargon-free communication**: Climate communication should prioritise clear, concise language, avoiding technical jargon and complex terminology. Government institutions, Civil Society Organisations, NGOs and media houses should employ storytelling, relatable examples, and visual aids (e.g., videos, images, artistic collaborations) to enhance comprehension and retention. These organisations should also leverage social media platforms to share engaging content on climate action. They should also support the development of interactive tools like mobile apps and games that promote public engagement on climate action.
3. **Mobilise religious organisations for climate outreach**: Government agencies and civil society groups must develop climate communication and training toolkits tailored for religious organisations. Faith-based leaders can use these resources to educate congregants and inspire behavioural change, using their platforms and trust networks to reach wide audiences.
4. **Strengthen media's role in climate education:** The media should take a proactive role in climate education. The data suggest the urgency of the media to create awareness and promote sustainable practices. Media organisations must deconstruct and reshape the ideas and conversations about climate change through their platforms.
5. **Integrate climate education into market structures**: Key climate advocates (e.g., governments, civil society, faith-based organisations) must collaborate with market leaders, such as market queens, to integrate climate education into regular market association meetings.

These gatherings will serve as platforms and opportunities to introduce climate awareness topics in a structured and peer-driven manner.

6. **Deliver practical, community-based climate education**: CSOs and local governments should design hands-on climate education programs focusing on practical adaptation strategies, such as food preservation techniques, water conservation, waste management, and eco-friendly business practices.

References

Adanu, S., Schneider, T. M., Stimm, B., & Mosandl, R. (2009). Effects of woodfuel production on the environment and people in Adaklu Traditional Area, Ghana. *Journal of Food, Agriculture and Environment, 7*, 241–247.

Amoako, C. G., & Agyei-Ohemeng, C. (2016). Enhancing understanding of climate change among rural populations: The role of accessible and culturally sensitive communication strategies. *Journal of Environmental Communication, 10*(3), 301–318. https://doi.org/10.1080/17524032.2015.1136111

Antwi-Agyei, P., & Nyantakyi-Frimpong, H. (2021). Evidence of climate change coping and adaptation practices by smallholder farmers in northern Ghana. *Sustainability, 13*(3), 1308.

Arunanondchai, P., Fei, C., Fisher, A., McCarl, B. A., Wang, W., & Yang, Y. (2018). How does climate change affect agriculture? In *The Routledge handbook of agricultural economics* (pp. xxx–xxx). Routledge.

Assan, E., Suvedi, M., Schmitt Olabisi, L., & Allen, A. (2018). Coping with and adapting to climate change: A gender perspective from smallholder farming in Ghana. *Environments, 5*(8), 86.

Awuah-Nyamekye, S. (2019). Climate change and indigenous Akan religio-cultural practices: Lessons for policy-makers and implementers in environmental conservation in Ghana. *Worldviews: Global Religions, Culture, and Ecology, 23*(1), 59–86.

Becken, S. (2010). The importance of climate and weather for tourism: A literature review. *Lincoln University, LEaP, Land Environment and People Miscellaneous Publications*, 23 pp.

Boyer, J. S. (1982). Plant productivity and environment. *Science, 218*(4571), 443–448.

Busby, J. W., Cook, K. H., Vizy, E. K., Smith, T. G., & Bekalo, M. (2014). Identifying hot spots of security vulnerability associated with climate change in Africa. *Climatic Change, 124*, 717–731.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., Ramirez-Villegas, J., Rosenstock, T., Sebastian, L., & Thornton, P. K. (2016). Reducing risks to food security from climate change. *Global Food Security, 11*, 34–43.

Champion, V. L. (1984). Instrument development for health belief model constructs. *ANS: Advances in Nursing Science, 6*, 73–85.

Codjoe, S. N. A., Atidoh, L. K., & Burkett, V. (2012). Gender and occupational perspectives on adaptation to climate extremes in the Afram Plains of Ghana. *Climatic Change, 110*, 431–454.

Darkwah, A. R., & Agyeman, K. O. (2020). Knowledge gaps and misconceptions about climate change among market women in Techiman. *Environmental Education Research, 26*(6), 804–822. https://doi.org/10.1080/13504622.2019.1594738

Diiro, G., Petri, M., Zemadim, B., Sinare, B., Dicko, M., & Traore, D. (2016). Gendered analysis of stakeholder perceptions of climate change and the barriers to its adaptation in Mopti region in Mali. *Telangana, India*.

Food and Agriculture Organization of the United Nations. (2015). *The state of agricultural commodity markets in depth: Value chains, agricultural markets and food security*. FAO.

Ghana Statistical Service. (2023). Slider headlines. https://www.statsghana.gov.gh/headlines.php?slidelocks=NjI1NDc2NjYyOS4yMzA1/headlines/q53o59r539

Gómez-Martín, M. B., Armesto-López, X. A., Cors-Iglesias, M., & Muñoz-Negrete, J. (2014). Communicating the effects of climate change on tourism: The Spanish written press as a case study. *European Journal of Geography, 5*(3), 73–84.

Griffin, M. J. (2012). Health belief model, social support, and intention to screen for colorectal cancer in older African American men. *Health Promotion & Education, 51*(1), 12–22.

Intergovernmental Panel on Climate Change (IPCC). (2007). *Impacts, adaptation and vulnerability: Contribution of Working Group II to the 4th Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC.

Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2023). Summary for policymakers. In *Climate change 2023: Synthesis report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the IPCC* (H. Lee & J. Romero, Eds., pp. 1–34). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Jalloh, A., Nelson, G. C., Thomas, T. S., Zougmore, R., & Roy-Macauley, H. (2013). *West African agriculture and climate change: A comprehensive analysis*. International Food Policy Research Institute.

KPMG. (2013). *The agricultural and food value chain: Entering a new era of cooperation*.

Mensah, J. O., & Acheampong, M. A. (2017). Perceived relevance of climate change among market women in Techiman: Implications for community engagement. *Journal of Climate Awareness, 5*(2), 87–104.

Myers, G. (2006). *Lusaka, Zambia: Colonial neglect and postcolonial struggles in African city planning*. Routledge.

NOAA Climate.gov. (2021). *Climate change: Atmospheric carbon dioxide*. https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Noya, I., González-García, S., Bacenetti, J., Fiala, M., & Moreira, M. T. (2018). Environmental impacts of the cultivation-phase associated with agricultural crops for feed production. *Journal of Cleaner Production, 172*, 3721–3733.

Owusu, M., Nursey-Bray, M., & Rudd, D. (2019). Gendered perception and vulnerability to climate change in urban slum communities in Accra, Ghana. *Regional Environmental Change, 19*, 13–25. https://doi.org/10.1007/s10113-018-1357-z

Rosenstock, I. M. (1974). Historical origins of the health belief model. *Health Education Monographs, 2*, 328–335. https://doi.org/10.1177/109019817400200403

Scarinci, I., Bandura, L., Hidalgo, B., & Cherrington, A. (2012). Development of a theory-based, culturally relevant intervention on cervical cancer prevention among Latina immigrants using intervention mapping. *Health Promotion Practice, 13*, 29–40. https://doi.org/10.1177/1524839910366416

Sifolo, P. P. S., & Henama, U. S. (2017). Implications of climate change for tourism in Africa. *GeoJournal of Tourism and Geosites, 20*(2), 191–198.

Sterman, J., Moomaw, W., Rooney-Varga, J. N., & Siegel, L. (2022). Does wood bioenergy help or harm the climate? *Bulletin of the Atomic Scientists, 78*(3), 128–138. https://doi.org/10.1080/00963402.2022.2062933

Sterman, J. D., Siegel, L., & Rooney-Varga, J. N. (2018). Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy. *Environmental Research Letters, 13*(1), 015007.

The New York Times. (2021, February 4). Paul Crutzen, Nobel Laureate who fought climate change, dies at 87. https://www.nytimes.com/2021/02/04/science/paul-crutzen-dead.html

United Nations. (2022, April). Small solutions, big impacts: 5 community-based projects tackling climate change. https://news.un.org/en/story/2022/04/1117122

Vaughan, M. M., Block, A., Christensen, S. A., Allen, L. H., & Schmelz, E. A. (2018). The effects of climate change-associated abiotic stresses on maize phytochemical defenses. *Phytochemistry Reviews, 17*(1), 37–49.

3

Community-Based Approaches Towards Climate Resilience in the Effutu Municipality: Integrating Traditional Knowledge and Scientific Methods for Sustainable Adaptation

Emmanuel Letsyo

Abstract

The coastal landscape, cultural heritage, and socioeconomic stability of communities along the coast of the Effutu Municipality are facing significant adverse impacts from climate change. This chapter explores how community-based approaches can enhance climate resilience in vulnerable communities by integrating traditional knowledge with scientific methods. The study employed a qualitative research approach and an exploratory case study design, grounded in the philosophical orientation of social constructivism. Through 30 in-depth interviews with community members, local leaders, and experts, the study explored the effectiveness of local knowledge, community-led initiatives, and governance structures in addressing climate impacts such as coastal erosion, flooding, and agricultural disruptions. The findings underscore the critical need to tailor climate resilience strategies to local contexts, as generalised approaches often fail to address the unique cultural, social, and institutional factors that shape community responses to climate risks. This study provides evidence for integrating Traditional-Ecology Knowledge with scientific methods in developing climate resilience strategies. It concludes that a bottom-up approach to climate resilience, where local knowledge and community engagement are central, is essential for developing effective and sustainable adaptation strategies and provides a framework for policymakers, development practitioners, and researchers to support community-driven climate resilience efforts, emphasising the need for enhanced collaboration between local communities, government agencies, and international partners. The study contributes to the growing body of literature on community-based climate adaptation, offering insights tailored to communities along coastal belts in Ghana.

Keywords: Effutu Municipality, Community-Based Approaches, Traditional Ecological Knowledge, Climate Resilience, Sustainable Adaptation

Introduction

Climate change poses significant challenges to coastal communities worldwide as rising sea levels, increased frequency of extreme weather events, and changing rainfall patterns threaten the livelihoods, infrastructure, and overall well-being of residents, especially in coastal communities (Adger et al., 2013; IPCC, 2014). Agricultural practices and fishing activities, crucial for food security and income diversification in these communities, are increasingly challenged by unpredictable rainfall patterns and soil degradation (Hind, 2015; Nyantakyi-Frimpong, 2020). The vulnerability of coastal communities is exacerbated by their limited adaptive capacity, which stems from factors such as poverty, inadequate infrastructure, and insufficient access to climate information and resources (Dasgupta et al., 2019; Villamayor-Tomas et al., 2024). Local communities can face irreversible economic losses, social disruption, and environmental degradation if these problems are not adequately addressed (Brown et al., 2019).

Specifically, the degradation of coastal ecosystems could result in a decline in biodiversity and the loss of crucial ecosystem services (Nalau & Becken, 2018). There is the risk of forced migration as areas closer to seas become uninhabitable due to sea-level rise or repeated extreme weather events (Baby et al., 2021; Bagheri et al., 2022), leading to the loss of cultural heritage and traditional ways of life (Aktürk & Hauser, 2021; Sesana et al., 2020; Zhu et al., 2022). The cumulative impact of these changes could overwhelm local coping mechanisms, leading to heightened social and economic instability (Ford et al., 2016).

Recognising the urgency of this already precarious situation, researchers and practitioners have explored various approaches to enhance climate resilience in coastal communities. Over the years, empirical literature has focused on community-based adaptation (CBA) strategies, which emphasise local participation, empowerment, and capacity building (Ayers & Forsyth, 2009). These approaches acknowledge the importance of the local context and seek to develop adaptation measures that are culturally appropriate and responsive to community needs (Dodman & Mitlin, 2013; Nalau et al., 2018). Another significant body of literature examines the role of traditional ecological knowledge (TEK) in climate adaptation. This strand of literature insinuates that local communities often possess a wealth of knowledge about their environments, accumulating over generations and can inform effective adaptation strategies (Berkes, 2009; Nyong et al., 2007).

Within this context, studies have documented how traditional farming practices, such as drought-resistant crop varieties and water conservation techniques, have helped communities adapt to climate variability (Antwi-Agyei et al., 2018; Chemura et al., 2020; Nyantakyi-Frimpong, 2020; Yeleliere et al., 2023). These indigenous adaptation strategies passed down through generations have been vital for food security in the face of changing weather patterns (Owusu et al., 2021). However, the accelerating pace of climate change outstrips the adaptive capacity of traditional approaches alone, necessitating the integration of TEK with modern scientific methods (Ford et al., 2016). Despite growing recognition of this need, gaps remain in our scientific understanding of how to effectively integrate TEK with scientific methods for climate resilience. Context-specific research is therefore essential to tailor these approaches to the cultural, ecological, and socioeconomic realities of different communities (Naess, 2013). To address this important limitation in the body of climate change adaptation literature, the book chapter adopts a knowledge co-production framework to examine the interplay between community-based approaches, TEK and scientific methods in building climate resilience in the Effutu Municipality. In addition to this, it is also imperative to document and analyse how the integration of TEK and scientific methods contributes to community-based climate resilience strategies in Effutu Municipality, with a focus on community engagement, local adaptation strategies, and sustainable practices. It argues that the most effective way to build climate resilience is through the structured integration of TEK and scientific knowledge within a community-based framework. The chapter is structured as follows—literature review, methodology, results and discussion, conclusion, policy recommendations, and references.

Literature Review - Bridging Traditional and Scientific Knowledge for Community-Based Climate Resilience

Traditional knowledge systems are deeply embedded in the cultural, social, and ecological contexts of local communities. Anecdotal and scientific data show that communities utilise traditional agricultural practices and natural resource management strategies that contribute significantly to landscape resilience and biodiversity conservation (Ahmed, 2022; Kamakaula et al., 2024; Mekonnen et al., 2021; Zenebe et al., 2021). These knowledge systems, such as the Gedeo agroforestry system,[2] sustain local livelihoods and enhance ecological stability. Similarly, the Munda local communities in coastal Bangladesh utilise TEK to inform community-based disaster risk reduction, showcasing an intrinsic link between cultural practices and climate resilience (Datta & Kairy, 2024). In African societies, traditional knowledge has been crucial for environmental management, where practices such as rain-making rituals and the conservation of wetlands have been used for centuries to mitigate the impacts of climate variability. The integration of this indigenous wisdom with scientific approaches is increasingly vital for effective climate adaptation, particularly in regions with high vulnerability to climate change (Makondo & Thomas, 2018).

Community-based adaptation (CBA) strategies have proven effective, particularly in coastal regions where communities face heightened risks from sea-level rise and extreme weather events (Jamero et al., 2017; Jamero et al., 2018; Myers et al., 2019; Onat et al., 2018; Song et al., 2017). A study in coastal areas revealed that integrating local knowledge with scientific data not only reduces economic losses from climate-related disasters but also strengthens infrastructure resilience by up to 80% (Niu et al., 2023). It is argued that engaging communities in decision-making empowers local populations, resulting in sustainable livelihoods and enhanced social cohesion. For example, in the Sistan region of Iran, indigenous nature-based solutions like the use of "Teng" barriers (a technique that uses woven branches to mitigate sandstorms) demonstrate how traditional practices can be adapted to modern climate challenges (Jarkeh et al., 2024). These practices protect local infrastructure and improve soil, promoting agricultural resilience (Miao et al., 2024).

The synergistic integration of traditional knowledge and scientific approaches offers a pathway for more holistic and sustainable climate adaptation (Raveena, 2024). Indigenous and local knowledge systems have proven invaluable in understanding climate patterns and developing resilient practices (Nalau et al.,

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[2] The **Gedeo agroforestry system** in Ethiopia is a traditional, multilayered farming practice that integrates trees, crops, and livestock, ensuring biodiversity conservation, soil fertility, and food security. Recognized for its sustainability, it faces threats from land pressure, deforestation, and climate change.

2018; David-Chavez & Gavin, 2018). Leveraging the strengths of both knowledge systems helps develop adaptive measures that are scientifically sound, inclusive, and culturally sensitive (Makondo & Thomas, 2018; Wheeler et al., 2020). Recent studies have demonstrated that this integrated approach leads to more effective and equitable climate solutions, particularly in vulnerable communities (Nursey-Bray et al., 2019). It is also crucial for achieving global sustainability goals, as traditional knowledge systems are particularly adept at addressing localised climate risks and promoting resilience at the community level (Donkor & Mearns, 2022).

Methods and Materials

This chapter employed a qualitative research approach underpinned by a social constructivist philosophical orientation to research (Creswell & Creswell, 2023; Fazlıoğulları, 2012; Kumar, 2019; O'Leary, 2017), and a case study design (Woodside, 2010; Yin, 2018). To enhance the trustworthiness of the findings, this chapter incorporated reflexivity, respondent validation, and intertextuality, aligning these techniques with the interpretive nature of the methodology.

Study Context

Several compelling factors substantiate the selection of Effutu municipality as the research setting for this study. Primarily, recent assessments by the Intergovernmental Panel on Climate Change (IPCC) emphasise that coastal communities, particularly those in Africa, demonstrate heightened vulnerability to climate change impacts owing to their substantial dependence on local water and food resources, which are increasingly susceptible to environmental degradation and extreme weather events (IPCC, 2022). Within this context, Effutu municipality presents a complex socio-ecological landscape. Of particular significance is the municipality's critical concern regarding groundwater quality and seasonal water availability, thereby necessitating strategies that effectively synthesise community insights with scientific practices to enhance sustainable water management and strengthen climate resilience (Kyeremeh et al., 2023).

From a cultural perspective, Effutu's rich heritage manifests prominently in its traditional practices, notably within the fishing industry's gender dynamics. Although women play substantial economic roles in fishing communities, their participation in decision-making remains constrained at the household and community levels, reflecting broader gender-based challenges that impact empowerment and poverty reduction initiatives (Adiikanbasi, 2018). The economic landscape of Effutu is characterised by diversified income sources, encompassing fishing, small-scale trading, and local agriculture. In this regard, groundwater serves as a critical economic resource, with recent research indicating significant community willingness to invest in enhanced water quality, thereby demonstrating both the resource's importance and local commitment to sustainable management practices (Kyeremeh et al., 2023).

The environmental dimension further underscores the municipality's vulnerability to climate variability. Specifically, seasonal rainfall patterns profoundly influence Effutu's ecosystem, directly impacting agricultural productivity. Relatedly, the high variability in rainfall, particularly affecting rice cultivation, has necessitated the adoption of adaptive farming strategies, including mulching techniques and integrating drought-resistant crop varieties (Dadson et al., 2020). This confluence of educational initiatives, traditional livelihoods, economic resource management, and environmental stewardship highlights Effutu municipality's dynamic socio-ecological system, ripe for integrated climate resilience strategies that blend traditional and scientific knowledge.

Sampling

This study was based on 30 in-depth interviews conducted with community members, leaders, and subject matter experts, selected through purposive sampling for broad stakeholder representation. Preliminary analysis showed that theoretical saturation began to occur around interview 20, with no new significant themes emerging after interview 25. Five additional interviews were conducted to confirm saturation, resulting in a final sample of 30 participants. The participants were selected via a purposive sampling to ensure representation across key stakeholder groups. The sample comprised 18 community members (60%) as primary stakeholders affected by climate impacts and 6 participants each (20%) from community leadership and subject matter expertise to capture institutional perspectives and technical insights. The inclusion criteria for community members were as follows.

- *Community members*: At least 10 years of residency, direct experience with climate impacts (e.g., coastal erosion, flooding, or agricultural disruptions), and involvement in local adaptation initiatives.
- *Community leaders*: Held official roles in local government, non-profits, or relevant institutions.
- *Subject matter experts*: Professionals in climate science, sustainable agriculture, or coastal zone management within the municipality.

Data Gathering Procedure

The data for this study were gathered through in-depth, semi-structured interviews with the selected participants. The interview process was designed to capture the participants' first-hand experiences, perspectives, and insights regarding using local knowledge, scientific knowledge, community-led initiatives, and governance structures in addressing climate impacts. The interview guide consisted of several key sections (Kumar, 2019) to elicit information relevant to the study's research objectives. The participants were first asked to describe the major climate-related challenges they have observed or experienced in their community. This approach enabled the researcher to gain a nuanced understanding of the local context and the lived realities of the participants.

Subsequent discussions concerned existing community-based efforts to mitigate or adapt to these climate challenges and the role of local knowledge, scientific knowledge, and leadership in shaping these initiatives. This inquiry provides valuable insights into the strengths and limitations of community-driven approaches to climate adaptation. Finally, participants shared recommendations for strengthening community resilience, and perspectives on the broader applicability and scalability of the strategies and techniques employed in their local context, providing valuable insights to address the study's key research objectives.

Throughout the interview, the participants were given ample opportunity to elaborate on their responses and to introduce new relevant topics. This open-ended approach enabled the researcher to capture the complexity and nuance of the participants' experiences and to uncover unexpected insights that may have been missed through a more rigid interview structure. The researcher conducted the interviews in person between April and July 2024. Each interview lasted 45—60 minutes and followed a semi-structured format, allowing participants to share their perspectives and experiences in depth. The interview process continued until data saturation was reached, indicating that no new significant themes or insights emerged. The interviews were audio-recorded, transcribed verbatim, and analysed via qualitative coding to identify key themes and insights (Braun & Clarke, 2022). This approach enabled a comprehensive exploration of the role of local knowledge, community action, and governance in climate adaptation at the community level.

Analytic Process

This study employed a six-phase reflexive thematic analysis (TA) approach (Braun & Clarke, 2006) to identify patterns and insights within the qualitative dataset. The recursive process allowed fluid movement between phases to ensure analytical rigour. The study employed deductive (i.e., predefined codes from the literature) and inductive (emergent themes from the data) analysis by closely examining the interview transcripts. The six-phase analytic steps are outlined below:

1. *Familiarisation with Data* – Transcripts were examined with initial observations, and potential patterns were identified to develop a deep understanding of the dataset.
2. *Systematic Coding* – Transcripts were coded using NVivo 14, with an evolving codebook to capture emerging insights while staying aligned with participants' perspectives.
3. *Theme Development* – Related codes were grouped into candidate themes by clustering similar concepts and identifying broader patterns in participants' experiences.
4. *Theme Review & Refinement* – Themes were examined for coherence and distinctiveness, ensuring they accurately reflected the data and captured key insights.
5. *Theme Definition & Naming* – Each theme was clearly defined and named to encapsulate its essence and significance within the research.
6. *Integration & Interpretation* – Thematic findings were woven into a cohesive narrative supported by participant quotes, while reflexive discussions helped minimise bias and strengthen analytical rigour.

Throughout the analytic process, the researcher engaged in regular reflexive discussions to critically examine their preconceptions, biases, and assumptions, ensuring that the emerging themes were genuinely grounded in the participants' experiences. This approach helped generate a comprehensive and contextually rich understanding of the role of local knowledge, community-led initiatives, and governance structures in addressing climate impacts at the local community level.

Results and Discussion

Contextual Understanding

The analysis reveals that climate resilience strategies must be tailored to local context—cultural, social, and institutional dimensions. The data revealed that a one-size-fits-all approach is often ineffective; instead, strategies should be designed with a deep understanding of local experiences and responses to climate risks. This approach also emphasises the importance of involving local stakeholders in planning and implementation processes, ensuring that resilience measures are relevant and sustainable over the long term. One of the research participants disclosed:

> **"**Just last year, we faced a major challenge with a government-funded climate adaptation project. They tried to implement an agricultural water management system that had worked well in the central region, but it completely failed here in our coastal area. The system didn't account for our higher salt content in the soil and different rainfall patterns. Plus, they scheduled community meetings during our fishing times when most people couldn't attend. If they had consulted with us first, we could have told them that our traditional method of using tiered gardens and water catchment systems works better here**"** (Interviewee A, Tuesday, April 02, 2024).

Another informant added:

> **"**…we helped identify the best locations for mangrove restoration based on our historical understanding of storm surges. The project team spent three months just talking to local fishermen and elderly residents before finalising any plans**"** (Interviewee Y, Friday, May 10, 2024).

Insight gleaned from the dataset reveals a significant issue in climate resilience efforts—the failure of strategies that do not consider local contexts. It follows that generic, externally imposed solutions often fall short due to their lack of alignment with a community's specific environmental, social, and cultural realities in Ghana. Here, national-level strategies failed to leverage indigenous practices, leading to suboptimal outcomes (Arkhurst et al., 2022).

The failure of well-intentioned projects that disregarded this knowledge suggests that top-down approaches to climate resilience often overlook the social dimensions of adaptation. It follows that resilience is not just a matter of technological or environmental solutions, but one deeply rooted in communities' social and cultural fabric. The research on climate resilience strategies reveals a consensus on the necessity of tailoring these strategies to local contexts, emphasising cultural, social, and environmental nuances for successful implementation. For example, Zobeidi et al. (2024) highlight the inefficacy of generalised adaptation methods, showing how localised strategies in southwest Iran, such as specific water management techniques and crop diversification, yielded better outcomes when adjusted to regional needs. These findings align with Shapiro-Garza et al. (2019), who stress the importance of participatory frameworks in Latin American coffee cooperatives to ensure that resilience strategies are economically feasible and culturally appropriate. The studies advocate a shift toward adaptive, participatory models that harness local knowledge.

This blend is critical for ensuring the success of resilience measures and for long-term sustainability and community buy-in. Contrastingly, the broader literature often focuses on technological or infrastructural solutions, which may overlook the socio-cultural dimensions critical for resilience. This underscores the need for policies integrating bottom-up community insights and top-down support mechanisms to address the multifaceted challenges of climate adaptation.

Bridging TEK with Scientific Methods: The Epistemological Convergence

In recent years, there has been a growing recognition of the value of integrating TEK with scientific methods, particularly in climate change and environmental management. This recognition seeks to explore how the foundational ideas of TEK and scientific methods can be aligned. The research data suggest that TEK offers insights that are often localised and context-specific, which can complement the broader, often more generalisable findings of scientific research. This combination yields more effective, culturally relevant, and sustainable solutions to environmental challenges. The research participants expressed how TEK's holistic, relational worldview can be reconciled with the empirical, reductionist approach of scientific methods to develop scientifically accurate and contextually relevant solutions. One of the informants intimated:

> **"**…our fishermen used natural indicators like seabird behaviour, seaweed ('dzetsi') patterns, and seasonal winds ('ahuma') to predict fish movements and abundance. When combined with scientific measurements of water temperature, salinity, and tidal patterns, this integrated approach has improved our fishing efficiency and sustainability**"** (Interviewee Q, Monday, July 24, 2024).

Echoing this perspective, another informant emphasised the complementary relationship between ancestral ecological knowledge and contemporary scientific practices:

"The traditional sea knowledge passed down through generations complements modern scientific methods. Our fishermen interpreted natural signs like 'Ahobaakese' (dawn), and sky colours for storm prediction and understood moon-phase effects on fishing. When combined with scientific tools like satellite data and tidal measurements, this integrated approach has improved both fishing safety and catch sustainability**"** (Interviewee W, Wednesday, May 01, 2024).

Participants' narratives demonstrate that reconciling these approaches involves recognising that both perspectives offer valuable insights. TEK provides a broader, contextually rich understanding of the environment, whereas scientific methods offer detailed, specific data.

> **"**...where our grandfathers once caught large quantities of 'eban' (herrings) close to shore year-round, both our fishermen's observations and scientific surveys now show these fish are moving further out to sea and appearing later in the season. When we shared our traditional calendar marking with researchers, their temperature and salinity data explained why some fish species now arrive a month later than they did 20 years ago. This collaboration has helped us adapt our fishing methods, we now adjust our net sizes and fishing zones based on both traditional knowledge and scientific fish population surveys**"** (Interviewee S, Tuesday, April 02, 2024).

Practically, examining how TEK's methods and approaches can be harmonised with scientific procedures is essential. Finding common ground or complementary aspects between these approaches is key to building a cohesive framework for climate resilience. Respondents highlight that the key philosophical commonality between TEK and scientific methods is that both seek to understand and predict environmental changes to improve human well-being. It reinforces the idea that TEK is not static but evolves through interaction with modern scientific advancements.

Additionally, interaction with study participants reveals how integration is most effective when it addresses tangible, community-relevant challenges, such as storm avoidance and sustainable fisheries. In response to these philosophical commonalities, one of the informants noted:

> **"**Both TEK and scientific methods aim to understand and predict changes in the environment to improve our lives. When we combined our traditional storm prediction methods with the Meteorological Agency's weather alerts, our fishing crews made better decisions about when to sail. Last fishing season, this integration helped us avoid three major storms that could have endangered our canoes. We've also noticed that when our traditional observations of fish breeding seasons align with marine biologists' data, we can better manage our fishing grounds near Muni Lagoon**"** (Interview A, Friday, April 12, 2024).

It is essential to recognise their shared goal to bridge the differences in epistemological foundations between TEK and scientific methods and create a more effective approach to environmental management. Integrating these approaches can leverage TEK's contextual and historical perspectives with scientific rigour, enhancing predictive accuracy and offering a more comprehensive understanding of climate challenges. This blend can help develop more holistic and effective environmental management strategies that benefit community well-being. One informant stated:

> **"**I agree with the idea that blending TEK and scientific approaches could improve our ability to manage the environment. We observed unusual bird migration patterns and changes in the flowering cycles of certain plants, these observations prompted further monitoring or verification with meteorological data, creating an integrated alert system that is both culturally resonant and scientifically grounded**"** (Interviewee Y, Monday, June 10, 2024).

The results indicate a recognition of the epistemological compatibility between TEK and scientific methods, particularly in the area of environmental management and climate resilience. Despite their different epistemological foundations, TEK and scientific methods aim to understand environmental changes to enhance community well-being. This integration is about merging data and harmonising the philosophical foundations underpinning both systems. This complementary relationship was highlighted by participants who noted the practical benefits of combining these approaches, leading to improved fishing efficiency and sustainability.

The evidence suggests that this synthesis enhances predictive accuracy and ensures culturally appropriate and sustainable environmental practices. It aligns with recent literature advocating combining indigenous knowledge systems with scientific research to address complex environmental challenges (Berkes, 2018; Moller et al., 2016; Whyte, 2017). Relatedly, scholars emphasise that TEK's long-term, place-based insights can enhance the specificity of scientific models, particularly in predicting ecological changes and resource management (Ford et al., 2021). The findings from the study participants align with this view, as they reveal a consensus on the value of combining the macro-level scientific data with the micro-level contextual knowledge inherent in TEK.

However, challenges remain in integrating TEK and scientific methods. These include the potential for misinterpretation or misrepresentation of TEK (Albuquerque et al., 2020), the need for rigorous methods to validate TEK (Ramos, 2021), and the challenges of bridging language and cultural barriers (Souther et al., 2023). To remedy these challenges, researchers and practitioners must adopt a collaborative and respectful approach that values TEK and scientific methods (Albuquerque et al., 2021; Chakraborty, 2024).

Community-Based Climate Resilience

Community-based approaches are becoming increasingly important in climate change adaptation initiatives, particularly in developing countries where vulnerable populations are disproportionately impacted by climate change. These approaches directly engage local communities in developing solutions tailored to their specific needs, priorities, knowledge, and capacities (Mungai, 2024).

Community Engagement in Climate Resilience

The data revealed that one effective strategy for engaging the Effutu community in developing climate resilience plans that integrate both TEK and scientific methods is community engagement. This was captured during the interview.

> **"**Decisions about environmental issues are made collectively in our community. The chief, elders, and leaders of various groups, such as young people and women, come together to discuss the best ways to address these challenges. We organised community labour days to implement decisions, such as building barriers to protect against flooding or planting trees to prevent soil erosion. Everyone has a role to play, and we relied on the strength of our community to get things done**"** (Interviewee Q, Wednesday, July 24, 2024).

The study further established that community engagement contributes to the successful integration of TEK and scientific methods into climate resilience strategies. One informant explained:

> **"**Community engagement is critical because it ensures that the strategies we develop are relevant and accepted by the people who will implement them. When we are engaged, we are more likely to share our traditional knowledge openly and see the value of combining it with scientific methods. This collaboration leads to strategies that are more comprehensive and tailored to our specific needs. It also builds trust between the community and scientists, making it easier to adopt new practices and technologies that are introduced through scientific methods**"** (Interviewee S, Monday, June 10, 2024).

The data underscores the critical role of community-based approaches in enhancing climate resilience, especially in regions heavily impacted by climate change. The evidence from extant research has shown that community involvement in decision-making processes leads to more sustainable and context-specific solutions, as it leverages local knowledge and increases the acceptability of interventions (Ayers & Forsyth, 2009; Dodman & Mitlin, 2013; Gómez-Baggethun et al., 2013; Smith & Sharp, 2023). Community engagement is highlighted as a pivotal mechanism for building trust and collaboration between local populations and scientific experts. This synergy is crucial for the success of resilience initiatives, as it facilitates the blending of TEK—grounded in long-term, place-based observations—with scientific data, thereby enriching the resilience strategies with a holistic perspective.

Current research corroborates this integration, noting that blending local knowledge systems with scientific approaches can enhance adaptive capacity by creating more robust and adaptable solutions to climate challenges (Nyong et al., 2022). Moreover, the data implies that community-led initiatives are not only effective in strategy development but also in the implementation phase. By involving community members in both planning and execution, the strategies are more likely to be practical and culturally relevant, thus ensuring higher levels of participation and commitment. This finding is consistent with studies that argue for the effectiveness of decentralised climate adaptation efforts, which emphasise local agency and ownership in addressing environmental challenges (Adger et al., 2021). However, while the benefits of community engagement are clear, some literature suggests that there are challenges to be navigated, such as power dynamics within communities and the potential for unequal participation (Armitage et al., 2020).

Local Adaptation Strategies

The Effutu Municipality faces several specific climate risks, such as flooding, coastal erosion (Jonah et al., 2016), and changes in rainfall that significantly impact its communities and livelihoods. These risks are exacerbated by the region's low-lying topography and dry equatorial climate characterised by low annual rainfall and prolonged dry seasons. Flooding, in particular, has become a pressing issue, with anecdotal evidence indicating that weak enforcement of building regulations, choked drainage systems, and the construction of homes on waterways contribute to the severity of flood events. The data reveals that Effutu municipality's local adaptation strategies, particularly in response to climate risks like flooding, coastal erosion, and erratic rainfall, rely heavily on a blend of TEK and scientific methods. The study identifies three key local adaptation strategies, which are outlined below:

1. **Vegetation-based coastal protection**: Traditional knowledge has long emphasised using vegetation as a natural barrier to slow erosion and protect shorelines. Communities create natural barriers that help stabilise the soil and reduce the impact of waves and storm surges by planting certain types of plants (e.g., grasses, shrubs, and other salt-tolerant plants) along coastal areas. The data reveals that scientific research has strengthened this practice by identifying the most effective plant species for erosion control and determining the best planting techniques to maximise their protective benefits. This collaboration enabled communities to select native vegetation more resistant to changing climate conditions, ensuring long-term sustainability.

> **"**Some of the specific climate risks we face include coastal erosion, unpredictable rainfall patterns, and declines in fish populations (…) our knowledge of traditional coastal protection techniques, such as planting certain types of vegetation to prevent erosion, was enhanced by scientific studies that identify the most effective plant species or optimal planting methods**"** (Interviewee T, Monday, June 24, 2024).

Vegetation-based strategies, such as mangroves, have extensive root systems that stabilise soil, reduce wave energy to provide storm surge protection and serve as critical habitats for marine life. Respondents indicated that coastal communities, especially around the Mooni Lagoon, have long relied on mangroves as a natural defence against erosion and flooding. Beyond coastline stabilisation, mangroves provide additional benefits, such as carbon sequestration, improved fish habitats, and storm protection. As a result, local conservation efforts have gained more structure, with better strategies for planting, protecting, and sustaining mangrove forests in high-risk coastal zones. Another research participant added:

"…particularly around the Mooni Lagoon, community-led initiatives have focused on using specific types of vegetation like mangroves to combat coastal erosion. We used them due to their robust root systems, which stabilise the soil and reduce erosion effectively**"** (Interviewee K, Thursday, May 30, 2024).

2. **Adapting fishing practices to changing fish migration**: The impacts of climate change on ocean temperatures contribute to the shifting patterns in fish migration, making traditional fishing practices less reliable. The study reveals that fishermen who have relied on generational knowledge to predict fish availability have noticed inconsistencies, leading to declining catches. To address this challenge, local fishing communities have combined their observations with scientific data on ocean temperatures and fish behaviour. Interaction with respondents revealed that community members have developed more strategic fishing practices, such as adjusting fishing seasons, modifying net placement techniques, and identifying new fishing zones. This adaptation improved fishing success and contributed to sustainable fishing practices by preventing overfishing in stressed areas.

"…also, our observations of changing fish migration patterns were combined with scientific data on ocean temperatures to develop more effective fishing practices. This integration allowed us to adapt more effectively to the changes we are experiencing, and we developed strategies that are both practical and evidence-based**"** (Interviewee T, Monday, June 24, 2024).

3. **Soil health monitoring for sustainable agriculture**: Agricultural productivity is heavily influenced by soil health, and traditional farmers have long relied on experience-based knowledge to manage soil fertility.

However, with changing climate conditions, traditional methods alone may not be sufficient to sustain high yields over time. Interaction with respondents revealed that incorporating scientific research into soil health monitoring helps farmers to better understand soil composition, nutrient levels, and the impact of climate variability on soil degradation. It allows for more informed decision-making regarding crop rotation, fertilisation techniques, and land management strategies. Continuous data collection ensures that adaptation measures are adjusted as conditions change, making agricultural practices more resilient to climate stressors. To determine how sustainable the integration is, the research participants were asked whether local adaptation strategies that integrate TEK and scientific methods can be designed to ensure that they are both effective and sustainable. One informant opined:

"…there is a need for scientific research on soil health to improve yields and soil fertility over the long term. Continuously monitoring and adjusting these strategies based on new data and observations helps ensure they remain effective as conditions change. Sustainability also comes from ensuring that these strategies are easy for everyone in the community to understand and implement, ensuring they can be maintained over the long haul**"** (Interviewee K, Tuesday, April 02, 2024).

This integrated approach appears crucial for building resilience, especially in a region marked by a vulnerable low-lying geography and a dry equatorial climate exacerbating these challenges. The utilisation of TEK, such as the planting of erosion-resistant mangrove species (Rhizophora mangle Avicennia germinans), aligns with scientific recommendations for ecosystem-based adaptation strategies, demonstrating a synergistic approach to environmental management (Davies-Vollum et al., 2018). This integration stabilises coastlines and enhances biodiversity, which is essential for sustaining local livelihoods dependent on fishing and agriculture.

In contrast to other studies highlighting the limitations of purely traditional or scientific approaches in addressing climate change impacts, this study suggests that a hybrid model can provide a more adaptive and resilient solution. Earlier studies indicate that while TEK offers context-specific insights, it often lacks the predictive precision of scientific methods (Nyong et al., 2022). Combining these approaches, communities in Effutu have optimised agricultural practices, such as using drought-resistant crops and enhancing soil moisture through mulching, thus improving food security in a region heavily reliant on subsistence farming (Adger et al., 2021).

However, challenges remain in scaling these integrated strategies, particularly given the need for capacity building and the consistent updating of scientific data to match the pace of environmental changes. Literature on sustainable adaptation emphasises that while community engagement is crucial, it must be paired with institutional support and policy frameworks that facilitate the flow of resources and knowledge (Adimle-Puplampu et al., 2023).

Sustainable Practices

Sustainability is critical in climate adaptation, particularly for communities facing persistent environmental changes. Sustainable practices ensure that adaptation strategies are not only effective in the short term but also provide long-term benefits for both the environment and local livelihoods. These sustainable practices differ from the previously identified local adaptation strategies, which focused on immediate actions to cope with climate risks, such as using vegetation to combat erosion or adjusting fishing techniques in response to changing fish migration patterns. In the context of the Effutu municipality, where communities face climate risks such as flooding and changing rainfall patterns, integrating TEK with scientific methods can lead to more effective and culturally relevant adaptation strategies. For example, local knowledge about seasonal weather patterns and traditional farming practices can be combined with scientific climate data to develop adaptive agricultural techniques that improve food security and resource management. Interaction with respondents reveals four key sustainable practices:

1. **Sustainable fisheries management:** Ensuring the long-term health of fish populations is crucial for coastal communities that depend on fishing for their livelihoods. Respondents noted that traditional fishing knowledge, such as seasonal fishing bans and community-enforced no-fishing zones, has long been used to manage fish stocks. However, with increasing climate impacts, integrating scientific research on fish populations and water quality has strengthened these practices. This dual approach allows fishers to decide where and when to fish, sustaining their livelihoods and marine ecosystems.

> **"**Integrating TEK and scientific methods in sustainable resource management can greatly increase long-term resilience. Our traditional practices of managing fishing areas and rotating crops have helped us maintain resources over time, but with the added insights from scientific methods, we have improved these practices. For example, using scientific data on fish populations and water quality, we set more accurate limits on fishing to prevent overharvesting, ensuring that fish stocks remain healthy where we fish**"** (Interviewee B, Sunday, June 30, 2024).

2. **Soil science and traditional farming for sustainable agriculture:** Soil health is fundamental to agricultural sustainability. Interactions with respondents reveal that many farmers traditionally relied on generational knowledge to determine periods for planting. They also used natural composting methods and crop rotation to maintain soil fertility. However, scientific methods, such as soil nutrient testing, have helped refine these practices to ensure long-term land productivity. Another informant intimated:

> **"**Yes, integrating scientific techniques for soil analysis with traditional farming methods helped us use our land more efficiently, reducing the need for chemical fertilisers and enhancing soil health. This combination of knowledge ensures that our resources are managed in a way that supports both our current needs and those of future generations**"** (Interviewee K, Sunday, April 7, 2024).

3. **Diversification of income sources:** The data revealed that many coastal communities, historically reliant on fishing, have started engaging in small-scale farming, petty trading, and other economic activities to supplement their income. This approach helps buffer the impacts of declining fish stocks and unpredictable weather conditions.

> **"**We've had to adjust our fishing practices. We go out earlier in the morning now when the sea is calmer. Some of us have started diversifying, doing some small-scale farming and petty trading to supplement our income when fishing is poor. These methods have developed out of necessity. They help, but it's still a struggle**"** (Interviewee I, Saturday, May 4, 2024).

Another informant added:

> **"**We've started using different fishing techniques, like going out further to sea and using different types of nets. As we noticed changes, we had to adapt to survive. Some methods work better than others. Diversifying income has been helpful, but going further out to sea is risky. Our practices are constantly evolving as we face new challenges. We're more open to new ideas now than we were in the past" (Interviewee P, Sunday, June 30, 2024).

The study revealed that communities are becoming more flexible and innovative in response to adversity, although not all adaptations are equally effective; some carry significant risks. The findings highlight the importance of continued experimentation, openness to new approaches, and the need for support in managing these risks. This approach reinforces environmental stewardship and empowers communities by valuing their knowledge systems and increasing their involvement in sustainable development initiatives. Literature supports this fusion of knowledge systems as a viable adaptation strategy. Berkes et al. (2020) underscores that integrating TEK with scientific data strengthens resilience in resource-dependent communities by fostering adaptive responses to environmental change. Similarly, Adger (2003) highlights that integrating local knowledge can improve social cohesion and community capacity to adapt, as it incorporates indigenous practices into sustainable resource management.

The narrative of local informants reveals pragmatic adjustments in fishing and farming techniques, which reflect a flexible, adaptive approach to climate challenges. Rotating crops and using soil analysis to reduce chemical fertilisers promote soil health and align with findings in agroecological studies. Altieri and Nicholls (2017) conceded this and argued that blending scientific analysis with local farming practices significantly enhances resource use efficiency, reduces reliance on chemical inputs, and supports long-term ecological balance. Such integration has been shown to improve both immediate survival strategies and future resilience by diversifying income sources—a necessity, as indicated by informants who have adapted by starting small businesses and adjusting fishing schedules. Echoing these findings, Thomas and Twyman (2005) note that diversified income strategies are critical for rural communities facing climate unpredictability, as they reduce dependency on single resources and foster economic resilience.

However, challenges remain, especially with certain adaptive practices such as fishing further out to sea, which can increase both physical and economic risk for local fishers. This mirrors findings by Béné et al. (2016), who caution that diversification and adaptive strategies are generally beneficial but present new risks, especially when unpredictable environmental changes stretch traditional practices. Thus, while TEK and scientific knowledge integration offer significant benefits for sustainable resource management and adaptation, a nuanced approach that considers the risks and limitations of each method is essential.

Conclusions and Policy Recommendations

The study underscores the critical need to tailor climate resilience strategies to local contexts, as generalised approaches often fail to address the unique cultural, social, and institutional factors that shape community responses to climate risks. This study provides compelling evidence for integrating TEK with scientific methods in developing climate resilience strategies. By bridging these different knowledge systems, communities can create more effective, sustainable, and culturally appropriate responses to the challenges posed by climate change. This integrated approach enhances adaptive capacity and promotes more equitable and inclusive forms of climate governance as climate change poses unprecedented challenges to communities worldwide. Such integrated approaches offer a promising pathway towards building resilience in uncertainty.

Based on the research findings, the study makes the following recommendations:

1. Policymakers should **establish frameworks that facilitate and incentivise knowledge co-production between local communities and scientific experts**. These frameworks could involve creating funding mechanisms for collaborative research projects and developing guidelines for equitable partnerships between academic institutions and local communities.

2. Policymakers should **prioritise the integration of TEK with scientific methods in the development of climate resilience strategies**. This prioritisation requires formally recognising TEK as a valuable component of environmental management and establishing platforms for knowledge co-production that facilitate collaboration between scientists and local communities.

3. Policymakers should **encourage and support community-led initiatives that engage local stakeholders in the planning, implementation, and monitoring of resilience strategies**, ensuring that these strategies are tailored to the specific needs and contexts of the communities involved.

4. The government must enact **policies that promote continuous learning and adaptation within climate resilience frameworks**. This involves the

development of mechanisms for regular data collection, monitoring, and evaluation, allowing strategies to evolve in response to new information and changing conditions.

5. Governments and development agencies should **invest in capacity-building programs that empower local communities by enhancing their understanding of scientific methods and tools while preserving and promoting traditional knowledge systems**. These policies can help build stronger, more resilient societies capable of effectively responding to the challenges posed by climate change by advancing a sense of ownership and responsibility among local communities.

References

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography, 79*(4), 387-404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Adger, W. N., Barnett, J., Brown, K., Marshall, N., & O'Brien, K. (2013). Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change, 3*(2), 112-117. https://doi.org/10.1038/nclimate1666

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., Otto Naess, L., Wolf, J., & Wreford, A. (2021). Are there social limits to adaptation to climate change? *Climatic Change*, *93*(3-4), 335-354. https://doi.org/10.1007/s10584-010-0005-6

Adiikanbasi, P. (2018). Women's participation in decision-making among fishmongers in the Effutu Municipality of Ghana. *UDS International Journal of Development (UDSIJD)*. https://www.udsijd.org/index.php/udsijd/article/view/241/119

Adimle-Puplampu, D., Alorbu, V., Owusu, A. B., Takaman, J. L., Iddris, K., & Asante, J. O. (2023). Shoreline change analysis of the eastern coast of Ghana between 1991 and 2020. *Journal of Environmental Geography*, *16(*2-3), 91-102. https://doi.org/10.14232/jengeo-2023-44339

Ahmed, S. (2022). Traditional beliefs and institutions for the conservation of biodiversity in Ethiopia: A review from a conservation perspective. *International Journal of Natural Resource Ecology and Management*, *7*(1), 1-5. https://doi.org/10.11648/j.ijnrem.20220701.11

Aktürk, E., & Hauser, M. C. (2021). Intangible cultural heritage: a benefit to climate-displaced and host communities. *Journal of Community Archaeology & Heritage, 8*(1), 3-18. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8105694/

Albuquerque, U. P., Ludwig, D., Gonçalves-Souza, T., Feitosa, I. S., Silva, T. C., Moura, J. M. B., Ferreira Júnior, W. S., Silva, R. H., & Gonçalves, P. H. S. (2021). Integrating traditional ecological knowledge into academic research at local and global scales. *Regional Environmental Change*, *21*(2), 45-58. https://doi.org/10.1007/s10113-021-01774-2

Albuquerque, U. P., Silva, T. C., Ferreira Júnior, W. S., Gonçalves-Souza, T., Feitosa, I. S., Ludwig, D., Silva, R. H., Moura, J. M. B., & Gonçalves, P. H. S. (2020). A reappraisal of the predictive power of traditional ecological knowledge in ecology and conservation. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3556479

Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change, 140*(1), 33-45. https://doi.org/10.1007/s10584-013-0909-y

Antwi-Agyei, P., Dougill, A. J., Stringer, L. C., & Codjoe, S. N. A. (2018). Adaptation opportunities and maladaptive outcomes in climate vulnerability hotspots of northern Ghana. *Climate Risk Management, 19*, 83-93.

Arkhurst, B. M., Poku-Boansi, M., & Adarkwa, K. K. (2022). Perception on coastal erosion: An assessment of how national-level coastal resilience strategies promote indigenous knowledge and affect local level adaptation in Ghanaian communities. *Environmental Science & Policy*, *137*(2022), 290-300. https://doi.org/10.1016/j.envsci.2022.08.019

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Diduck, A. P., Doubleday, N. C., Johnson, D. S., Marschke, M., McConney, P., Pinkerton, E. W., & Wollenberg, E. K. (2009). Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and the Environment, 7*(2), 95-102.

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change, 21*(3), 995-1004. https://doi.org/10.1016/j.gloenvcha.2011.04.006

Ayers, J., & Forsyth, T. (2009). Community-based adaptation to climate change. Environment: *Science and Policy for Sustainable Development, 51*(4), 22-31. https://doi.org/10.3200/ENV.51.4.22-31

Baby, S. N., Arrowsmith, C., Abbas, N., Liu, G. J., & Mitchell, D. (2021). Developing a spatial tool for assessing coastal communities and identifying infrastructure at risk. Engineering, 13(1), 123-140. https://doi.org/10.4236/eng.2021.131004

Bagheri, M., Oryani, B., Wolf, I. D., Ibrahim, Z. Z., Wan Talaat, W. I. A., & Akhir, M. F. (2022). Sea-level projections using a NARX-NN model of tide gauge data for the coastal city of Kuala Terengganu in Malaysia. *Environmental Science and Pollution Research International, 29*(33), 49018-49033. https://doi.org/10.1007/s11356-022-21662-4

Béné, C., Steel, E., Luadia, B. K., & Gordon, A. (2016). Do 'resilience interventions' help the poor to cope better? Evidence from a mixed-methods study in northern Uganda. *World Development, 79*, 68-82. https://doi.org/10.1016/j.worlddev.2015.10.007

Berkes, F. (2009). Community conserved areas: Policy issues in historic and contemporary context. *Conservation Letters, 2*(1), 19–24. https://doi.org/10.1111/j.1755-263X.2008.00040.x

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management, 90*(5), 1692-1702. https://doi.org/10.1016/j.jenvman.2008.12.001

Berkes, F. (2009). Indigenous ways of knowing and the study of environmental change. *Journal of the Royal Society of New Zealand, 39*(4), 151-156.

https://doi.org/10.1080/03014220909510568

Berkes, F. (2018). *Sacred ecology* (4th ed.). Routledge.
https://doi.org/10.4324/9780429494235

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Brown, K., Adger, W. N., Devine-Wright, P., Anderies, J. M., Barr, S., Bousquet, F., Butler, C., Evans, L., Marshall, N., & Quinn, T. (2019). Empathy, place and identity interactions for sustainability. *Global Environmental Change, 56*, 11–17. https://doi.org/10.1016/j.gloenvcha.2019.03.003

Chakraborty, S. (2024). Synergy of Traditional Ecological Knowledge (TEK) and intellectual property rights (IPR) in biodiversity management and conservation. *Uttar Pradesh Journal of Zoology*, *45*(1), 132-148. https://doi.org/10.56557/upjoz/2024/v45i164326

Chemura, A., Schauberger, B., & Gornott, C. (2020). Impacts of climate change on agro-climatic suitability of major food crops in Ghana. *PLOS One, 15*(6), e0229881. https://doi.org/10.1371/journal.pone.0229881

Creswell, J. W., & Creswell, D. J. (2023). *Research design: Qualitative, quantitative, and mixed methods approaches (6th ed).* Sage Publications, Inc.

Dasgupta, S., Laplante, B., Murray, S., & Wheeler, D. (2011). Exposure of developing countries to sea-level rise and storm surges. *Climatic Change, 106*(4), 567-579.

https://doi.org/10.1007/s10584-010-9959-6

Datta, R., & Kairy, B. (2024). Decolonizing climate change adaptations from Indigenous perspectives: Learning reflections from Munda Indigenous communities, coastal areas in Bangladesh. *Sustainability 2024, 16*(2), 769; https://doi.org/10.3390/su16020769

David-Chavez, D. M., & Gavin, M. C. (2018). A global assessment of Indigenous community engagement in climate research. *Environmental Research Letters, 13*(12), 123005.

Davies-Vollum, K. S., Agyekumhene, A., & Zhang, Z. (2018). Impacts of lagoon opening and implications for coastal management: A case study from Muni-Pomadze lagoon, Ghana. *Journal of Coastal Conservation*, *22*(4), 735-746. https://doi.org/10.1007/s11852-018-0658-1

Dodman, D., & Mitlin, D. (2013). Challenges for community-based adaptation: Discovering the potential for transformation. *Journal of International Development, 25*(5), 640-659. https://doi.org/10.1002/jid.1772

Donkor, F. K., & Mearns, K. (2022). Harnessing Indigenous knowledge systems for enhanced climate change adaptation and governance: Perspectives from Sub-Saharan Africa. In *Sustainable Development and Climate Resilience* (pp. 328-335). Springer. https://doi.org/10.1007/978-3-030-99411-2_14

Fazlıoğulları, O. (2012). Scientific research paradigms in Social Sciences. *International Journal of Educational Policies, 6*(1), 41–55.

Ford, J. D., Labbé, J., & Berrang-Ford, L. (2016). The impact of climate change on the health of Indigenous peoples in Canada: A systematic review. *Environmental Research Letters, 11*(12), 123006. https://doi.org/10.1088/1748-9326/11/12/123006

Gómez-Baggethun, E., Corbera, E., & Reyes-García, V. (2013). Traditional ecological knowledge and global environmental change: Research findings and policy implications. *Ecology and Society, 18*(4), 72.

Gómez-Baggethun, E., Reyes-García, V., Olsson, P., & Montes, C. (2012). Traditional ecological knowledge and community resilience to environmental extremes: A case study in Doñana, SW Spain. *Global Environmental Change, 22*(3), 640-650. https://doi.org/10.1016/j.gloenvcha.2012.02.005

Gyampoh, B. A., Amisah, S., Idinoba, M., & Nkem, J. N. (2020). *Using traditional knowledge to cope with climate change in rural Ghana.* FAO. Retrieved from https://www.fao.org/4/i0670e/i0670e14.htm

Hind, E. J. (2015). A review of the past, the present, and the future of fishers' knowledge research: A challenge to established fisheries science. *ICES Journal of Marine Science, 72*(2), 341-358. https://doi.org/10.1093/icesjms/fsu169

Intergovernmental Panel on Climate Change (2014). *Climate change 2014: Impacts, adaptation, and vulnerability. Part a: Global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Intergovernmental Panel on Climate Change (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report on the Intergovernmental Panel on Climate Change.* University of Cambridge Press.

Jamero, M. L., Takagi, H., Billones-Sensano, X. K., Nellas, A., Onuki, M., Thao, N. D., Tan, N., Valenzuela, V. P., & Esteban, M. (2017). Small-island communities in the Philippines prefer local measures to relocation in response to sea-level rise. *Nature Climate Change*, 7(8), 581–586. https://doi.org/10.1038/nclimate3344

Jamero, M. L., Onuki, M., Esteban, M., & Tan, N. (2018). Community-based adaptation in low-lying islands in the Philippines: Challenges and lessons learned. *Regional Environmental Change*, 18(2), 2245–2257. https://doi.org/10.1007/s10113-018-1332-8

Jarkeh, M., Miri, A., Shahriari, A., Middleton, N., & Ahmadian, S. (2024). Teng: Indigenous-nature-based solutions for sand mitigation in Sistan region, Iran - A comprehensive approach to climate resilience and sustainable development. *EGU Sphere*. https://doi.org/10.5194/egusphere-egu24-12477

Jonah, F. E., Mensah, E. A., Edziyie, R. E., Agbo, N. W., & Adjei-Boateng, D. (2016). Coastal erosion in Ghana: Causes, policies, and management. *Coastal Management*, *44*(1), 35-50. https://doi.org/10.1080/08920753.2016.1135273

Kamakaula, Y., Amruddin, A., Demmanggasa, Y., Nugroho, R. J., & Saprudin, S. (2024). The role of local knowledge in natural resources conservation: An environmental anthropological perspective in traditional agriculture. *Global International Journal of Innovative Research*, *1*(2), 97–106. https://doi.org/10.59613/global.v1i2.13

Kumar, R. (2019). *Research methodology: A step-by-step guide for beginners (5th ed.).* SAGE Publications, Ltd.

Kyeremeh, S., Adu-Boahen, K., & Addai, M. O. (2023). Economic evaluation of groundwater resource in the Effutu Municipality: An application of the Gisser-Sanchez effect. *Heliyon*,*1*(2), 97–106. https://doi.org/10.1016/j.heliyon.2023.e16398

Makondo, C. C., & Thomas, D. S. G. (2018). Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. *Environmental Science & Policy*, 85, 86-92. https://doi.org/10.1016/j.envsci.2018.06.014

Mekonnen, Z., Kidemu, M., Abebe, H., Semere, M., Gebreyesus, M., Worku, A., Tesfaye, M., & Chernet, A. (2021). Traditional knowledge and institutions for sustainable climate change adaptation in Ethiopia. *Current Research in Environmental Sustainability*, 3, 2021, 100080 https://doi.org/10.1016/j.crsust.2021.100080

Miao, L., Wang, H., Sun, X., & Wu, L. (2024). Biomineralization for reducing and controlling sand-dust storms. *Advanced Science*, *11*(10), Article 202403961.

https://doi.org/10.1002/advs.202403961

Mistry, J., & Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science*, *352*(6291), 1274-1275. https://doi.org/10.1126/science.aaf1160

Moller, H., Berkes, F., & Laidlaw, M. (2016). Traditional ecological knowledge and climate change adaptation. *Annual Review of Environment and Resources, 41*, 525-551

Mungai, C. (2024). *Community-Based Climate Resilience; Grassroot Initiatives Making a Difference.* African Sustainability Matters.

https://africasustainabilitymatters.com/community-based-climate-resilience/

Myers, M. R., Barnard, P. L., Beighley, E., Cayan, D. R., Dugan, J. E., Feng, D., Hubbard, D. M., Iacobellis, S. F., Melack, J. M., & Page, H. M. (2019). A multidisciplinary coastal vulnerability assessment for local government focused on ecosystems, Santa Barbara area, California. *Ocean & Coastal Management*, 182, 104921. https://doi.org/10.1016/j.ocecoaman.2019.104921

Naess, L. O. (2013). The role of local knowledge in adaptation to climate change. Wiley Interdisciplinary Reviews: *Climate Change, 4*(2), 99-106.

https://doi.org/10.1002/wcc.204

Nalau, J., & Becken, S. (2018). *Ecosystem-based adaptation to climate change: Review of concepts. Griffith Institute for Tourism Research Report Series No. 15*. Griffith University.

Nalau, J., Becken, S., Schliephack, J., Parsons, M., Brown, C., & Mackey, B. (2018). The role of indigenous and traditional knowledge in ecosystem-based adaptation: A review of the literature and case studies from the Pacific Islands. *Weather, Climate, and Society, 10*(4), 851-865. https://doi.org/10.1175/WCAS-D-18-0032.1

Niu, Y., Abdullayev, V., Alyar, A. V., & Kamran, T. A. (2023). Resilience and adaptation to climate change: Community-based strategies in coastal regions. *Estidamaa*. https://doi.org/10.70470/estidamaa/2023/005

Nursey-Bray, M., Palmer, R., Smith, T. F., & Rist, P. (2019). Old ways for new days: Australian Indigenous peoples and climate change. Local Environment, 24(5), 473-486. https://doi.org/10.1080/13549839.2019.1590325

Nyantakyi-Frimpong, H. (2020). What lies beneath Climate change, land expropriation, and zaï agroecological innovations by smallholder farmers in Northern Ghana. *Land Use Policy, 92,* 104469. https://doi.org/10.1016/j.landusepol.2020.104469

Nyong, A., Adesina, F., & Osman Elasha, B. (2007). The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change, 12*(5), 787-797.

https://doi.org/10.1007/s11027-007-9099-0

O'Leary, Z. (2017). *The essential guide to doing your research project (3rd ed.)*. Sage Publication Ltd.

Onat, Y., Francis, O. P., & Kim, K. (2018). Vulnerability assessment and adaptation to sea level rise in high-wave environments: A case study on O'ahu, Hawai'i. *Ocean & Coastal Management*, 157, 56–66. https://doi.org/10.1016/j.ocecoaman.2018.02.021

Owusu, M., Nursey-Bray, M., & Rudd, D. (2021). Gendered perception and vulnerability to climate change in urban slum communities in Accra, Ghana. *Regional Environmental Change, 21*(1), 1-14. https://doi.org/10.1007/s10113-018-1357-z

Ramos, S. C. (2021). Understanding Yurok traditional ecological knowledge and wildlife management. *The Journal of Wildlife Management*, *85*(4), 687-698. https://doi.org/10.1002/jwmg.22140

Raveena, N. K. (2024). Traditional knowledge for sustainable practices: Indigenous tribal people's cognizance of climate change. *International Journal of Scientific Research in Engineering and Management*, *3*(2), 31-45. https://doi.org/10.55041/ijsrem34478

Sesana, E., Gagnon, A. S., Bonazza, A., & Hughes, J. J. (2020). An integrated approach for assessing the vulnerability of World Heritage Sites to climate change impacts. *Journal of Cultural Heritage, 41*, 211-224. https://www.britishcouncil.org/research-insight/british-council-strategic-literature-review-climate-change-impacts-cultural

Shapiro-Garza, E., King, D., Rivera-Aguirre, A., Wang, S., & Finley-Lezcano, J. (2019). A participatory framework for feasibility assessments of climate change resilience strategies for smallholders: Lessons from coffee cooperatives in Latin America. *International Journal of Agricultural Sustainability, 18*(1), 21–34.

https://doi.org/10.1080/14735903.2019.1658841

Smith, P., & Sharp, R. (2023). Enhancing community resilience through participatory climate change adaptation planning. *Environmental Science & Policy*, 133, 146-154. https://doi.org/10.1016/j.envsci.2022.09.015

Song, J., Wang, R., Gu, Z., Peng, Z. R., & Fu, X. (2017). Does planned retreat matter? Investigating land use change under the impacts of flooding induced by sea level rise. *Mitigation and Adaptation Strategies for Global Change*, 22(6), 1017–1034. https://doi.org/10.1007/s11027-017-9756-x

Souther, S., Lyndon, N. N., & Colombo, S. (2023). Integrating traditional ecological knowledge into US public land management: Knowledge gaps and research priorities. *Frontiers in Ecology and Evolution*, 11, 988126. https://doi.org/10.3389/fevo.2023.988126

Thomas, D. S. G., & Twyman, C. (2005). Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Global Environmental Change, 15*(2), 115-124. https://doi.org/10.1016/j.gloenvcha.2004.10.001

Villamayor-Tomas, S., Bisaro, A., Moull, K., Albizua, A., Mank, I., Hinkel, J., Leppert, G., & Noltze, M. (2024). Developing countries can adapt to climate change effectively using nature-based solutions. *Communications Earth & Environment, 5*(1), 214. https://doi.org/10.1038/s43247-024-01356-0

Wheeler, H. C., Danielsen, F., Fidel, M., Hausner, V., Horstkotte, T., Johnson, N., Lee, O., Mukherjee, N., Amos, A., Ashthorn, H., Ballari, Ø., Behe, C., Breton-Honeyman, K., Retter, G., Buschman, V., Jakobsen, P., Johnson, F., Lyberth, B., Parrott, J. A., ... Vronski, N. (2020). The need for transformative changes in the use of Indigenous knowledge along with science for environmental decision-making in the Arctic. *People and Nature, 2*(3), 544-556. https://doi.org/10.1002/pan3.10131

Whyte, K. P. (2017). Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene. *English Language Notes, 55*(1-2), 153-162.

Woodside, Arch. G. (2010). *Case study research: Theory, methods and practice.* Emerald Group Publishing Limited.

Yeleliere, E., Antwi-Agyei, P., & Guodaar, L. (2023). Farmers' response to climate variability and change in rainfed farming systems: Insight from lived experiences of farmers. *Environmental Science and Pollution Research, 30*(1), 1234-1249. https://doi.org/10.1016/j.heliyon.2023.e19656

Yin, R. K. (2018). *Case study research and applications: Designs and methods (6th ed.).* SAGE Publications, Inc.

Zenebe, M., Kidemu, M., Abebe, H., Semere, M., Gebreyesus, M., Worku, A., Tesfaye, M., & Chernet, A. (2021). Traditional knowledge and institutions for sustainable climate change adaptation in Ethiopia. *Current Research in Environmental Sustainability, 3, 100080,* . https://doi.org/10.1016/j.crsust.2021.100080

Zhu, X., Dai, Q., Liu, Y., Wu, Y., Niu, Y., Yin, K., ... & Gu, X. (2022). Beyond inundation: a comprehensive assessment of sea level rise impact on coastal cultural heritage in China. *Heritage Science, 10*(1), 1-16.

https://heritagesciencejournal.springeropen.com/articles/10.1186/s40494-024-01233-1

Zobeidi, T., Yazdanpanah, M., Komendantova, N., Löhr, K., & Sieber, S. (2024). Evaluating climate change adaptation options in the agriculture sector: A PROMETHEE-GAIA Analysis. *Environmental and Sustainability Indicators, 2*, 100395. https://doi.org/10.1016/j.indic.2024.100395

Circular Economy and Waste Management

4

Waste Management and Climate Change: Perspectives and Opportunities Towards Resilient Pathways in Ghana

Khadija Sarquah and Mubarick Issahaku

Abstract

Although relatively minor, the waste sector's contribution to GHG emissions exacerbates climate-related issues such as pollution, urban flooding, and biodiversity loss. On the other hand, effective waste recovery replaces raw materials, reducing environmental harm from extraction in sectors like manufacturing, energy, and transport. Ghana faces increasing challenges in waste management, with over 14,100 tons of municipal solid waste (MSW) generated daily. This high rate of waste generation, combined with inadequate infrastructure and weak regulatory enforcement, poses significant environmental, social, and economic risks. This chapter examines Ghana's waste management practices and their alignment with climate resilience and circular economy principles. Through a review of existing literature and institutional reports, the study identifies critical gaps, including the lack of infrastructure, limited integration of the informal sector, and weak regulation enforcement. The analysis highlights opportunities for transformative solutions, such as leveraging decentralised waste processing and fostering partnerships. Key recommendations include upscaling source segregation, incentivising private sector investment in recycling and waste-to-energy projects and strengthening regulatory frameworks for product design and waste value chain. The chapter also emphasises the need for green financing mechanisms, education, and capacity building to support innovation in sustainable waste management practices. The diversity presents opportunities to decrease the impacts and vulnerability of waste challenges on climate action while fostering economic growth and achieving sustainable development goals.

Keywords: Pollution; Municipal Solid Waste; Environment; Circular Economy; Climate Change

Introduction

Waste management is a global concern which has prompted nations to explore more sustainable solutions. Waste management's effect may vary from jurisdiction to jurisdiction, resulting from different economies of scale, managerial skills, and socio-economic levels. Waste forms are diverse and can be classified by source or origin, product type, materials type, structure, or form (UNEP, 2024), as illustrated in Figure 1. Waste is generated in all human settlements, but its quantity and composition vary based on factors such as population growth, human activities, production, and consumption patterns. This includes different waste types such as municipal, industrial, healthcare, construction and demolition, and agricultural waste. Additionally, waste classification systems differ across countries, reflecting variations in regulations, economic structures, and environmental policies.

Municipal Solid Waste (MSW) includes waste from residential areas, businesses, and service providers. It comprises food waste, packaging materials, household items such as broken furniture and electronics, clothing and footwear, and personal hygiene products. The World Bank estimates that MSW forms about 8% of the total waste generation. While this may represent a smaller fraction of total waste generation compared to industrial and construction waste, inadequate waste management systems in some regions lead to mixing other waste types with MSW. For instance, in areas with insufficient disposal regulations, demolition debris and healthcare waste may end up in MSW streams. Therefore, understanding waste composition is essential for developing effective management strategies.

Figure 1: Forms of Waste

Source/Origin	Material/Product type	State waste	Risk Level
Industrial Agricultural Municipal Medical	Plastic Food Electronics Textile Composite materials	Solid Liquid Gaseous Radioactive	Hazardous Non hazardous

Source: Authors' construct from adapted literature (Antwi, 2019; Bigos, 2024; UNEP, 2024)

Most nations continue to face considerable challenges in overcoming the waste menace. According to UNEP, the increasing generation rate, coupled with mismanagement efforts, contributes to about 87% of the total MSW generated (UNEP, 2024). The uncontrolled MSW disposal rate is projected to increase from 38% in 2020 to 41% by 2050 in the sub-Saharan Africa region. Waste (wastewater and landfill) is responsible for relatively low levels of emissions, 3%-5% of total global anthropogenic emissions (Ritchie, 2020). However, the consequences of improper waste disposal and management extend far beyond climate impacts or greenhouse gas (GHG) emissions, which tend to have broader effects. The more immediate and pronounced consequences are felt mainly regarding human health. Poor waste management practices can lead to severe public health risks such as waterborne diseases, respiratory issues from air pollution, and exposure to toxic substances. Expanding landfills and unmanaged waste sites also encroach upon valuable land resources, leading to environmental degradation and lost economic opportunities. Proper waste management also plays a critical role in reducing emissions across multiple sectors, as practices such as recycling help to reduce emissions linked to industrial production and energy generation.

In Ghana, municipal solid waste (MSW) generation amounts to approximately 0.47 kg/person per day (Miezah et al., 2015), resulting in an estimated daily waste generation of about 15,407 tons, given a population size of 33.4 million. Waste management in Ghana is primarily based on collection and disposal, with minimal emphasis on waste separation, recycling, or recovery. This conventional strategy does not align with circular economy principles and SDGs, as it fails to maximise resource efficiency and minimise environmental impact.

Uncontrolled waste management threatens the ecosystem and burdens the economy. An example is Ghana's long-standing challenge of electronic waste disposal (13,090 to 17,094 tons per annum), which is often improperly managed in markets such as Agbogbloshie. The open burning of e-waste at these sites has led to severe land, air, and water contamination, exacerbating environmental degradation and health hazards (Owusu-Sekyere et al., 2022).

Proper waste management is vital to achieving the SDGs. One major challenge is methane emissions from open waste disposal. Methane is a potent greenhouse gas, with a warming potential 25 times greater than carbon dioxide (CO_2). Addressing waste management must, therefore, be recognised as a national priority. In identifying strategies, recognising existing efforts and ongoing activities helps reveal the challenges in developing robust and sustainable solutions.

This chapter focuses on solid waste management, particularly municipal solid waste (MSW) and electronic waste (e-waste). It assesses the country's waste management situation and recommends effective oversight and performance improvement to sustain long-term goals.

This chapter is based on a review of existing literature, secondary data, and institutional reports. An evidence-based framework guided the literature search, utilising databases, and search engines such as Scopus, Google Scholar, and relevant websites. The inclusion criteria focused on English-language literature specific to Ghana and similar contexts, covering themes related to solid waste management and the circular economy. Studies were excluded if they lacked a rigorous methodology, contained incomplete or insufficient data for meta-analysis, or were duplicates to avoid redundancy. An inductive qualitative approach was applied to analyse the selected materials, focusing on key indicators relevant to the scope and thematic areas for content analysis and discussion.

Literature Review

Waste Management Nexus: Climate Change and SDGs

The link between waste management, climate change, and the SDGs is multifaceted. Every stage of waste management—from generation to final disposal and treatment—contributes to climate and SDG-related challenges. These links are evident through the three major planetary crises: greenhouse gas (GHG) emissions, pollution, and biodiversity loss (See Figure 2)

Waste management and GHG emissions

Methane and carbon dioxide (CO_2) are the primary GHGs contributing to global warming and climate change. In the waste sector, the decomposition of organic waste in dumpsites via biochemical activities accumulates methane in the atmosphere. Even after disposal, carbon-containing waste in landfills decomposes slowly, generating emissions over time due to the gradual progression of chemical and biochemical reactions. However, when reporting landfill emissions, the Intergovernmental Panel on Climate Change (IPCC) follows an international convention that excludes CO_2 emissions from the decomposition or incineration of biogenic carbon sources. Biogenic carbon is accounted for under the land use, land-use change, and forestry (LULUCF) category. Consequently, methane emissions from landfills are reported and expressed as tonnes of CO_2 equivalent.

Furthermore, the combustion of waste (controlled or uncontrolled) and biological treatment are minor sources of GHG in the global waste sector. Uncontrolled waste burning is obsolete mainly in developed countries but prevalent in developing regions, causing the release of CO_2. Black carbon from open or uncontrolled waste burning into the atmosphere has a global warming effect. The black carbon settles on the sea's surface and accelerates ice melting.

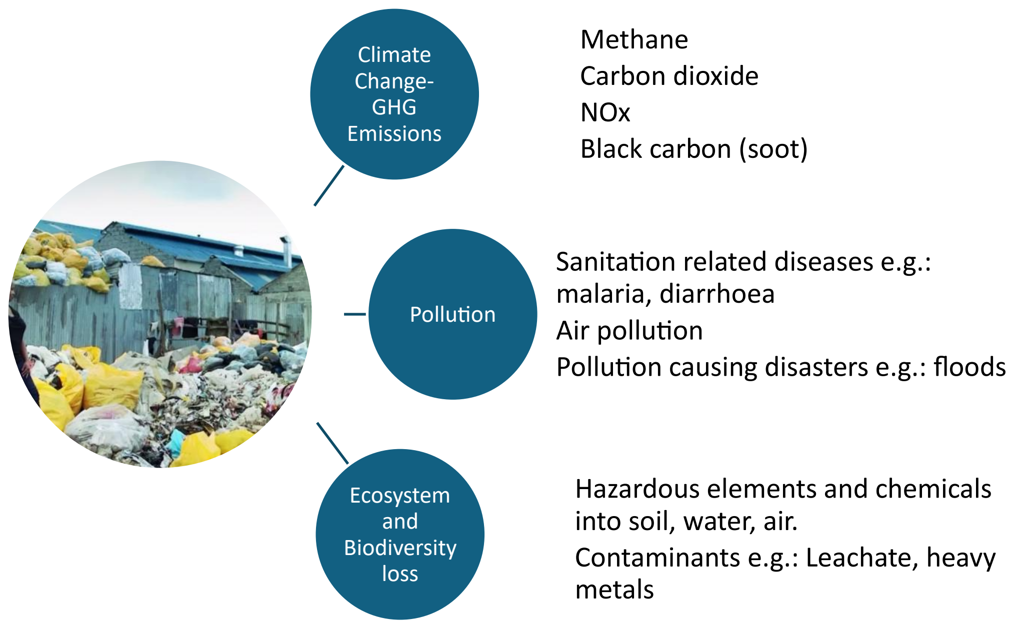
Waste treatment processes are also significant sources of GHG emissions, with variations depending on the technology used and process management. These emissions arise from waste materials' direct combustion or decomposition and the energy inputs required to operate the treatment facilities. In cases where incinerators are energy recovery units (e.g., waste to energy or cogeneration plants), GHG may also be credited. In contrast, incinerators without energy recovery act as net energy users, consuming external energy while releasing emissions.

Advanced thermal treatment technologies like gasification and pyrolysis may emit fewer emissions than traditional mass-burn incineration. These advanced methods often have higher efficiency in capturing and utilising the energy content of waste, leading to potentially lower overall emissions. Aerobic composting primarily emits carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The amount of methane and nitrous oxide released depends on how well the process is managed. For example, poorly aerated compost piles can create anaerobic conditions, leading to higher methane emissions, while excessive nitrogen content can increase nitrous oxide emissions.

Pollution: Improper waste disposal on land contaminates fresh and groundwater sources through the action of pathogens, heavy metals, chemicals, and other hazardous compounds. The open and uncontrolled burning of waste releases Persistent Organic Pollutants (POPs) that can remain in the atmosphere for longer periods. According to the World Health Organisation, about 24% of deaths are attributable to environmental causes, which are largely preventable (WHO, 2022). Similarly, a report by Tearfund estimates that about 400,000 to a million people in low- and middle-income countries die every year from diseases related to mismanaged waste, including respiratory infections, diarrhoea, malaria, heart disease and cancer (Tearfund, 2019). The waste sector exacerbates climate-related disasters. For instance, waste-blocked drainages lead to severe urban flooding during heavy rainfalls and landslides. This affects human lives, settlement displacement and total well-being, limiting the concept of reducing vulnerability due to climate impacts.

Ecosystem and biodiversity loss: Indiscriminate waste disposal practices introduce pathogens and hazardous elements into soil, water bodies and the air. This causes long-term, potentially irreversible damage to local flora and fauna, negatively impacting biodiversity, harming entire ecosystems, and entering the human food chain. The long-term pollution of land and aquatic ecosystems by waste has been recognised as one of the main drivers of biodiversity loss and puts the integrity of entire ecosystems at risk.

Figure 2: Waste Issues and Planetary Crises



Source: Authors' construct synthesised from literature (UNEP, 2013, 2024)

Waste management and SDG nexus

The waste sector is linked to several aspects of the Sustainable Development Goals (SDGs). Waste pollution directly threatens **Goal 3 (Good Health and Well-being)** by exposing communities to harmful pollutants, particularly from dumping and open burning, which have severe health consequences, especially for women and children. It also undermines **Goal 13 (Climate Action),** as poor waste management contributes to greenhouse gas emissions and environmental degradation. Additionally, pollutants leaching from dumpsites contaminate freshwater sources and food chains, jeopardising **Goal 6 (Clean Water and Sanitation)**. Regarding **Goal 15 (Life on Land),** terrestrial ecosystems act as primary waste sinks, with rural communities facing complex waste management challenges that threaten biodiversity and local livelihoods.

In line with **Goal 7 (Affordable and clean energy)**, unavoidable and residual combustible waste can be utilised for waste-to-energy purposes other than disposal following the waste hierarchy. Food waste can also produce biogas, a renewable fuel that helps combat energy poverty. Waste management and recycling contribute to **Goal 8 (Decent work and economic growth)** by providing safe and decent work opportunities for all and improving global resource efficiency and economic growth. Similarly, Goal 9 (**Industry, innovation, and infrastructure**) benefits from private sector investment, promoting innovation, entrepreneurship, domestic technology development and enhanced resource efficiency. Lastly, achieving **Goal 11 (Sustainable cities and communities)** requires universal access to municipal waste management services, ensuring that cities and communities are inclusive, safe, resilient, and sustainable.

Figure 3: Waste management and its linkage with SDGs

Circular Economy and Waste Management

Circular Economy (CE) is a widely accepted concept beyond managing waste. It plays a crucial role in sustainable economic models by promoting product reuse, remanufacturing, recycling and recovery, thus minimising waste generation. The increasing global demand for finite raw materials drives the shift from the linear economy approach. The CE minimises the need for new raw materials and excessive energy consumption, lowering the environmental pressure linked to the life cycle of products. In many developed nations, governments, businesses, and R&D-oriented organisations facilitate the transition to a CE, which creates innovative and practical solutions. Intermediaries such as business incubators, financial institutions, and public organisations also support the developers by fostering collaboration, resource mobilisation, supporting commercialisation or creating and promoting common visions and strategies.

In many cases, intentional actions to increase circularity are well defined and provide a roadmap through regulations, education, and public participation for progression towards improved circularity. A notable example is South Korea's ban on food landfilling in 2005, which was driven by public concern and protests over mounting food waste on the streets. In response, the government introduced 6,000 waste bins equipped with scales and Radio Frequency Identification (RFID) technology to measure food waste at the disposal point and charge residents accordingly. Additionally, Seoul has explored innovative solutions, such as using food waste for urban farming initiatives. This initiative helped reduce food landfilling in Seoul by nearly 47,000 tons in six years (World Economic Forum, 2023a).

The Circular Economy Action Plan (CEAP), a key pillar of the European Green Deal, has significantly advanced circularity in Europe. Europe now consumes more recycled materials, achieving a circularity rate of 11.5% in 2022 (European Environment Agency, 2023). The overall circularity is supported by the waste hierarchy, prioritising waste prevention, reuse, recycling, and recovery, with disposal being the least preferred option. The CEAP also promotes the 9Rs framework, which organises circular strategies along a product's life cycle:

- **Before use**: Refuse, Rethink, Reduce (minimising material consumption).

- **During use**: Retain, Reuse & Share, Repair, Remanufacture (extending product lifespan).
- **After use**: Recycle and Return (recovering materials for new production).

While the circular economy concept is not fully established in Africa, several countries are making strides. Governments are increasingly strengthening their governance and policy framework to initiate circular economy aspects to develop waste reduction and resource efficiency innovations. Organisations like the African Circular Economy Network (ACEN) aim to promote waste management creativity and economic productivity through skilled expertise teaming. Policy and regulation efforts by nations are shifting from linear production and consumption patterns. For instance, Rwanda has taken a proactive stance by banning single-use plastic bags and implementing Extended Producer Responsibility (EPR) programs, which hold manufacturers accountable for the entire life cycle of their products. These initiatives demonstrate a growing commitment to circular economy principles, encouraging waste reduction, resource efficiency, and sustainable business practices.

The UNDP reported that over 70 countries have applied Circular Economy initiatives across various productive sectors. It is projected that scale-up initiatives could lead to a 25% reduction in global resource use, with a 90% reduction in greenhouse gas emissions, 0.1% growth in employment, and feed over two billion hungry and malnourished people by reducing food waste by 2030 (UNDP, 2024). Circular Economy is a systems solution framework that calls for a sustainable paradigm shift from a “take-make-waste” linear system to a circular system.

Solid Waste Management in Ghana

Overview and Current Practices

Waste generation in Ghana (particularly MSW and e-waste) is rapidly increasing, especially in urban areas. This growth is driven by urbanisation, population growth, and changes in consumption patterns. Various studies show that the composition and amount of MSW generated per capita vary with income levels (Denteh et al., 2017; Miezah, Obiri-Danso et al., 2015; Osei-

Mensah et al., 2014; Owusu-Nimo et al., 2019). Municipal solid waste from low-income areas averages about 0.4 kg/person/day and 0.68 kg/person/day. High-income areas generate an average of 0.62 kg per capita per day. MSW from lower-income areas are characterised by higher portions of organic and inert waste.[3]

The high organic waste content in Ghana's MSW reflects a pattern common in **Global South cities**, where food waste dominates, unlike **Global North cities**, where packaging and inorganic waste are more prevalent. However, the composition of MSW has changed in recent times. Packaging waste is increasing, attributed to changes in lifestyle and urbanisation, as more people adopt packaged food and consumer goods. E-waste has become a significant waste stream, often mixed with MSW due to poor waste separation practices, exacerbated by post-consumer electronic waste and imported second-hand electronic devices.

The central government has managed the MSW Collection through Metropolitan, Municipal and District Assemblies (MMDAs). Population growth has necessitated prioritising and increasing waste collection due to its generation rate. Public-Private-Partnership was therefore introduced in the early 1990s to improve waste collection services. The MMDAs outsource waste collection to private entities through PPP arrangements. Currently, Zoomlion dominates the MSW collection business in Ghana, with several successful small-scale waste collectors in the informal sector distributed across all regions.

According to Oduro-Appiah et al., (2019), the informal service providers contributed to an increase in collection coverage from 75% to 90%, waste capture from 53% to 90%, and recycling rates from 5% to 18%, saving the municipalities in Accra about $5.46 million in annual operational costs. The inception of plastic recycling systems has increased the informal sector collection of plastic waste such as PET (Polyethylene Terephthalate used for beverage bottles and food packaging), HDPE (High-Density Polyethylene used for detergent bottles and pipes), LDPE (Low-Density Polyethylene used for plastic bags and shrink wraps), and PP (Polypropylene, used for food containers, straws and bottle caps). Additionally, the informal sector collects a

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[3]Inert waste do not disintegrate naturally, either through a chemical or biological process. It is largely characterized by a very slow decomposition process and can last for hundreds to thousands of years. Examples include glass, concrete bricks, plastics etc.

large part of electronic waste before ending up in the waste stream. Ghana generated 52,000 tons of e-waste in 2019, of which the informal sector collected 93–97% through door-to-door collection. However, unsafe treatment and recycling methods, such as the open burning of cables and plastics and the draining of liquids from cartridges or batteries onto the ground, expose the general environment to hazards.

Waste collection and treatment in Ghana

Waste collection forms in Ghana include:

Door-to-door pick up: This approach involves waste collectors visiting households and commercial areas to collect garbage. Waste collection companies and agents provide bins or containers for their customers, which are collected periodically. Today, this method is used by both the formal and informal sectors, including registered and unregistered waste collection entities. For informal service providers, waste is often packed into sacks and plastic bags for collection.

Community or communal containers: These are designated fixed points or in the neighbourhood where people dispose of waste. The service providers are responsible for picking up and emptying the containers at scheduled times. This approach is mainly practised in market areas in Ghana's cities, towns, and villages.

Self-delivery: This is where waste is sent directly to dumpsites, whether authorised or not, which is very common in most rural settings and villages in Ghana.

The treatment of solid waste in Ghana has gradually improved over the years. Integrated waste management practices like metal scrap and paper recycling, composting, and anaerobic digestion of organic waste are evolving. However, waste disposal remains the dominant practice, indicating a need for further progress in waste recovery and recycling. To improve waste management practices, the Ghana National Plastic Action Partnership provides a multi-stakeholder platform for coordinating action on plastic waste reduction. In 2023, about a 10% plastic recycling rate was recorded out of the estimated 840,000 tons of plastic waste generated (World Economic Forum, 2023b). Plastic recycling produces plastic pellets to feed new raw materials into the industry.

Organic wastes are also utilised for compost and bio-fertilisers, which substitute inorganic fertilisers. Facilities like IRECOP in regional capitals, ACRAP, KACRP, Safisana Ltd, Jekora, and many more in Ghana have been instrumental in treating MSW in the last decade. Metal scraps are largely collected and recycled into other products. Upcycling and recycling of waste fractions are primarily led by the private sector. Additionally, energy recovery from waste, such as biogas for electricity, is being implemented by Safisana Ghana Ltd. Safisana currently has an installed capacity of 0.1MW, contributing about 1GWh of power to support Ghana’s electricity generation in 2024 (Energy Commission, 2025). A hybrid waste-to-energy pilot project is currently being installed in Kumasi through a collaboration between Ghanaian and German partners.

While various studies have demonstrated the potential of energy recovery from waste—using both thermal and biological methods to generate electricity and alternative fuels—practical implementation remains limited. Despite these insights, large-scale adoption of waste-to-energy solutions has yet to materialise. About 80% of MSW directly goes to disposal sites (Mariwah, 2020). In major cities, controlled landfills are managed to some extent. However, disposal sites remain unregulated in small towns and remote areas, increasing the potential for leachate contamination and methane emissions from decomposing waste. Additionally, because waste is mixed at the source, determining the proportion of hazardous vs. non-hazardous materials being disposed of is difficult.

These conditions present a threat to ground, surface water and soil contamination due to the presence of unsuitable chemicals. A striking example is the Korle Lagoon, arguably one of Accra's most polluted water bodies. The lagoon, which is surrounded by some of Accra’s slums and informal waste disposal sites, has been found to contain heavy metals such as cadmium, lead, and copper. The proximity of illicit e-waste markets and disposal sites also influences the high concentration of metals in the Korle Lagoon.

Although the Environmental Protection Agency (EPA) has issued landfill guidelines, it is challenging to determine how they are considered in constructing and maintaining controlled dumpsites and disposal sites. Without proper waste management systems, Ghana faces growing risks to public health—through contaminated water and air pollution—as well as economic consequences due to increased costs in healthcare and environmental rehabilitation.

Governance and Regulatory Frameworks

The Environmental Protection Agency Act, 2025 (Act 1124) is the current legislation that guides Ghana's waste management sector after the repeal of the EPA Act, 490 (1994). The Ministry of Local Government and Rural Development (MLGRD), the Ministry of Environment, Science and Technology, and the Ministry of Trade and Industry, with their representation at the district assembly levels, play a coordination role. MMDAs largely implement policies, and treaties are made at the national level. The National Policy Document, Ghana Shared Growth and Development Agenda 2010-2013 (GSGDA 2009-2013), also guides the execution of plans and strategies, treatment, and projection of concepts for changes. The policy document emphasises the need for sustainable waste management practices and outlines specific targets for waste reduction and recycling (Government of Ghana, 2014).

In addition, various guidelines and policies exist to regulate and support waste management standards in Ghana. Key among them are:

- **National Environmental Quality Guidelines (1998)** – Establishes standards for pollution control and environmental quality.
- **Ghana Landfill Guidelines (2002)** – Provides regulations for the proper siting, design, and management of landfills.
- **Manual for the Preparation of District Waste Management Plans (2002)** – Offers a framework for local authorities to develop waste management strategies.
- **Handbook for the Preparation of District-Level Environmental Sanitation Strategies and Action Plans (DESSAPs)** – Guides local governments in planning and implementing sanitation programs.

Several laws and regulations also indirectly govern specific waste streams. Some of the most relevant ones include:

- **Ghana E-Waste Management (Regulatory Policy Act 917, L.I. 2250)** – Regulates the handling, collection, and disposal of electronic waste.
- **National Guidelines for Healthcare Waste Management** – Provides protocols for the safe disposal of medical and hazardous waste.

- **Minerals and Mining Policy (under Mineral Commission Act 1993, Act 450)** – Includes provisions for managing waste from mining activities.
- **Regulations on the Disposal of Goods and Equipment** – Covers procedures for handling obsolete or discarded materials.

The government also established the Extended Producer Responsibility (EPR) policy to hold producers accountable for the entire lifecycle of their products, especially in Ghana's textile industry. This policy aims to shift the burden of waste management from the government to the producers, encouraging the design of sustainable products. The government aims to implement stricter regulations and incentives to support this transition, including fines for non-compliance and tax breaks for companies that adopt sustainable practices (Akpan & Olukanni, 2020; Asante-Duah, 2021; Zhang et al., 2022). The establishment of a system for monitoring and reporting on the implementation of waste management policies will ensure accountability and transparency in the waste management sector.

Waste management Challenges in Ghana

Ghana has undertaken multiple initiatives to implement existing waste management measures, including investing in waste collection, composting and anaerobic digestion of organic waste, recycling, and waste-to-energy options. However, these strategies have not yielded the anticipated outcomes due to socio-economic challenges, primarily technical, governance, and financial challenges. (Owusu-Ansah et al., 2021).

1. **Financial constraints**: Financial constraints are visible in many instances. For example, the inability of municipalities to secure adequate funding remains a critical challenge in Ghana's MSW management. While private sector involvement has helped, local authorities still struggle with high operational costs, limited financial support, and inefficient economic instruments for cost recovery. On the other hand, many residents are also unwilling or unable to pay for waste collection services, further straining the financial sustainability of waste management programs. (Owusu-Ansah et al., 2021; Douti *et al.,* 2017)
2. **Weak institutional capacities**: Waste management institutions face governance challenges, including poor enforcement of existing waste management policies, limited oversight of informal waste collection activities, and weak coordination between municipal authorities and

private service providers. For example, the Ghana National Environmental Sanitation Policy outlines strategies for effective waste management, yet enforcement remains inadequate, leading to persistent issues such as illegal dumping and unregulated disposal sites. Additionally, The Renewable Energy Master Plan and Sustainable Energy Plans mention waste-to-energy, but without strong institutional commitment, these remain underutilised policy documents rather than actionable frameworks.

3. **Inadequate infrastructure for waste management:** Ghana's waste management faces significant challenges due to inadequate waste collection, treatment, and disposal infrastructure. Limited recycling plants, composting sites, and waste-to-energy facilities result in inefficient processing, with most waste ending up in poorly managed landfills. Without strategic investments in waste treatment facilities and collection systems, Ghana will struggle with effective waste management.
4. **Social and behavioural challenges:** Public attitudes and behaviours toward waste management in Ghana present a significant challenge, with widespread indiscriminate dumping, low cooperation with waste collection agencies, and limited community participation in recycling initiatives. A key issue is the lack of source segregation, which results in high contamination rates and reduced recovery rates for recyclables like plastics. Studies show that about 30-48% of waste processed at sorting facilities is rejected and sent to landfills due to contamination (Sarquah et al., 2023). This not only undermines recycling efforts but also increases operational costs.
5. **Limited data availability and underestimation of pollution impacts:** The lack of comprehensive data on waste generation, composition, and pollution effects makes it difficult to develop evidence-based policies and interventions. Many pollution impacts, including air and water contamination, are underestimated due to inadequate monitoring and reporting systems. Assessing the full scale of Ghana's waste crisis and implementing appropriate mitigation strategies is challenging without reliable data. (Owusu-Ansah et al., 2021).
6. **Challenges with informal waste sector integration:** The informal waste sector plays a significant role in waste collection, sorting, and recycling, yet it remains undervalued and unregulated. While informal waste

pickers contribute significantly to plastic and electronic waste recovery, unsafe handling methods, such as open burning of cables, pose severe environmental and health risks. Efforts to formalise the sector have been slow, limiting its potential for effective collaboration with formal waste management systems.

Opportunities and Lessons for Scaling Up Sustainable Solid Waste Management in Ghana

Adopting sustainable solid waste management solutions requires lessons from successful experiences while tailoring them to suit Ghana's unique challenges. As already noted, inadequate dominance of mixed waste systems reduces recovery rates due to contamination at the source. Therefore, encouraging and implementing source separation will improve segregation of organic waste, recyclables, and non-recyclable materials for their respective treatment, reducing operational costs for waste processors.

Studies in various parts of Ghana have demonstrated positive results in source separation efficiency, achieving about 60-70% efficiency in test runs (Alhassan et al., 2020; Ama & Asase, 2011; Dagadu & Nunoo, 2011; Oduro-Kwarteng et al., 2016). Lessons from other global case studies, such as the "*pay-as-you-throw"* initiative in Seattle, aimed to reduce organic waste in bins. Additionally, the zero-waste programme by San Francisco is committed to reducing solid waste generation and landfill and incineration centres by 15% and 50%, respectively (EPA, 2018). Other notable case studies are Sweden's waste-to-energy programmes and Kamikatsu, Japan's zero waste town initiatives that could serve as technology transfer.

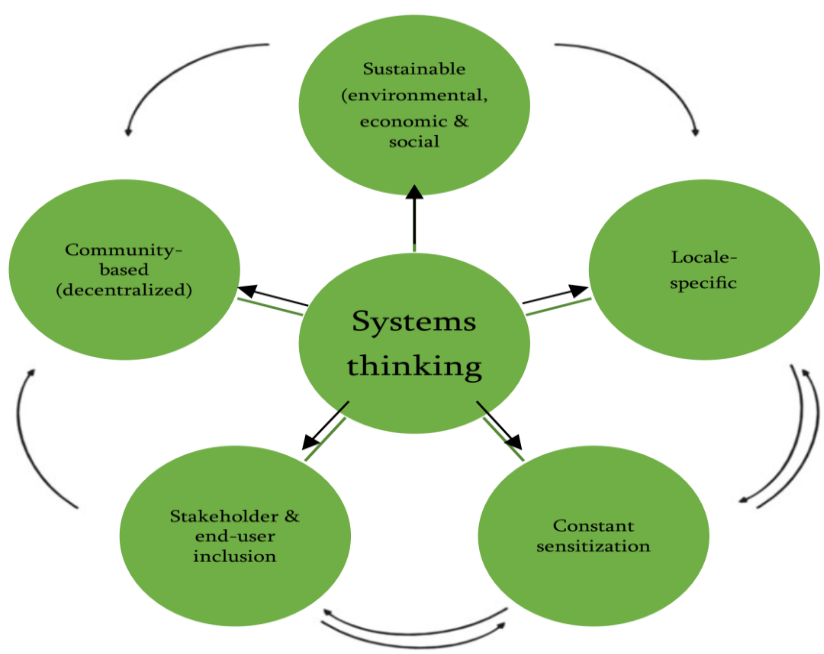
These case studies provide valuable insights that can be adapted to enhance Ghana's waste management strategies. The ensuing subsections outline additional approaches and opportunities for Ghana to improve its waste management practices.

Community driven approaches

Local community initiatives towards waste management contribute to sustainable waste management and utilisation at the community level. Community members can monitor waste management practices and advocate support from the local authorities. This approach empowers the community to take ownership of their waste management practices and ensures long-term sustainability (Nartey et al., 2021). These initiatives include local community by-laws, implementing smart waste disposal facilities, utilising waste for compost production and community gardening, and establishing compost markets. This approach further creates jobs, innovations, and transforms dumping sites into operating recycling hubs.

Individuals are assigned roles in addition to more robust decentralised systems and regulatory law enforcement measures. Providing relevant and appropriate innovative incentive-based attention to uninformed individuals may be beneficial through community partnerships. This approach aims to foster recognition of the necessity to undertake individual responsibility in waste management and recycling activities, ultimately leading to a more sustainable and resilient community (Deku, 2020; Williams et al., 2023). Figure 4 illustrates a sustainable community-based waste management framework that has been adopted.

Figure 4: Community-based Sustainable Waste Management (Deku, 2020)



Participatory approach

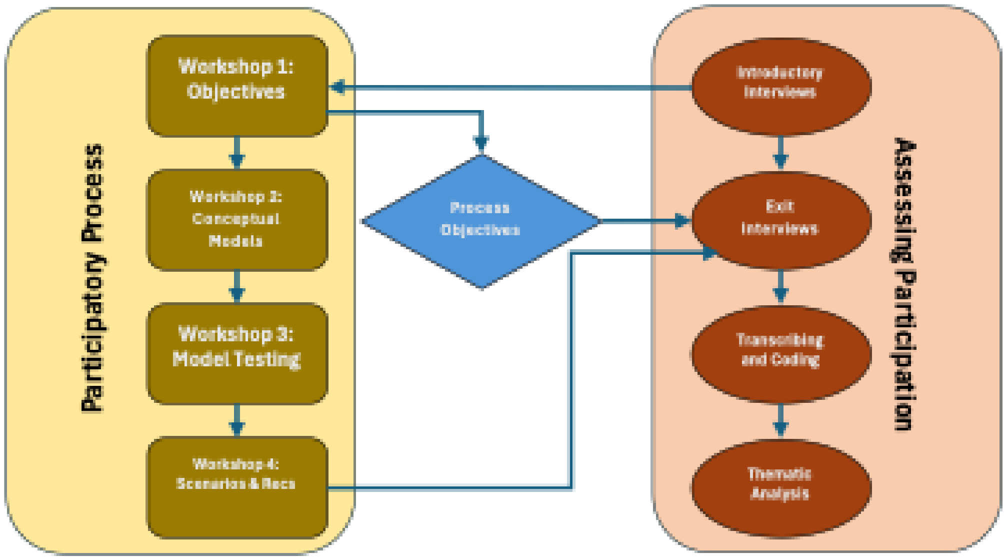
The participatory approach emphasises involving the community as active contributors in waste management, prioritising their experiences, opinions, and perceptions of the challenges. The underlying principle is that when community members are directly involved in waste management projects, they are more likely to take ownership, actively communicate outcomes, and harness the power of authoritative knowledge.

This approach also values co-creating new knowledge and integrating diverse insights from the community. To foster meaningful participation, waste management programs must be designed to encourage community members to join activities and share their expertise. Key characteristics of this approach include engaging in relevant activities, respect for community knowledge, empowerment throughout the process and outcomes, and ensuring both practical and social relevance (Camarillo & Bellotindos, 2021).

A participatory approach has been suggested to support and empower sustainable waste management initiatives. This approach prioritises treating community members not as passive recipients but as active participants in decision-making. It emphasises meaningful involvement and capacity-building for effective contributions. Additionally, integrating diverse knowledge sources enhances the effectiveness of policy recommendations and practical solutions. Engaging community members in defining problems increases the relevance and quality of research, amplifying its overall impact. This approach also facilitates the integration of knowledge from various stakeholders, fostering comprehensive and inclusive solutions.

Another key aspect is that community involvement often leads to greater support for policies and solutions and increased trust in the process. This approach also promotes a sense of ownership and responsibility among community members while fostering optimism about the opportunities that change can bring. (Beyuo, 2020; Lissah et al., 2021). Figure 5 illustrates the interconnection between the participatory process (yellow) and the assessment process (red), as described by (Horne et al., 2022).

Figure 5: Schematic of Participatory Process and Assessing Participation



Source: (Horne et al., 2022)

Education and capacity building

Capacity building in waste management focuses on equipping individuals and organisations with skills, knowledge, and resources for effective waste treatment. Globally, citizens and organisations play a significant role waste collection, processing, and treatment. While several technologies involve simple control and operating systems, others require a deeper understanding of the complete waste-to-resources value chain. A well-understood and efficiently executed waste-to-resources process is an avenue for investment attraction (Brotosusilo et al., 2020; Kala et al., 2020).

Therefore, waste processors require capacity building to manage material flows efficiently to support closed-loop systems (i.e., continuous reuse, recycling or repurposing instead of outright disposal). Public education (i.e., formal and informal), sensitisation, community training, and stakeholder collaboration are crucial to support students, community members and leaders, and other stakeholders in finding the best waste management practices. This approach will help create the capacity to tackle a more sustainable and resilient waste management system in Ghana (Oh & Hettiarachchi, 2020; Salem et al., 2020).

Research and Development is crucial in advancing education and capacity building in waste management. It improves techniques, process efficiency, and communication among stakeholders. Beyond technological advancements, R&D plays a crucial role in shaping public perceptions, which are crucial actors that influence and shape waste management practices. However, the overreliance on public budget reallocations and short-term economic incentives has slowed progress toward a circular economy (Aning-Agyei, 2020). To address this, capacity-building efforts must align with the waste hierarchy, prioritising waste prevention, minimisation, reuse, recycling, energy recovery, and disposal as a last resort. Targeting such tailored techniques provides an opportunity for further stakeholder cooperation for implementation. With the implementation and support of innovative technologies, Ghana can overcome these barriers and achieve a more sustainable waste management system.

Strengthening regulatory framework

Strengthening regulatory frameworks is essential for addressing local value chain development gaps for sustainable waste management transition. Governments play a role in coordinating consistent waste management policies, such as the EPR and the "*polluter pays*" principle. These approaches limit non-recyclable and single-use products such as polystyrene and LLDPE packaging materials. They effectively reduce waste and microplastic pollution, as has worked in many African cities such as Rwanda and Kenya.

Waste generators must assume responsibility for treating components of their products at the end of product life. A well-implemented EPR system encourages eco-friendly product design ("design for environment") while fostering collaboration between governments, industries, and consumers to ensure compliance and effectiveness (Fadhullah et al., 2022; Muisa Zikali et al., 2022). However, Ghana's current system imposes rigid rules and control procedures targeting specific industries, which limits its ability to adapt to transformative, cutting-edge technologies that could benefit diverse contexts, including addressing throw-away culture. This rigidity creates a significant obstacle to adopting innovative waste management technologies in Ghana.

To overcome this challenge, it is essential for the government to establish and enforce robust regulatory frameworks and guidelines that support and incentivise sustainable practices and innovations (Abalansa et al., 2021; Ofori & Mensah, 2022). Other fiscal and financial measures tailored to local contexts include increasing tipping fees, providing tax incentives for recycling and composting, and imposing higher taxes on non-recyclable materials, which can strengthen financial sustainability and help achieve zero-waste city initiatives. These strategies form part of the revenue models for achieving zero-waste city initiatives.

Role of stakeholders

Stakeholder involvement has been identified as crucial for developing and implementing successful waste management systems. As noted in previous studies, different stakeholders play diverse roles in waste management, which can be divided into five categories: (1) the value chain, (2) waste producers, (3) end-users, (4) government, and (5) other stakeholders (Akon-Yamga et al., 2021; Asibey et al., 2021). Each category plays a crucial role in successfully implementing waste management strategies.

Value creation in waste management, especially for traditional recyclers, can drive their participation. As resource-efficient products are still under development, waste producers play a large part in improving waste systems. Waste producers can improve waste management by reducing waste at the source, segregating waste for better recovery, supporting circular economy practices, complying with Extended Producer Responsibility (EPR), and collaborating with stakeholders. Additionally, they can support strategies undertaken during design, manufacturing, and end-of-life product management to improve the given systems.

End-users, particularly household consumers, have a role to play in waste collection, storage, and disposal through appropriate handling at end-of-life. End-users' active involvement in waste management could lead to safer working conditions for recyclers and lowered hazardous waste generation. Improving collection measures could stimulate the active engagement of end-users.

Stakeholder roles and responsibilities vary based on the waste management systems in place. This diversity requires that policy and awareness campaigns be collaborative among governments, businesses, and the public (Akon-Yamga et al., 2021; Asibey et al., 2021). Ensuring the inclusion and representation of the informal sector and the gendered aspect of the waste supply chain is also crucial to encouraging stakeholders to pursue the structural integration of informal service providers into the formal waste management system. Collaboration between research institutions, industries, and regulators can help address the challenges of divided agencies and fragmented governance. Partnerships among established players and stakeholders can accelerate collective learning, leverage individual expertise, and facilitate the implementation of integrated waste management strategies.

Conclusion and Recommendations

This chapter explored the relationship between waste management and climate resilience in Ghana, aiming to identify transformative pathways towards sustainability. Using a comprehensive review of existing literature, secondary data, and institutional reports, the chapter assessed Ghana's waste management practices, their alignment with circular economy principles, and their role in achieving climate and sustainable development goals.

Key findings highlighted the significant challenges faced by Ghana's waste management sector, including weak regulatory enforcement, limited infrastructure, and a high prevalence of mixed waste practices. Despite these hurdles, the analysis revealed promising opportunities, such as integrating informal service providers, community-driven initiatives, and advancements in recycling and waste-to-energy technologies. The chapter underscored the importance of strengthening regulatory frameworks, promoting stakeholder collaborations, and implementing fiscal incentives to foster innovation and efficiency in waste management systems.

Although the country is progressing in policy formulations to support sustainable development and is a forerunner in the subregion, effective implementation is needed. The following policy recommendations have been suggested to transition towards a circular economy that integrates sustainable practices and resource recovery.

1. **Promote decentralised waste management systems:** The current centralised waste management system has proven challenging due to rapid urbanisation and varied geographical contexts. The Government must work with MMDAs to develop decentralised waste collection and processing systems using appropriate technologies to improve waste collection and processing in respective districts. The MMDAs should

also support community-based waste processing facilities, particularly in urban and peri-urban areas, to reduce transport costs, manage waste locally, and create job opportunities.

2. **Strengthen enforcement and regulatory frameworks:** Weak enforcement and regulatory gaps are key enablers of harmful waste management practices. The Environmental Protection Agency (EPA) and other regulatory bodies must strengthen their capacities to enforce existing waste management and environmental protection policies. The government should update and enforce the Extended Producer Responsibility (EPR) policy, mandating producers to manage waste throughout their products' lifecycle, thus reducing the environmental burden.
3. **Boost private sector investment in waste management:** Private sector involvement is essential for scaling waste management solutions, but financial risks deter investment. The government must incentivise private sector involvement (i.e. tax breaks, subsidies, competitively priced loans) to encourage investment in waste recycling, waste-to-energy projects, and technology innovation for material recovery. Establishing green financing options can also help create a stable investment climate for sustainable waste management industries.
4. **Enhance public awareness and participation:** Effective waste management requires public understanding and participation, but awareness and waste separation practices remain low. The government and its MMDAs, with support from NGOs and Civil Society, must undertake nationwide public education campaigns and community programs on waste separation, recycling, and responsible disposal. The Ghana Education Service must also sustain the integration of waste management education into schools' curricula to instil sustainable habits in school children.
5. **Implement and enforce waste separation at source:** Mixed waste collection increases contamination, reduces recycling rates, and makes organic waste management expensive. The government and its agencies should provide infrastructure for household waste separation, including designated collection bins for organic, recyclable, and residual waste. Additionally, waste collection and transport systems must be designed to maintain segregation throughout the waste management process. Encouraging community-level organic waste composting can

produce bio-fertilisers, reduce landfill pressure, and support local agriculture.

6. **Improve waste data collection and monitoring**: The Ministry of Environment, Science and Technology, the Environmental Protection Agency (EPA), and municipal authorities should establish a national waste database. They must equip municipalities with digital tools, enforce mandatory waste reporting for industries, and collaborate with universities for research-based policy development.
7. **Formalise and integrate the informal waste sector**: The government, local authorities, and waste management companies should develop policies to regulate and support informal waste collectors. They must provide training, safety gear, and business support while creating formal partnerships to enhance market access, improve working conditions, and reduce environmental hazards.

References

Abalansa, S., El Mahrad, B., Icely, J., & Newton, A. (2021). Electronic waste, an environmental problem exported to developing countries: The good, the bad and the ugly. *Sustainability (Switzerland)*, *13*(9), 1–24. https://doi.org/10.3390/su13095302

Akon-Yamga, G., Daniels, C. U., Quaye, W., Ting, B. M., & Asante, A. A. (2021). Transformative innovation policy approach to e-waste management in Ghana: Perspectives of actors on transformative changes. *Science and Public Policy*, *48*(3), 387–397. https://doi.org/10.1093/scipol/scab005

Akpan, V. E., & Olukanni, D. O. (2020). Hazardous waste management: An African overview. *Recycling*, *5*(3), 1–28. https://doi.org/10.3390/recycling5030015

Alhassan, H., Adjei, P., & Owusu-sekyere, E. (2020). Households ' source separation behaviour and solid waste disposal options in Ghana's Millennium City. *Journal of Environmental Management*, *259* (August 2019), 110055. https://doi.org/10.1016/j.jenvman.2019.110055

Ama, M., & Asase, D. (2011). *Solid Waste Separation at Source: A Case Study of the Kumasi Metropolitan Area*.

Aning-Agyei, M. A. (2020). *University of Cape Coast Assessing the Sustainability of Public-Private Partnership in Solid Waste Management in Ghana*.

Antwi, E. O. (2019). *Collection of Municipal Solid Waste in Ghana: a case of Public-Private-Partnership in Accra Metropolitan Assembly*. Vaasan Ammattikorkeakoulu University of Applied Sciences.

Asante-Duah, K. (2021). *Hazardous Waste Risk Assessment*. CRC Press Taylor & Francis Group. https://doi.org/https://doi.org/10.1201/9781003070009

Asibey, M. O., King, R. S., Lykke, A. M., & Inkoom, D. K. B. (2021). Urban planning trends on e-waste management in Ghanaian cities. *Cities*, *108*(November 2019), 102943. https://doi.org/10.1016/j.cities.2020.102943

Azevedo, B. D., Scavarda, L. F., Caiado, R. G. G., & Fuss, M. (2021). Improving urban household solid waste management in developing countries based on the German experience. *Waste Management*, *120*, 772–783. https://doi.org/10.1016/J.WASMAN.2020.11.001

Beyuo, A. (2020). NGO grassroots participatory approaches to promoting sustainable agriculture: Reality or Myth in Ghana's Upper-West Region? *Renewable Agriculture and Food Systems*, *35*(1), 15–25. https://doi.org/10.1017/S1742170518000169

Bigos, T. (2024). Understanding Types of Waste and Effective Management Strategies. *EnvironBuzz Magazine*. https://environbuzz.com/understanding-types-of-waste-and-effective-management-strategies/

Brotosusilo, A., Nabila, S. H., Negoro, H. A., & Utari, D. (2020). The level of individual participation of community in implementing effective solid waste management policies. *Global Journal of Environmental Science and Management*, *6*(3), 341–354. https://doi.org/10.22034/gjesm.2020.03.05

Camarillo, M. E. C., & Bellotindos, L. M. (2021). A study of policy implementation and community participation in the municipal solid waste management in the Philippines. *Applied Environmental Research*, *43*(2), 30–45.
https://doi.org/10.35762/AER.2021.43.2.3

Dagadu, P. K., & Nunoo, F. K. E. (2011). Towards municipal solid waste source separation at the household level in Accra, Ghana. *International Journal of Environment and Waste Management*, *7*(3–4), 411–422. https://doi.org/10.1504/IJEWM.2011.039479

Deku, P. S. (2020). An Assessment of Sustainable Solid Waste Management. *ProQuest*, *May*.

Denteh, S. N., Cobbina, S. J., Adam, W., & Aboka. (2017). Household Solid Waste Management: Compositional Analysis, Storage and Collection in the Vittin Target Area, Tamale-Ghana. In *UDSIJD* (Vol. 5, Issue 1). http://www.udsijd.org

Dijkstra, H., van Beukering, P., & Brouwer, R. (2020). Business models and sustainable plastic management: A systematic review of the literature. *Journal of Cleaner Production*, *258*, 120967. https://doi.org/10.1016/J.JCLEPRO.2020.120967

Earth5R. (2024). *Sustainable Waste Management In Indore: A Case Study* -.

EPA. (2018). *Zero Waste Case Study: San Francisco*. Zero Waste Case Study: San Francisco.

European Environment Agency. (2023). *Accelerating the circular economy in Europe. State and outlook 2024*. https://doi.org/10.2800/055236

Ezeudu, O. B. (2024). Harnessing the Drivers and Barriers to Implementation of Extended Producer Responsibility for Circular Economy in Nigeria. *Circular Economy and Sustainability*, *4*, 1461–1486. https://doi.org/https://doi.org/10.1007/s43615-023-00340-8

Fadhullah, W., Imran, N. I. N., Ismail, S. N. S., Jaafar, M. H., & Abdullah, H. (2022). Household solid waste management practices and perceptions among residents in the East Coast of Malaysia. *BMC Public Health*, *22*(1), 1–20. https://doi.org/10.1186/s12889-021-12274-7

Government of Ghana. (2014). *Ghana Shared Growth and Development Agenda*.

Horne, A. C., Webb, J. A., Mussehl, M., John, A., Rumpff, L., Fowler, K., Lovell, D., & Poff, L. R. (2022). Not Just Another Assessment Method: Reimagining Environmental Flows Assessments in the Face of Uncertainty. *Frontiers in Environmental Science*, *10*(May), 1–17. https://doi.org/10.3389/fenvs.2022.808943

Kala, K., Bolia, N. B., & Sushil. (2020). Waste management communication policy for effective citizen awareness. *Journal of Policy Modeling*, *42*(3), 661–678.
https://doi.org/10.1016/J.v.2020.01.012

Lissah, Y. S., Ayanore, M. A., Krugu, J. K., Aberese-Ako, M., & Ruiter, R. A. C. (2021). Managing urban solid waste in Ghana: Perspectives and experiences of municipal waste company managers and supervisors in an urban municipality. *PLOS ONE*, 1–18. https://doi.org/10.1371/journal.pone.0248392

Mariwah, S. (2020). The Sanitation and Waste Management Conundrum in Ghana: The Case for High Level Prioritization and Fiscal Incentives. *IMANI and ESPA Webinar*, *11th June*.

Miezah, K., Obiri-danso, K., Kádár, Z., Fei-baffoe, B., & Mensah, M. Y. (2015). Municipal solid waste characterisation and quantification as a measure towards effective waste management in Ghana. *Waste Management*, *46*, 15–27. https://doi.org/10.1016/j.wasman.2015.09.009

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., & Mensah, M. Y. (2015). Municipal solid waste characterisation and quantification as a measure towards effective waste management in Ghana. *Waste Management*, *46*, 15–27. https://doi.org/10.1016/j.wasman.2015.09.009

Muisa Zikali, N., Chingoto, R. M., Utete, B., & Kunedzimwe, F. (2022). Household solid waste handling practices and recycling value for integrated solid waste management in a developing city in Zimbabwe. *Scientific African*, *16*, e01150. https://doi.org/10.1016/J.SCIAF.2022.E01150

Nartey, E. G., Cofie, O., Gebrezgabher, S., & Nikiema, J. (2021). Crops and farmers' response to application of fecal sludge derived - Fortifer™ in different agro-ecological zones in Ghana. *Journal of Environmental Management*, *293*, 112970. https://doi.org/10.1016/J.JENVMAN.2021.112970

Oduro-Appiah, K., Afful, A., Kotey, V. N., & de Vries, N. (2019). Working with the informal service chain as a locally appropriate strategy for sustainable modernisation of municipal solid waste management systems in lower-middle income cities: Lessons from Accra, Ghana. *Resources*, *8*(1), 1–16. https://doi.org/10.3390/resources8010012

Oduro-Kwarteng, S., Anarfi, K. P., & Essandoh, H. M. K. (2016). Source separation and recycling potential of municipal solid waste in Ghana. *Management of Environmental Quality: An International Journal*, *27*(2), 210–226. https://doi.org/10.1108/MEQ-03-2015-0038

Ofori, D., & Mensah, A. O. (2022). Sustainable electronic waste management among households: a circular economy perspective from a developing economy. *Management of Environmental Quality: An International Journal*. https://doi.org/https://doi.org/10.1108/MEQ-04-2021-0089

Oh, J., & Hettiarachchi, H. (2020). Collective Action in Waste Management: A Comparative Study of Recycling and Recovery Initiatives from Brazil, Indonesia, and Nigeria. *Recycling*, *5*(4), 1–16.

Osei-Mensah, P., Adjaottor, A. A., & Owusu-Boateng, G. (2014). *Characterisation of Solid Waste in the Atwima-Nwabiagya District of the Ashanti Region, Kumasi-Ghana*. *2*(1), 1–14.

Owusu-Ansah, P., Woangbah, S. K., Anim, B., & Azabu, F. (2021). Solid Waste Disposal

Management Practices in Ghana, A Case Study of Subin Metropolis. *Environmental Management and Sustainable Development*, *10*(4), 1. https://doi.org/10.5296/emsd.v10i4.18773

Owusu-Nimo, F., Oduro-Kwarteng, S., Essandoh, H., Wayo, F., & Shamudeen, M. (2019). Characteristics and management of landfill solid waste in Kumasi, Ghana. In *Scientific African* (Vol. 3, p. e00052). Elsevier B.V. https://doi.org/10.1016/j.sciaf.2019.e00052

Owusu-Sekyere, K., Batteiger, A., Afoblikame, R., Hafner, G., & Kranert, M. (2022). Assessing data in the informal e-waste sector: The Agbogbloshie Scrapyard. *Waste Management*, *139*, 158–167. https://doi.org/10.1016/j.wasman.2021.12.026

Ritchie, H. (2020). *Sector by sector: where do global greenhouse gas emissions come from?* Our World in Data. https://ourworldindata.org/ghg-emissions-by-sector

Salem, M., Raab, K., & Wagner, R. (2020). Solid waste management: The disposal behavior of poor people living in Gaza Strip refugee camps. *Resources, Conservation and Recycling*, *153*, 104550. https://doi.org/10.1016/J.RESCONREC.2019.104550

Sarquah, K., Narra, S., Beck, G., Bassey, U., Antwi, E., Hartmann, M., Derkyi, N. S. A., Awafo, E. A., & Nelles, M. (2023). Characterisation of Municipal Solid Waste and Assessment of Its Potential for Refuse-Derived Fuel (RDF) Valorization. *Energies*, *16*(1). https://doi.org/10.3390/en16010200

Sharma, B., Goswami, Y., Sharma, S., & Shekhar, S. (2021). Inherent roadmap of conversion of plastic waste into energy and its life cycle assessment: A frontrunner compendium. *Renewable and Sustainable Energy Reviews*, *146*, 111070. https://doi.org/10.1016/J.RSER.2021.111070

Tearfund (2019). No time to waste: Tackling the plastic pollution crisis before it's too late. Available at https://www.tearfund.ie/wp-content/uploads/2019/05/2019-Tearfund-Consortium-No-time-to-waste-En.pdf#page=11.09

UNDP. (2024). *Chemicals and Waste Hub-Circular Economy*. https://www.undp.org/chemicals-waste/our-work/circular-economy

UNEP. (2013). Climate and climate change: Global trends and Strategy Framework. In *United Nations Environmental Programme, Division of Technology, Industry and Economics International Environmental Technology Centre*. https://doi.org/10.4324/9781315073774

UNEP. (2024). *Beyond an age - Global Waste Management Outlook 2024*. https://doi.org/10.59117/20.500.11822/44939

Williams, P. A., Narra, S., Antwi, E., Quaye, W., Hagan, E., Asare, R., Owusu-Arthur, J., & Ekanthalu, V. S. (2023). Review of Barriers to Effective Implementation of Waste and Energy Management Policies in Ghana: Implications for the Promotion of Waste-to-Energy Technologies. *Waste*, *1*(2), 313–332. https://doi.org/10.3390/waste1020021

World Economic Forum. (2023a). *Circular economy in action: 9 examples of businesses and policy-makers accelerating the transition*.
https://www.weforum.org/agenda/2023/03/9-examples-circular-economy-accelerating-transition/

World Economic Forum. (2023b). *The impact of fighting plastic pollution.*
https://www.weforum.org/impact/data-benefits-ghana-fight-against-plastic-pollution/

World Health Organisation (2022). Compendium of WHO and other UN guidance on health and environment, 2022 update. Geneva: World Health Organization; 2022 (WHO/HEP/ECH/EHD/22.01). Licence: CC BY-NC-SA 3.0 IGO.

Zaman, A. (2022). Zero-waste: A new sustainability paradigm for addressing the global waste problem. *The Vision Zero Handbook: Theory, Technology and Management for a Zero Casualty Policy*, 1195–1218. https://doi.org/10.1007/978-3-030-76505-7_49

Zhang, Z., Malik, M. Z., Khan, A., Ali, N., Malik, S., & Bilal, M. (2022). Environmental impacts of hazardous waste, and management strategies to reconcile circular economy and eco-sustainability. *Science of The Total Environment*, *807*, 150856. https://doi.org/10.1016/J.SCITOTENV.2021.150856

5

Recycling and Reuse Practices for Post-Consumer Textiles Waste as a Comprehensive Climate Solution in Ghana: A Review

Josephine Cudjoe Sarfo

Abstract

Solid waste disposal has been a major concern for Africa and its nations. Over the years, the use of landfills and incinerators for solid waste disposals, including post-consumer textile waste, has posed serious climatic challenges, affecting the general health and well-being of the population. In Ghana, the growing consumption of second-hand clothing and the lack of effective waste management practices have led to the build-up of post-consumer textile waste, heightening the climate change problems in the country. This review synthesises existing literature on the recycling and reuse practises of post-consumer textile waste and explores their potential as a comprehensive climate solution. It also highlights the benefits of recycling and reuse practices, the opportunities for scaling up these practices and the potential challenges that need to be tackled. This review utilised evidence from Google Scholar, ProQuest, Scopus, and Science Direct. It is evident some recycling and reuse practices exist. However, many factors hinder their widespread adoption and implementation. It concludes with recommendations for public-private partnerships, innovation and technological advancements, and community engagement to improve the environmental and socio-economic benefits of post-consumer textile waste.

Keywords: Ghana, Open Burning, Landfill, Post-Consumer Textile Waste, Recycling, Sustainability.

Introduction

The textile and apparel industries are vital in serving clothing and economic needs (Adeloye et al., 2023; Cassidy & Goswami, 2017; Nayak & Padhye, 2015; Uddin, 2019). Globally, these industries have recorded increased production and consistent revenue growth, except during the COVID-19 pandemic years, which significantly disrupted many economic activities worldwide (Smith, 2020). In recent years, the demand for clothing, driven by fast fashion, has dramatically impacted both environmental sustainability and consumer behaviour (Garcia-Ortega et al., 2023; Papasolomou et al., 2023). This shift has led to increased consumption, waste generation, and a culture of disposable fashion, raising concerns about the long-term effects on society (Maiti, 2024).

The indiscriminate disposal of Post-Consumer Textile Waste (PCTW) has contributed to overflowing landfills, increased pollution, and the depletion of natural resources while posing challenges for waste management systems and sustainability efforts (Ajila, 2019; Balasaraswathi & Rathinamoorthy, 2022; Maiti, 2024). Like many other developing countries, Ghana struggles with the same challenge as the global effect of fast fashion keeps escalating.

The Context for Ghana

Generally, PCTW pertains to textile products consumers discard after use. According to Aronsson and Persson (2020), PCTW may have multiple wear and tear and be nearing the end of its usable life. However, some post-consumer textile wastes are still in good condition and are collected, sorted, bailed, and sold as second-hand clothing to extend their usability (Hur, 2020). Although this activity promotes reuse practices, the influx of second-hand clothing contributes largely to the quantity of PTCW for its importers, mainly the developing countries.

Ghana's largest second-hand clothing hub, the Kantamanto Market, trades approximately 15 million clothing items every week (Ricketts & Skinner, 2020). According to recent data from the Observatory of Economic Complexity (OEC, 2023), Ghana imported about $121 million worth of used clothing, representing about 2.35% of global imports. However, not all imported items are sold due to usability, quality, grade, and demand. As a result, large volumes of textile waste are generated. According to Skinner (2019), about 70 metric tons of textile waste from Kantamanto are disposed of annually in Accra's main landfills, which is already beyond its designed capacity. Remarkably, this figure only represents 60% of the total estimated textile waste the market generates.

Clothing waste is one of the largest sources of solid waste in the capital and other major cities across the country, creating a significant burden for municipal governments (The Or Foundation, 2020). The inappropriate disposal of PCTW, including second-hand clothing and the lack of efficient management practices have led to economic strain and environmental degradation as local authorities are already struggling to provide essential public services (Skinner, 2019). Already, there is substantial evidence demonstrating the significant environmental harm caused by waste that is either landfilled or incinerated (Siddiqua et al., 2022; Mor & Ravindra, 2023; Yaashikaa et al., 2022). Landfilling not only takes up valuable land but also generates methane, a potent greenhouse gas with a global warming potential approximately 80 times greater than CO_2 over a 20-year period and 28 times greater over a 100-year period (Forster et al., 2021; Iravanian & Ravari, 2020). At the same time, harmful pollutants like dioxins, furans, and heavy metals sublime into the atmosphere while reducing waste volume through open burning (Daffi et al., 2020). This situation affects air quality and the general health of individuals.

The collapse of the Kpone landfill, built initially to serve Tema residents and manage various types of waste, including textiles (Renwick, 2023), underscores the significant challenges Ghana faces in tackling clothing waste. Constructed in 2013 with an expected lifespan of 25 years, the landfill reached capacity far sooner due to the cost and difficulty of compressing textile waste. This led to a fire outbreak that lasted for months and caused significant environmental damage, including the destruction of natural habitats, contamination of local water supplies, and air pollution from smoke, affecting the health of nearby communities (The Or Foundation, 2020). Additionally, fishermen now struggle with the effects of textile waste and microplastics in their fishing ventures (Tuppens, 2023), calling for sustainable environmental action.

Recycling and reuse of PCTW is essential in promoting a sustainable and healthier environment. As the fashion industry continues to grow due to rapid urbanisation, population growth, and fast fashion, the swelling volumes of PCTW cannot be underrated (Maiti, 2024). Hence, embracing recycling and reuse practices for clothing waste will help reduce the environmental burden caused by overflowing landfills and inappropriate clothing waste management.

Despite growing global research on textile waste and recycling technologies as sustainable solutions, literature specific to the Ghanaian context remains limited and fragmented. A comprehensive analysis of local and international data would bridge this gap and offer profound insight into existing practices, challenges, and opportunities for improving textile recycling systems in Ghana. This review highlights gaps in current structures and equips stakeholders, policymakers, and investors with evidence-based strategies to improve decision-making on textile waste management. A deeper understanding of textile recycling within the African context could also drive the development of innovative, community-led recycling enterprises, fostering economic growth and environmental sustainability.

Overview of Study and Methodology

This review synthesises literature on the historical and cultural context of textile use in Ghana, highlighting traditional reuse practices while comparing them with the current consumption patterns that have led to increased textile waste. It also examines the challenge of textile waste management as affected by rapid urbanisation and inadequate infrastructure. Additionally, the review explores the impact of textile waste on the environment, health, and society. It evaluates existing recycling and reuse practices in Ghana and compares them with thriving global approaches. Lastly, the review outlines opportunities for scaling recycling initiatives and presents recommended actions to enhance sustainability and address climate change challenges.

An online search was conducted on academic databases, covering a wide range of literature, including reviews, quantitative and qualitative studies and theses, and other relevant materials. Literature was retrieved from Google Scholar, ProQuest, Scopus and Science Direct. To gain deeper insights into current trends and perspectives, grey literature – such as reports and content from government agencies, industry journals, and environmental organisations - was also included.

Based on the overview for the review, relevant keywords were combined and used for the search using Boolean operators (AND, OR). Keywords that were used for the search included: *(post-consumer textile waste OR textile waste), AND (textile recycling OR upcycling Or Reuse), AND (textile OR garment OR apparel industry), AND (environmental impact), AND (natural fabrics OR fibres), AND (synthetic fabrics OR fibres) AND (second hand OR Used Clothing), AND (Ghana).* Additionally, relevant research identified during the review of other studies was incorporated. Lastly, data was extracted from the selected literature in alignment with the objectives of this chapter. The following inclusion and exclusion criteria were used.

Inclusion Criteria:

1. Any type of available study
2. Reports and Insights from Expert and industry websites
3. Studies addressing recycling, reuse, and sustainable practices for textile waste.
4. Studies and reports of any geographical area.

Exclusion Criteria

1. Study older than 10 years (before 2014)
2. Studies on energy recovery from textile waste
3. Articles that solely addressed technical production processes without incorporating aspects of textile waste management.

Textile waste in Ghana – A Historical and Cultural Context and the Growing Challenge

Textiles in Ghana are deeply connected with the country's history and culture. The symbolic Ghanaian traditional woven fabrics like the *kente*, *batakari*, and *ntoma* were icons for identity, status, and traditional purposes (Adade, 2023; Dzramedo et al., 2013). These textiles were made to serve generations and thus was preserved and handed over from generation to generation. It reflected a culture of value, longevity, and admiration for traditional fabrics and artefacts (Ankora, 2022; Martino, 2018). In the past, tears in fabrics (*Ntoma*) were mended and remodelled into new household items to serve new purposes and clothing for the younger generations. Worn–out fabrics (*ntomago*) that were beyond repairs were used as household rags for cleaning and sanitary purposes. Reuse practice was paramount to the ancient Ghanaian society; thus, textile waste was not much of a burden on the society.

However, the narrative surrounding textile consumption and waste has shifted significantly in recent decades. The rise of PCTW has become a growing concern for researchers, climate activists, and environmentalists (Desore & Narula, 2018; Niinimäki et al., 2020; Sandin & Peters, 2018). The cultural norm of textile reuse has declined due to the influx of inexpensive, mass-produced second-hand clothing ("*obroni wawu*") contributed by fast fashion (Agra et al., 2015). In 2018, Ghana was among the five leading global importers of second-hand clothing (OECD, 2018). Today, many Ghanaians have abundant imported second-hand clothing, contributing to a disposable culture due to its accessibility, affordability, and poor quality. Meanwhile, developed countries profit significantly from exporting textile waste under the guise of second-hand clothing, leaving importing countries to shoulder the burden of managing this growing volume of textile waste.

Global population growth and urbanisation have further fuelled the demand for clothing, increasing the production curve and the revenue generated by the textile and apparel industries internationally and locally (Echeverria et al., 2019). Industries are prioritising speed and cost-efficiency over sustainability and promoting the fast fashion model to meet the rising demand for clothing. Due to the affordability, accessibility, and short life span of clothes under this model, there is an increased cycle of consumption and disposal of textile and apparel products (Bailey et al., 2022; Echeverria et al., 2019)

This alarming effect of the never-ending cycle of consumption and disposal gives rise to the indiscriminate disposal of PCTW. Typically, used textile wastes from homes and businesses, which, once discarded into general bins, are mixed with other household waste materials and transported to landfills or incinerated. Acquaye et al. (2023) assessed consumer attitude and disposal behaviour toward second-hand clothing in Ghana and discovered a significant positive relation between consumers' disposal behaviour and consumption intention. Instead of utilising recycling bins or returning them for reuse, consumers often burnt their second-hand clothes in the open or discarded them in landfills (Acquaye et al., 2023). Typically, recycling and reusing behaviour is a practice that is not common in Ghana (Kanhai et al., 2019). Acquaye et al. (2023) identified that some consumers donate unwanted clothing to charity. However, the overwhelming volume of low-quality garments makes redistribution unsustainable, ultimately contributing to the waste crisis. These behaviours aggravate waste management challenges and hinder efforts toward sustainable textile disposal.

Environmental Impacts of Textile Waste

An increase in textile manufacturing and consumption has been linked to adverse environmental impacts. The production of textile materials contributes significantly to carbon dioxide emissions, water, and micro-plastic pollution (DeVoy et al., 2021). In the EU region, textile industries contribute about 20% of water pollution from dyeing, finishing and other chemical products (European Parliament, 2020). After the manufacturing stage, the concern shifts to the environmental hazards PCTW poses. Recent global data shows that only 25% of PCTW is recycled; the remaining 75% is incinerated or buried in landfills (Juanga-Labayen et al., 2022; Sumo et al., 2022). Similarly, landfills are the most used and adopted waste management option in Ghana (Kuranchie et al., 2020), even though studies have shown that landfills have adverse effects on the environment.

Overall, PCTW in landfills takes time to decompose. Unlike natural fibres, synthetic fibres such as polyester and nylon may decompose completely for up to twenty to hundred years (Egan & Salmon, 2022). During decomposition, plant-based textiles like cotton undergo anaerobic digestion, where bacteria break down organic components like cellulose, producing methane (Shoaf, 2022). Methane emissions from landfills contribute significantly to climate change, as methane is a potent greenhouse gas. The release of methane into the air and water bodies from landfills as a result of decomposition poses health risks to the environment (Moazzem et al., 2021). On the other hand, microplastics from synthetic fibres like polyester leach into water bodies, causing pollution.

Chronic exposure to these pollutants can result in long-term health issues, disproportionately affecting vulnerable populations with limited access to healthcare (Miller et al., 2020). For instance, polluted water poses health risks to local communities and affects livelihoods, mainly farmers and fisherfolk who rely on water (Barrows et al., 2018). In effect, landfilling and the open burning methods of managing PCTW are considered unsustainable, contributing to climate change issues and inflicting lasting ecological damage.

Existing Recycling and Reuse Practices in Ghana

In recent years, various stakeholders, including policymakers, stakeholders, including private sector businesses, local communities, local artisans, students, and some NGOs, have seen the need for recycling and reusing actions in the country, contributing their quota to ensure sustainable textile waste management actions are implemented and sustained. Several primary initiatives aimed at reducing PCTW and indiscriminate disposal have been initiated, while others are underway. This section highlights some of the key initiatives that such stakeholders have undertaken.

Initiatives by Private Sector Actors and NGOs

In response to the growing textile waste crisis, various private sector actors and non-governmental organisations (NGOs) in Ghana have launched initiatives to promote recycling and sustainable waste management. These efforts aim to reduce environmental harm while creating economic opportunities, particularly for young entrepreneurs.

1. **Recycling textile waste into products**: Among these initiatives is a project by Sai and Acquaye (2022), who collected and recycled about 280 kg of textile waste into decorative household items to serve a new purpose. The transformation provides discarded textiles a second life, promoting sustainability and reducing waste. This initiative not only helps minimise textile waste but also encourages creative reuse and circular economy practices. Also, a youth-led business, Koliko Ghana, has successfully transformed 500 kg of PCTW into quality footwear and bags (Laaru Consulting, 2023). Although it is a small enterprise, it aims to expand its capacity to further reduce the negative impact of textile waste while addressing the unemployment rate among Ghanaian youth.

2. **Promoting job creation through recycling**: The Revival Earth Organization, a non-governmental organisation established in Ghana recently with partners from the United Kingdom, has taken the initiative to promote

sustainable design and job creation by upcycling textile waste. They educate communities through workshops, support artistic expression and raise awareness with campaigns. The project fosters entrepreneurship by training artisans and facilitating market access for upcycled products (United Nations, n.d). To sum up, there is a need for collaboration with stakeholders and evaluation to ensure success and sustainability while planning towards expansion.

3. **Promoting ethical textile waste management**: The Or Foundation is a USA-based not-for-profit organisation and a registered charity in Ghana. Their work in Ghana and the United States of America (USA) cut across environmental justice, education, and fashion development. Over the last five years, the Or Foundation, in partnership with the Kantamanto Market Community, has advocated for a more structured second-hand clothing system, sustainable waste management, and labour conditions. As part of their mission and work in Ghana, they have initiated several programs, including the Kanta Keepers Market Collective, Tide Turners Cleanup Team, Stop Waste Colonialism, Community Business Incubator, Obroni Wawu October, and Material Research & Development.

   Under the ***Kanta Keepers Market Collective*** initiative, individuals are engaged through the various group leaders to collect and separate textile waste generated throughout the market. In partnership with the Accra Metropolitan Assembly, a designated truck transports the waste to an authorised dumpsite away from the coastline. These individuals responsible for the collection, referred to as *Kanta Keepers* under this initiative, are responsible for gathering and loading the waste onto this truck for disposal. This initiative aims to curb the indiscriminate disposal of excessive textile waste from unsold and damaged second-hand clothing (The Or Foundation).

   The ***Tide Turners Clean-up Team*** collaborates with the waste management department of the Accra Metropolitan Assembly and other community clean-up groups to tackle waste pollution. Their primary focus is to remove textile waste, often forming "*clothing tentacles*" from the beaches in Accra. About 10 tons of textile waste are removed and transported off the beaches weekly.

Obroni Wawu October was launched in 2022 as an annual event that seeks to promote upcycling practices of second-hand clothing imported into the country. It also pays homage to "Kantamanto", the hub of Ghana's second-hand clothing and upcycling drive. Over time, the event has become a key platform for celebrating circular fashion, uniting communities, and raising awareness of sustainable practices in second-hand clothing (Baisie, 2024)

The ***Material Research & Development*** project was designed to establish the methodology and community infrastructure required to collect, sort, transport, store and process industrial-scale quantities of clothing for more efficient use. As part of this initiative, a recycling and decomposition centre has been established on the outskirts of Kantamanto and Old Fadama. The centre uses local and foreign machinery to transform post-consumer textile waste into fibreboards, a versatile material with multiple applications and zero harmful by-products. These fibreboards are converted into useful and valuable products such as speakers, shelves, sound insulation panels and tables, replacing virgin wood, foam, plastic, and more that are already in use. Over the past two years, this initiative has collected and recycled over 32,000kg (168,000+ items) that would otherwise have left the market as waste (The Or Foundation). Remarkably, most textile waste recycling machinery is locally designed and built with scrap materials by local fabricators in the market (Galloway Market). In addition to textile waste recycling, this initiative seeks to advance product development and commercialise diverse material transformation pathways within the Kantamanto Market ecosystem.

Government Initiatives for Textile Management

With the implementation of the Extended Producer Responsibility (EPR), Ghana's textile industry is envisioned to be transformed. The EPR is an environmental policy initiated by the Organisation for Economic Cooperation and Development (OECD) to hold producers responsible for their product's lifecycle, including post-consumer disposal and recycling (OECD, 2001). This policy requires textile producers to integrate environmental concerns into product design, production, end-of-life management, and recycling of textiles.

The Ministry of the Environment, Science and Technology (MEST) enforces mandatory EPR compliance in Ghana, replacing the previous voluntary system

(Modern Ghana, 2024). The policy aims to create a more circular economy where textile waste is minimised through better recycling systems, extended product durability, and producer-led waste recovery programs. Amidst the challenges and limitations, the adoption of the EPR system shows the immense commitment of the country, to ensuring environmental sustainability in all production industries in which the textile industry is involved.

Barriers to Textile Recycling and Reuse Practices in Ghana

Implementing sustainable textile waste management practices in Ghana can be achieved through a collaborative effort by the government, individuals, and businesses. However, several challenges hinder the implementation of effective recycling and reuse practices. These barriers range from technological to economic, cultural, and regulatory scope.

1. **Limited recycling technology and infrastructure**: A major challenge in managing PCTW is the limited technological and infrastructural resources for sorting, processing, and transforming PCTW into reusable materials. Effective recycling requires specialised technologies and facilities for collection, shredding, and processing (Ghosh, 2022). In the countries where textile recycling practices are successfully implemented, PCTW is collected through specialised collection bins, which are transported to centralised areas for sorting, disinfection, and further processes. The lack of structured collection protocols and machinery for recycling PCTW in Ghana hinders efforts to manage textile waste.
2. **Inadequate Funding for Recycling Initiatives:** Financial constraints result in limited capacity for developing and expanding sustainable textile waste management systems in Ghana. This funding gap restricts the ability of small and medium-sized enterprises that are engaged in textile recycling to expand their operations. Consequently, many recycling efforts remain small-scale or informal, preventing the industry from growing and creating widespread economic opportunities.
3. **Low market demand for recycled products:** The cycle of rapid consumption and textiles disposal combined with a strong preference for new and imported clothing over locally produced textiles poses a significant challenge to generating market demand for recycled textile products. Additionally, limited awareness of textile waste, its

environmental impact, and the importance of recycling discourages investment and innovation in the sector, keeping demand low.

4. **Weak regulatory frameworks:** The absence of strong regulatory structures on textile waste management in Ghana likewise affects sustainable textile PCTW management advancement. In other parts of the world, associations and regulatory bodies exist to govern recycling businesses and enterprises to adopt sustainable practices. The textile waste management sector is primarily informal and underdeveloped due to the lack of government enforcement and regulatory bodies. It is essential for the country to develop and implement comprehensive policies that promote recycling, offer financial incentives for sustainable businesses, and encourage public participation in textile waste management initiatives.

Global Approaches to Textile Waste Management

The previous sections discussed the growing challenge of PCTW and its environmental impacts. The sections also examined the existing recycling and reuse methods in Ghana and the challenges that impede their widespread use. This section discusses some standardised textile waste management practices that are available, focusing on the two management systems used in the major developed countries. The section also examines how these systems can be applied to the situation in Ghana.

Globally, textile waste recycling follows two systems: open–loop and closed–loop recycling. In the open-loop system, novel products, quite different from the original ones, are created using textile waste. Conversely, the closed-loop system repeatedly processes textile waste to recreate the same product. While both systems foster waste reduction, the open-loop system extends the life span of the textile waste material by reprocessing it into new materials (either textile or non-textile-related products). At the same time, closed-loop recycling minimises resource extraction (Payne, 2015). It keeps the textile material circulating within the same product cycle.

The appeal for recycling and reuse practices is a pressing global concern. In the international efforts to recycle and reuse PCTW, several countries have initiated and implemented successful approaches. These methods could be tailored to fit Ghana’s cultural, economic, and environmental context to address the country's waste management needs. The discussions below provide some successful approaches implemented across different parts of the world.

Textile recycling in the US – Systems, companies, and community efforts

In the US, about 2000 companies are involved in textile recycling and post-textile waste chain. The country has established systems for PCTW collection, sorting, and distribution. Standard recycling methods include exporting clothing to other parts of the world as second-hand goods. For example, a renowned textile recycling company, Goodwill, reported that about 45 per cent of PCTW are exported to foreign countries. The revenues from these exports support social programs such as care for the homeless and the jobless. While this contributes to a circular economy by extending the lifespan of textiles, it shifts the burden and responsibility for waste management practices to importing countries.

Beyond exports, many US-based recycling companies use recycled textile waste as raw materials for their products. For example, Phoenix Fibres, an Arizona-based recycling company, engages in open-loop recycling by converting tons of denim and cotton fabrics into appliance insulation, automotive insulation, and prison mattresses (Phoenix, n.d). Similarly, Patagonia, an outdoor apparel company based in California, has established its textile recycling program termed "*The Common Threads Garment Recycling Program*". This initiative presents a closed-loop system where worn-out clothes are collected from customers and recycled into new polyester fibre. This program collaborates with *Teijins Ecocircle Recycling System* in Japan, which specialises in manufacturing new polyester from recycled textile waste (Patagonia, n.d).

Community-level efforts also play a crucial role in the reduction of textile waste. Cities such as Westchester County in New York State are making massive contributions to keeping textiles out of the waste stream. They offer free textile pickup for residents and have a textile collection bin where residents are to deposit their textile waste (Scarsdale, n.d)

Textile Recycling Industry in Brazil – Prospects and Challenges

According to Amaral et al. (2018), Brazil has about twenty-one textile recycling companies of varying sizes. These companies collect, sort, transport and recycle textile waste. While some companies use post-consumer waste from households and industries, others use only post-industrial waste (textile waste coming directly from the production companies) for their recycling.

Recycling companies in Brazil transform textile waste into new fibres, Polyethylene terephthalate (PET), wires, and fabrics. The national industry then reuses the recycled materials as raw materials for clothing, automobiles, and packages. However, the demand for recycled materials exceeds the available supply of textile waste collected and processed within the country. This shortage is largely due to the absence of a structured selective textile waste collection system, which limits the efficiency and scale of recycling efforts (Amaral et al., 2018; Grando et al., 2022). As a result, Brazil has to import textile waste to meet the needs of its recycling industry.

Textile Waste Management in Belgium – Commitment and Innovations

Belgium has demonstrated a strong commitment to the collection and recycling of PCTW. Existing recycling programs provide households with a free recycling bag to collect their used clothing and other textile items that are no longer in use. The companies arrange for collection on a particular day, and the collection is sorted into categories. The sorted clothes are sent to the factories, disinfected, and regenerated into pulp or complete fibres.

A notable initiative is the *Retex Project* of the *Centexbel Consultant Technical Textiles*, which focuses on recycling cotton and polyester-based textile waste into yarn for upcycling (Centexbel, n.d). Additionally, municipal and commercial companies, including charity organisations, are actively involved in collecting, sorting and selling discarded textiles. An example is *Sematex*, which is engaged mainly in the sorting, bailing and selling these clothing as second-hand goods worldwide (Samtex, n.d.). These efforts contribute to a more structured and sustainable approach to textile waste management in Belgium.

Textile Waste Management in India: The Role of the Informal Sector

India runs an exclusive example of textile waste management through its enormous informal recycling sector. Leading industrial cities like *Panipat* have emerged as key hubs for textile recycling, specialising in shredding and pulping textile waste into new materials such as blankets, doormats, door linens and industrial wipes. These recycled products have gained international market share, as their shoddy blankets are exported to Tanzania, Australia, and other parts of Africa (Dwij, 2014).

These recycling projects are supported by partnerships that help map out and sustain textile waste flow. For instance, a recent initiative, *Saamuhika Shakti* (meaning collective strength), led by the H&M Foundation in collaboration with many other organisations, aims to improve the livelihoods of waste collectors to live a secure and dignified life (Waste 360, 2023). These efforts highlight India's commitment to leveraging informal and formal sectors to advance sustainable textile waste management.

Kenya's Approach to Textile Waste: Closing the Loop

The growing textile production rate in Kenya and a lack of recycling solutions created an opportunity for innovative partnerships to address textile waste. One such initiative, *Closing the Loop on Textile Waste*, is working to reduce textile waste in East Africa with support *from PurFi*, a US-based company specialising in advanced textile recycling. PurFi has developed a revolutionary chemical recycling technology that restores fabric waste material to its virgin-quality fibre (PurFi, n.d.).

While this initiative currently focuses on the post-industrial textile waste model, it plans to scale up to post-consumer textile waste, the most challenging waste stream in Kenya and the larger East Africa (World Resource Institute, 2021). The project's sorting team, composed entirely of women, processes 36,000 kg of textile waste monthly.

Although such international initiatives offer valuable models, adapting them to **Ghana's socio-cultural and economic context** requires careful consideration.

Recycling and reuse practices come with collection, sorting, processing, and recycling costs. For Ghana to implement similar strategies effectively, evaluating **the expenses** associated with existing waste management practices will be crucial while considering their long-term environmental impact.

Scaling Textile Recycling and Reuse as a Climate Solution in Ghana

There are two main *textile recycling* methods: mechanical processing and chemical processing. Mechanical recycling focuses on regenerating textile wastes into usable products without substantially altering the chemical structure of the fabrics. It involves a combination of processes such as sorting, carding, shredding, and blending waste fabrics into fibrous forms and re-spun into yarns or manufactured into nonwoven textiles (Johnson et al., 2020). Mechanical recycling is a typical and most-used method that can be used with a low-cost budget (Chen et al., 2023).

However, the mechanical shredding process shortens fibre length and reduces fibre quality. Thus, about 95% of recovered fibres through shredding or disintegration are processed into nonwoven textile products instead of re-spun into yarns for fabrics (Piribauer & Bartl, 2019). Another form of mechanical recycling is thermo-mechanical recycling, which involves the application of heat. This method suits synthetic textile waste fibres and involves sorting, melting, and remoulding (Voytyuk, 2020).

In chemical recycling, textile waste is broken down into smaller polymers used to manufacture new polymers (textiles). Chemical recycling provides substantial opportunities to maintain materials in a closed loop (Ellen MacArthur Foundation, 2017). The chemical recycling option becomes a better alternative for textile waste recycling as it addresses some of the limitations associated with mechanical recycling. Synthetic fibres, including polyesters, polyamides, and polyolefin, can be chemically recycled to produce (Baloyi et al., 2024). Chemical recycling is characterised by higher energy demands than mechanical recycling due to the high temperatures and pressure required for the various processes (Qureshi, 2022). However, the energy consumption in chemical recycling is lesser as compared to the energy demands for producing virgin fibres (Qureshi, 2022; Khan et al., 2024).

Given the country's unique challenges and opportunities, mechanical recycling presents a practical and cost-effective solution for textile waste management. This approach could involve establishing small-scale community-based units dedicated to textile waste collection, sorting, shredding, and regenerating PCTW across local communities. For this initiative to achieve impactful results, it will be crucial to actively engage community leaders, opinion leaders, and other gatekeepers regarding the need for and opportunities to engage in textile recycling and reuse practices.

Additionally, these small-scale community-based units could utilise compact, low-energy mechanical machinery to process post-consumer textiles into fibres for various uses, such as insulation, padding, or low-grade yarn for weaving. The government must invest in fabric shredders and establish dedicated PCTW collection points to support this initiative. This commitment will strengthen the recycling framework, promote the effective processing and repurposing of textiles, and foster a more sustainable circular economy. These units could be sited in various regions or designed to serve many areas with the potential for nationwide expansion. Adopting the small-scale regionalised system will help curb the huge cost of logistics and infrastructure involved in running large-scale industries.

Implementing such structures will catalyse the expansion of the nation’s textile recycling practices, fostering socio-economic growth. As mechanical recycling gains traction, the inevitable increase in demand for human resources will manifest in creating employment opportunities for citizens, particularly youth and women, who are currently grappling with a high unemployment rate. This will encompass roles in recycling facilities, collection, sorting, processing, product design, and expanding market demand for recycled products. Consequently, women and youth will have access to decent jobs and enhance their livelihoods. Over time, Ghana can build on this foundation by collaborating with major industries to develop more advanced and robust chemical recycling solutions, further improving efficiency and sustainability in textile waste management.

Lastly, mounting textile recycling and reuse systems in the country will fuel environmental sustainability, economic development, and improve livelihoods. Consequently, Ghana can retain more value within its economy, promote sustainable consumption, and reduce the environmental footprint of imported goods.

Conclusions and Policy Recommendations

This chapter presents a review that emphasises the issue of PCTW, its disposal, and its adverse effect on the environment. It examines the country's existing recycling and reuse practices and the bottlenecks to its expansion. It also highlights some successful international programs on textile recycling and how these initiatives could be tailored to the country’s context, considering the opportunities and challenges at hand. Successful waste management strategies can help reduce PCTW and foster job creation in recycling industries. To scale these initiatives up, the government must take an active role by adopting responsible consumption habits, supporting existing recycling programs, and increasing awareness campaigns.

It has been established that the open-loop and closed-loop recycling systems and the two methods of recycling, mechanical and chemical, can be used to divert tonnes of textile waste from landfills and open-burning sites. The review has underlined factors like limited infrastructure, awareness, and policy support as challenges to the widespread adoption of textile recycling practices. Yet, it shows the promising potential of scaling up recycling practices through small-scale businesses and technological advancements and the benefits it will bring. The study makes the following recommendations to improve textile waste management practices in Ghana.

1. **Strengthen Policy Implementation and Enforcement**: Government agencies such as the Ministry of Environment, Science and Technology, the EPA must collaborate to enforce stricter regulations on textile waste management by strengthening the implementation of the Extended Producer Responsibility (EPR) policy. Strict enforcement will require textile manufacturers and importers to take responsibility for collecting, recycling, or repurposing their textiles. The EPA must also establish robust monitoring and evaluation systems to track compliance, impose penalties for violations, and offer incentives for businesses that adopt sustainable waste management practices. Additionally, the GSA should develop and enforce quality standards for recycled textile products, ensuring they meet local and international market requirements.

2. **Promote Community-Led Recycling and Upcycling Initiatives:** Metropolitan, Municipal and District Assemblies (MMDAs) must take the lead in coordinating and funding community-driven recycling initiatives, ensuring that local governments actively support waste collection, sorting, and upcycling programs. They should collaborate with NGOs to organise training sessions for artisans and local businesses on textile recycling techniques. The private sector, particularly fashion brands and textile manufacturers, should be encouraged to partner with MMDAs and community-led groups to provide financial support, materials, and market access for upcycled products.
3. **Expand Consumer Awareness and Behavioural Change Campaigns:** The EPA and MEST must support the National Commission for Civic Education (NCCE) to lead nationwide public awareness campaigns on the environmental impact of textile waste and the importance of sustainable fashion. These campaigns should target schools, churches, and traditional gatherings, educating people on responsible clothing consumption and the benefits of recycling. Additionally, media outlets must actively disseminate information through radio, television, and social media, discouraging fast fashion and promoting sustainable alternatives. CSOs should also work alongside these institutions to organise community workshops and events to encourage responsible textile consumption.
4. **Integrate PCTW into education curricula**: The GES must revise educational curricula to include topics on textile sustainability, ensuring that students at all levels understand the environmental impact of textile waste and the principles of a circular economy. TVET institutions should introduce specialised courses on textile recycling, eco-friendly fashion design, and sustainable production techniques. Universities should research innovative ways to recycle textile waste and incorporate sustainability into their fashion and textile programs. These initiatives will equip future industry professionals with the skills to drive Ghana's textile recycling agenda.
5. **Provide Financial Incentives for Textile Recycling Businesses:** The Ministry of Finance, in collaboration with the GRA, must introduce incentives to support textile recycling businesses. These financial incentives will encourage companies to invest in sustainable waste management and recycling infrastructure. The GIPC should actively

promote Ghana's textile recycling sector to local and foreign investors, showcasing opportunities for growth and innovation. Commercial banks and microfinance institutions should also be encouraged to offer green financing solutions tailored to the needs of textile recycling start-ups and SMEs.

6. **Invest in Regional Textile Recycling Hubs:** The Ministry of Trade and Industry must develop a national strategy for regional textile recycling hubs, ensuring that recycling facilities are distributed across the country to minimise logistical costs. Further, the government should provide land, infrastructure, and support services to facilitate the establishment of these hubs. Private investors must also be encouraged to partner with the government in financing and managing these facilities, particularly by introducing low-energy mechanical machinery for sorting, shredding, and repurposing textiles. Over time, as Ghana builds capacity, the ministry should work with major industrial players to develop advanced chemical recycling solutions to further enhance textile waste management.
7. **Strengthen Public-Private Partnerships (PPPs) for Textile Recycling:** The Ministry of Trade and Industry must initiate and facilitate partnerships between the government, private sector, and academic institutions to drive textile waste recycling. Private textile companies should be encouraged to invest in research and development to explore new recycling technologies, while international donors can provide funding and technical expertise. Research institutions, including universities and technical colleges, should be engaged in developing cost-effective, innovative textile recycling methods, ensuring that Ghana adopts best practices suited to its economic and environmental context.

References

Acquaye, R., Seidu, R. K., Eghan, B., & Fobiri, G. K. (2023). Consumer attitude and disposal behaviour to second-hand clothing in Ghana. *Scientific African*, *21*, e01887.

Adeloye, A. A., Akinbogun, T. L., & Ogunduyile, S. R. (2023). The production of African print fabric designs: A user-centric design approach. *Prithvi Academic Journal*, 32-48.

Agra, F. E., Gbadegbe, S. R., Amanda, S., & Gbetodeme, S. (2015). The impact of the use of second-hand clothing on the garment and textile industries in Ghana: A case study of the Ho Municipality. *Research on Humanities and Social Sciences, 5*(21), 37-48.

Ajila, K. O. (2019). Analysis of post-consumer solid textile waste management among households in Oyo State of Nigeria. *Journal of Environmental Protection*, *10*(11), 1419-1435

Amaral, M. C., Zonatti, W. F., Silva, K. L., Karam Junior, D., Amato Neto, J., & Baruque-Ramos, J. (2018). Industrial textile recycling and reuse in Brazil: Case study and considerations concerning the circular economy. Gestão & Produção. 25. https://doi.org/10.1590/0104-530x3305.

Ankora, M. W. E. (2022). Material Culture, African Textiles and National Identity [Doctoral dissertation] University of Guelph.

Aronsson, J. & Persson, A. (2020). Tearing of post-consumer cotton T-shirts and jeans of varying degree of wear. *Journal of Engineered Fibers and Fabrics 15*. 155892502090132. https://doi.org/10.1177/1558925020901322.

Ayesu, S. M., Acquaye, R., Howard, E. K., and Asinyo, B. K. (2023). Promotion and Preservation of Indigenous Textiles and Culture in Ghana. *East African Journal of Education and Social Sciences 4*(1) 15-29. doi: https://doi.org/10.46606/eajess2022v03i06.0252

Bailey, K., Basu, A., & Sharma, S. (2022). The environmental impacts of fast fashion on water quality: A systematic review. *Water, 14*(7), Article 1073.
https://doi.org/10.3390/w14071073

Balasaraswathi, S.R., Rathinamoorthy, R. (2022). Synthetic Textile and Microplastic Pollution: An Analysis on Environmental and Health Impact. In: Muthu, S.S. (eds) *Sustainable Approaches in Textiles and Fashion. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry.* Springer, Singapore. https://doi.org/10.1007/978-981-19-0530-8

Baloyi, R. B., Gbadeyan, O. J., Sithole, B., & Chunilall, V. (2024). Recent advances in recycling technologies for waste textile fabrics: A review. *Textile Research Journal*, *94*(3-4), 508-529.

Baisie, S. (October, 2024). Obroni Wawu October 2024: Ghana's thrift & upcycling festival receives massive turnout. Retrieved from;

https://www.gbcghanaonline.com/entertainment/obroni-wawu-october/2024/

Barrows, A. P. W., Cathey, S. E., & Petersen, C. W. (2018). Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins. *Environmental Pollution, 237*, 275-284. https://doi.org/10.1016/j.envpol.2018.02.062

Cao, H. (2021) End of life clothes and their management. In *Waste Management in the Fashion and Textile Industries*; Nayak, R., Patnaik, A., Eds.; Woodhead Publishing: Duxford, UK, pp. 157–172

Cassidy, T., & Goswami, P. (Eds.). (2017). *Textile and clothing design technology*. CRC Press.

Centexbel, (n.d). *Cotton/polyester recycling*. Retrieved from:

https://www.centexbel.be/en/expertise/textile-recycling

Chen, Z., Sun, H., Kong, W., Chen, L., & Zuo, W. Closed-loop utilization of polyester in the textile industry. Green Chem. 25, 4429–4437 (2023).

Daffi, R. E., Chaimang, A. N., & Alfa, M. I. (2020). Environmental impact of open burning of municipal solid wastes dumps in parts of Jos Metropolis, Nigeria. *J. Eng. Res. Rep*, *12*, 30-43.

Desore, A., & Narula, S. A. (2018). An overview on corporate response towards sustainability issues in textile industry. *Environment, Development and Sustainability*, *20*, 1439-1459.

DeVoy, J. E., Congiusta, E., Lundberg, D. J., Findeisen, S., & Bhattacharya, S. (2021). Post-consumer textile waste and disposal: Differences by socio-economic, demographic, and retail factors. *Waste Management, 136*, 303-309.
https://doi.org/10.1016/j.wasman.2021.10.009

Dwij, (June 2014) *The story of Asia's biggest textile recycling hub*. Retrieved from; https://dwijproducts.com/blogs/dwijblogs/the-story-of-asia-s-biggest-textile-recycling-hub?srsltid=AfmBOooP1BRG39VMoikNaVPY-HrNDbRFkP0xLFvplXjWLh2pf4rPdITT

Echeverria CA, Handoko W, Pahlevani F, Sahajwalla V (2019) *Cascading use of textile waste for the advancement of fibre rein forced composites for building applications*. J Clean Prod 208: 1524–1536. https://doi.org/10.1016/j.jclepro.2018.10.227

Egan, J., & Salmon, S. (2022). Strategies and progress in synthetic textile fiber biodegradability. *SN Applied Sciences, 4,* 22. https://doi.org/10.1007/s42452-021-04851-7

Ellen MacArthur Foundation, (December, 2017). *A new textiles economy: Redesigning fashion's future*. Retrieved from: https://www.ellenmacarthurfoundation.org/a-new-textiles-economy

European Parliament (2020, December 29). *Circular Economy: The impact of textile production waste on the environment (infographics*). Retrieved from https://www.europarl.europa.eu/topics/en/article/20201208STO93327

Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D.J. Lunt, T. Mauritsen, M.D. Palmer, M. Watanabe, M. Wild, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. I*n Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press,

Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054, doi:10.1017/9781009157896.009

Garcia-Ortega, B., Galan-Cubillo, J., Llorens-Montes, F. J., & de-Miguel-Molina, B. (2023). Sufficient consumption as a missing link toward sustainability: The case of fast fashion. *Journal of Cleaner Production*, *399*, 136678.

Ghosh S. (2022, January*). HKRITA's Green Machine is a breakthrough in the recycling of blended textiles needed at scale*. Retrieved from https://texfash.com/special/hkritas-green-machine-is-breakthrough-that-recycling-of-blended-textiles-needed-at-scale

Grando, F. S., Sette, S. K., Batiston, E. R., Colpani, G. L., de Mello, J. M. M., & Silva, L. L. (2022). Reciclagem de resíduos têxteis: uma revisão: Textile waste recycling: a review. *Brazilian Journal of Development*, 57050-57067.

Ho, S., & H&M Circular. (2023, February 7): *Textile Recycling Startup Renewcell Lands Multi-Year Agreement With Fashion Group, Green Queen.* Retrieved from, https://www.greenqueen.com.hk/hm-circular-textile-recycling-startup-renewcell-lands-multi-year-agreement-with-fashion-group/

Hur, E. (2020). Rebirth fashion: Second-hand clothing consumption values and perceived risks. *Journal of Cleaner Production*, *273*, 122951.

Iravanian, A., & Ravari, S. O. (2020,). Types of contamination in landfills and effects on the environment: A review study. In IOP conference series: *Earth and environmental science 64*(1) 012083

Johnson, S.; Echeverria, D.; Venditti, R.; Jameel, H.& Yao, Y. (2020) Supply chain of waste cotton recycling and reuse: A review. *AATCC Journal. Res. 7*, 19–29.

Juanga-Labayen, J. P., Labayen, I.V., & Yuan, Q. (2022) A Review on Textile Recycling Practices and Challenges. *Textiles 2*(1), 174-188. https://doi.org/10.3390/textiles2010010

Kanhai, G., Agyei-Mensah, S., & Mudu, P. (2019). Population awareness and attitudes toward waste-related health risks in Accra, Ghana. *International Journal of Environmental Health Research*, *31*(6), 670–686. https://doi.org/10.1080/09603123.2019.1680818

Kuranchie, F. A., Attiogbe, F., Quarshie, J. T., & Ntibrey, R. A. K. (2020). Land scarcity as a site selection challenge for the management of municipal solid wastes in Accra, Ghana. *International Journal of Environment and Waste Management*, *26*(4), 423-437.

Laaru Consulting, (2023, September 19). *How sustainable are your shoes? Ghanaian footwear design from recycled materials.* Retrieved from https://www.laaruconsulting.com/post/how-sustainable-are-your-shoes-ghanaian-footwear-design-from-sustainable-materials

Lellis, B., Fávaro-Polonio, C.Z., Pamphile, J.A., & Polonio, J.C. (2019). Effects of textile dyes on health and the environment and bioremediation potential of living organisms, *Biotechnology Research and Innovation 3(2)* (275-290). https://doi.org/10.1016/j.biori.2019.09.0 01

Maiti, R. (2024, January 4). *Fast fashion and its environmental impact in 2024*. Earth.Org. Retrieved from https://earth.org/fast-fashions-detrimental-effect-on-the-environment/

Martino, A. (2018). Stamping History: *Stories of Social Change in Ghana's Adinkra Cloth* [Doctoral dissertation, University of Michigan]. University of Michigan Library.

Moazzem, S., Wang, L., Daver, F., & Crossin, E. (2021). Environmental impact of discarded apparel landfilling and recycling. *Resources, conservation and recycling, 166,* 105338

Modern Ghana, (2024, July 2). *Ghana's Textile Revolution: Implementing Extended Producer Responsibility*. Retrieved from https://www.modernghana.com/news/1324050/ghanas-textile-revolution-implementing-extended.html

Mor, S., & Ravindra, K. (2023). Municipal solid waste landfills in lower-and middle-income countries: Environmental impacts, challenges and sustainable management practices. *Process Safety and Environmental Protection*, *174*, 510-530.

Navone, L., Moffitt, K., Hansen, K. A., Blinco, J., Payne, A., & Speight, R. (2020). Closing the textile loop: Enzymatic fibre separation and recycling of wool/polyester fabric blends. *Waste Management, 102*, (149-160. https://doi.org/10.1016/j.wasman.2019.10.026

Nayak, R., & Padhye, R. (2015). Introduction: the apparel industry. In *Garment manufacturing technology* (pp. 1-17). Woodhead Publishing.

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nature Reviews Earth & Environment*, *1*(4), 189-200.

Papasolomou, I., Melanthiou, Y., & Tsamouridis, A. (2023). The fast fashion vs environment debate: Consumers' level of awareness, feelings, and behaviour towards sustainability within the fast-fashion sector. *Journal of Marketing Communications*, *29*(2), 191-209.

Patagonia (n.d). *Patagonia's Common Threads Garment Recycling Program. A Detailed Analysis.* Retrieved from; https://www.patagonia.com/on/demandware.static/Sites-patagonia-us-Site/Library-Sites-PatagoniaShared/en_US/PDF-US/common_threads_whitepaper.pdf

Patti, A., Cicala, G., & Acierno, D. (2020). Eco-sustainability of the textile production: Waste recovery and current recycling in the composites world. *Polymers, 13(1),* 134. https://doi.org/10.3390/polym13010134

Payne, A. (2015). Open and closed-loop recycling of textile and apparel products. In Muthu, S (Ed.) *Handbook of life cycle assessment (LCA) of textiles and clothing [1st Edition*]. Woodhead Publishing, United Kingdom, pp. 103-123.

Phoenix (n.d). Retrieved from https://www.phxfibers.com

Piribauer, B. & Bartl, A. (2019). Textile recycling processes, state of the art and current development: A mini review. Waste Manag. Res. 37, 112–119

PurFi, (n.d). Rejuvenating fibers for a circular world. Retrieved from: https://purfi.com/

Que-Ramos, J. (2018). Industrial textile recycling and reuse in Brazil: case study and consi-

Renwick, D. (2023, September 21). *A look at the secret world where our waste ends up*. Corporate Knights. Retrieved from https://www.corporateknights.com/waste/secret-waste-world-toxic-landfill/ss

Ricketts, L., & Skinner, J. B. (2020). *Our long recovery: Catalyzing a justice-led circular textiles economy.* The OR Foundation.

Sandin, G., & Peters, G. M. (2018). Environmental impact of textile reuse and recycling–A review. *Journal of cleaner production*, *184*, 353-365.

Scarsdale, (n.d). *Textile Recycling; New Curbside Textile Recycling Program – Starting October 5*. Retrieved from: https://www.scarsdale.gov/176/Textile-Recycling

Shoaf, T. J. (2022). *A Study to Assess Methane Potential of Plant Based Textiles Through Anaerobic Digestion*. {Master's thesis, Purdue University}.

Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research*, *29*(39), 58514-58536.

Skinner, J. B. (2019). *Fashioning Waste: Considering the Global and Local Impacts of the Second-hand Clothing Trade in Accra, Ghana and Charting an Inclusive Path Forward* [Master's thesis, University of Cincinnati]. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=ucin1553613566277155

Smith, P. (2024, May). *Global revenue of the apparel market 2018-2028*. Statista 2024. Retrieved from https://www.statista.com/forecasts/821415/value-of-the-global-apparel-market

Stanbic Bank (September, 2024). *Bridging the Finance Gap for SMEs as a Pathway to Sustainable Growth*. Retrieved from: https://www.stanbicbank.co.zw/gh/personal/about-us/news/bridging-the-finance-gap-for-smes-as-a-pathway-to-sustainable-growth

Sumo, D., Ji, X.& Cai, L.(2022). Efficiency evaluation and loan assessment of fashion upcyclers in Liberia using fuzzy, DEA and FIS models, *Research Journal of Textile and Apparel*, (1-23.) https://doi.org/10.1108/RJTA-07-2022 0082

The Observatory of Economic Complexities (2022). *Used Clothing: Textiles; worn clothing and other worn articles. Multidimensional Economic Complexity Rankings 2022*. Retrieved from https://oec.world/en/profile/hs/used-clothing\

The Or Foundation (2020, May 16) The Perspective of an expert; Solomon Noi.{Video}youtube; https://www.youtube.com/watch?v=CGoJ0rySbGE

The World Bank (July, 2019). *Improving Access to Finance for Ghanaian SMEs: Is there a Role for a New Development Finance Institution?* Retrieved from: https://documents1.worldbank.org/curated/en/934351587974318392/pdf/Improving-Access-to-Finance-for-Ghanaian-SMEs-Role-for-a-New-DFI.pdf

Tuppens, H. (2024). *The Impact of Textile Waste in Ghana.* The Borgen Project. Retrieved from https://borgenproject.org/textile-waste-in-ghana/

Uddin, F. (2019). Introductory chapter: textile manufacturing processes. In *Textile manufacturing processes*. IntechOpen.

United Nation(n.d). The Revival: *Upcycling and Circular Economy, Ghanaian Creative solutions to Global Textile Waste*. Retrieved from https://sdgs.un.org/partnerships/revival-upcycling-and-circular-economy-ghanaian-creative-solutions-global-textile

Voytyuk, N. (2020). *Recycling of polypropylene and polyamide blends using thermomechanical recycling*. Stockholm

Waste 360, (May, 2023). *Bengaluru Waste Pickers in the Driver's Seat of New Textile Recycling Initiative*. Retrieved from; https://www.waste360.com/textiles/bengaluru-waste-pickers-in-the-driver-s-seat-of-new-textile-recycling-initiative

Wojnowska-Baryła, I., Bernat, K., & Zaborowska, M. (2022). Strategies of recovery and organic recycling used in textile waste management. *International Journal of Environmental Research and Public Health, 19*(10), 5859. https://doi.org/10.3390/ijerph19105859

World Resource Institute, (December 2, 2021). How a Partnership in Kenya Recycled 100,000 Kilograms of Fashion Waste. Retrieved from https://www.wri.org/insights/closing-loop-textile-waste-recycling-kenya

Yaashikaa, P. R., Kumar, P. S., Nhung, T. C., Hemavathy, R. V., Jawahar, M. J., Neshaanthini, J. P., & Rangasamy, G. (2022). A review on landfill system for municipal solid wastes: Insight into leachate, gas emissions, environmental and economic analysis. *Chemosphere*, *309*, 136627.

6

Transforming Waste into Wealth: Composting as a Climate Solution in Ghana

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Abstract

The waste industry is a major contributor to greenhouse gas emissions, making it a crucial area for climate action. Globally, the waste sector contributes about 3% of the total greenhouse gas emission, emitting gases such as methane and nitrous oxides, which are more potent than carbon dioxide in terms of the greenhouse effect. Ghana is currently at a juncture where sustainable waste management is crucial. The waste sector accounts for about 6.9% of greenhouse gas (GHG) emissions. It is also the leading source of methane pollution, accounting for about 43% of methane emissions in the country. These high methane emissions are primarily due to the high (about 60%) organic content in domestic waste and the poor management of waste in the country. This chapter applies innovative composting approaches (both centralised and decentralised) to address the organic waste problem in Ghana. Centralised composting reduces methane emissions but requires high capital investment and strict waste segregation for efficiency. Decentralised composting is low-cost and community-driven, making it suitable for peri-urban and rural areas, though its success depends on public engagement and policy support. The study also introduces a tumbling bin composting system to enhance decentralised composting efficiency. These findings recommend a hybrid approach: centralised composting in urban areas for large-scale waste processing and decentralised composting in peri-urban and rural areas to encourage community-led waste management. Policy measures such as financial incentives, public education, and agricultural integration are crucial to scaling up composting nationwide.

Keywords: Composting, Waste Management, Decentralised Composting, Centralised Composting, Sustainable Waste Management,

Introduction

The increasing demand for goods and services of a growing world population has made applying sustainability in all aspects of life imperative. For industries and ecosystems to remain sustainable over the long term, goods and services must prioritise efficient use of resources, waste reduction, renewable energy integration, ethical supply chains, circular economy, fair labour, and environmentally friendly technologies. Waste management is particularly crucial as it correlates with increasing demand for goods. However, the rate at which waste is produced in recent years far exceeds the rate at which waste is treated, reused, or recycled. Poorly managed waste creates issues of poor human health, pollution of the natural environment and the destruction of important ecosystems (UNDP, 2023a).

According to the World Bank (2024), the world generated about 2.074 billion tons of solid waste in 2023, averaging 0.29 tons of waste generated per person annually. Considering the current trajectory, it is projected that by 2050, the waste generated by the world will increase by 73%. Ineffective waste management also contributes significantly to greenhouse gas (GHG) emissions, particularly methane—a potent greenhouse gas produced under anaerobic conditions in landfills and open dumpsites. Furthermore, open burning, a prevalent practice in developing countries, also contributes to carbon dioxide emissions. The fight against climate change demands a drastic reduction in GHG emissions in all industries and all sectors of the world to ensure the rise of the average global temperature does not exceed the 1.5℃ limit (IEA, 2024). Carbon dioxide contributes most to the global net anthropogenic emissions and is the gas that has gained the most attention in terms of climate change control (World Bank, 2022).

Globally, the waste sector accounts for about 3.3% of GHG emissions and 20% of methane emissions (GAIA, 2022). Although methane is emitted in smaller quantities than carbon dioxide, it is responsible for about 30% of the global temperature rise due to its 28 times greater warming potential over 100 years (IEA, 2022; Ritchie et al., 2020). This underscores the critical role of effective waste management in reducing methane emissions and combating climate change.

Several strategies for managing waste include landfilling, incineration, recycling, and composting. Composting, in particular, is a biological process where organic waste is decomposed under controlled aerobic conditions by micro-organisms to produce compost, which is a stabilised, nutrient-rich organic product used primarily as fertiliser. Composting reduces the volume of waste, contributes to soil health, supports agricultural productivity, and serves as a long-term carbon sink by storing carbon that would otherwise be released into the atmosphere as carbon dioxide or methane. Additionally, compost improves plant growth, enhancing natural carbon capture processes.

In 2012, Ghana expanded its waste processing and composting efforts by establishing the Accra Composting Plant, the first state-of-the-art waste sorting and composting facility in West Africa. This milestone was followed by the construction of the Kumasi Composting and Recycling Plant, marking another critical step in expanding the country's composting capacity. Although Ghana produces 14,473 tonnes of MSW daily, the combined composting capacity of these plants is 2,600 tonnes per day; thus, the available plants cannot fully meet the waste treatment demand of Ghana (UNDP, 2022). In collaboration with the government of Switzerland, the Integrated Recycling and Compost Plant (IRECOP), a subsidiary of the Jospong Group of Companies, has subsequently constructed six composting facilities (UNDP, 2022). These plants are located in the Bono, Volta, Oti, Western North, Savannah and Ahafo regions of Ghana and collectively process 2600 tonnes of municipal solid waste (MSW) daily (Environmental Protection Agency, 2023). The project is expected to reduce carbon emissions by 1.5 $MtCO_2e$ by 2023 and produce 13,000 tonnes of high-quality organic fertilizer annually (UNDP, 2023b).

Despite these developments, composting remains a significantly underutilised waste management solution in Ghana. Like most developing countries, Ghana's waste stream has a high organic matter content, estimated at 60% (Miezah et al., 2015). However, only about roughly 10% of the country's daily waste is appropriately treated, recycled, or composted (UNDP, 2023a). Thus, a vast majority of organic waste, which could be converted into valuable agricultural compost, ends up in landfills or open dumpsites. The waste sector has, therefore, become Ghana's largest source of methane pollution, accounting for approximately 43% of the country's methane emissions (UNDP, 2023a). Addressing these challenges requires more innovative solutions towards waste management through effective composting. Given the global nature of climate change, Ghana has a shared responsibility to mitigate its emissions by promoting composting as a key climate action strategy.

This chapter seeks to provide innovative composting techniques to support the waste management plan and to critically examine how centralised and decentralised composting methods best fit the Ghanaian context. This chapter is laid out as follows: this introductory section has considered the substandard state of waste management in Ghana, the health and environmental impacts and the limitations of existing composting infrastructure. The second section presents an in-depth literature review, while the third and fourth sections discuss the methodology and results, respectively. Section 5 concludes the chapter and provides policy recommendations.

Literature Review

The State of MSW Management in Ghana

Waste management systems in Ghana have proven inadequate in effectively managing its ever-increasing municipal waste. With an average waste generation rate of 0.47kg/person/day and a population of about 30,792,608, Ghana generates approximately 14,473 tonnes of waste daily (Ghana Statistical Service, 2022). Most of this waste is indiscriminately disposed on land, in gutters or water bodies, or openly burned, with the rest ending up in non-engineered landfills. This poor waste management practice can be attributed to poor planning and implementation, inadequate financing to construct necessary infrastructure and insufficient public education to engender citizen responsibility. These inefficiencies are further exacerbated in cities due to higher waste generation rates, about 0.72 kg/day/person, resulting from high population increase rates and urbanisation (Miezah et al., 2015).

Consequently, the country's improper MSW management systems have consistently resulted in far-reaching environmental impacts, including the release of GHG. The waste sector is responsible for about 6.9% of GHG emissions and is also the leading source of methane pollution, accounting for about 43% of the methane emissions in Ghana (Environmental Protection Agency, 2022). The significant contribution of the waste sector to climate change can be explained by anaerobic organic waste decomposition and open burning. Like many other developing countries, Ghana’s domestic solid waste has a high organic content; hence, with improper waste management systems, the organics turn to decompose anaerobically to release methane, a harmful and toxic gas with 28 times more significant global warming potential than carbon dioxide (IEA, 2022). Again, the open burning of domestic waste releases gases and particles such as carbon dioxide, nitrous oxide, and black carbon, adversely affecting the climate. Other particles and gases released, such as particulate matter, carbon monoxide, furans, and dioxins, also pose severe risks to public health.

Furthermore, the indiscriminate waste disposal into gutters, water bodies and unmanaged or non-engineered landfills consistently contributes to public health risks and environmental degradation. Waste disposal into drains has persistently led to floods, particularly in urban areas, disease outbreaks and health hazards. The waste management issues of Ghana have also impacted the aesthetics of many urban areas, potentially impacting tourism and other economic activities. These impacts underscore the need to establish and implement a more sustainable waste management approach in the country.

Institutional and Legal Framework

The laws and policies governing Ghana's waste sector cut across several ministries and governance bodies. One of Ghana's main institutions responsible for waste management is the Environmental Protection Agency (EPA). Additionally, domestic waste management powers are exercised through the Waste Management Department (WMD) and Environmental Health and Sanitation Unit at the Metropolitan, Municipal and District Agencies (MMDAs). Other institutional stakeholders in waste management include the Ministry of Environment, Science and Technology, the Ministry of Local Government and Rural Development and the Ministry of Health. The primary laws governing the waste sectors are the EPA Act 2025 (Act 1124) and the Environmental Assessment Regulation L.I. 1652. Table 1 below summarises the institutional and legal frameworks for domestic solid waste management and relevant policies in Ghana.

Table 1:Summary of the Waste Management Institutional and Legal Framework of Ghana

Institution	**Function**
Ministry of Environment, Science, and Technology (MEST)	Responsible for policy formulation, implementation, and oversight of science and technology.
Ministry of Local Government and Rural Development (MLGRD) and Sanitation	Oversees efforts of Metropolitan, Municipal and District Assemblies (MMDAs). It is also responsible for policy formulation, implementation, and oversight of sanitation.
Ministry of Health	Collaborates with sanitation agencies to address health risks associated with poor waste management.
Environmental Protection Agency (EPA)	Regulates and enforces environmental laws in Ghana, including those on waste management.
Metropolitan, Municipal and District Assemblies (MMDAs)	Responsible for waste collection, transportation, and disposal within their jurisdictions.
Legal Framework	
Law	**Objective**
Local Government Act (1994), Act 462	Provides legal framework for local government responsibilities in waste management
Environmental Protection Agency (EPA) Act 1124	Establishes the EPA
Policies and Guidelines	
Policy/Guidelines	**Objective**
Environmental Sanitation Policy (ESP) of 1999 (revised 2009)	Guides environmental sanitation and waste management practices
Ghana Landfill Guidelines	Provides guidelines for managing and upgrading landfills to improve waste disposal practices
Manual for Preparation of District Waste Management Plans	Provides MMDAs guidance in developing waste management plans
Guidelines for Management of Healthcare and Veterinary Waste	Provides guidance on managing medical waste
National Solid Waste Management Strategy	Sets Ghana on a path towards progressive, high-quality, cost-effective, and sustainable waste management services.
National Plastic Management Policy (2019)	Aims to establish an extended producer responsibility scheme for plastic products

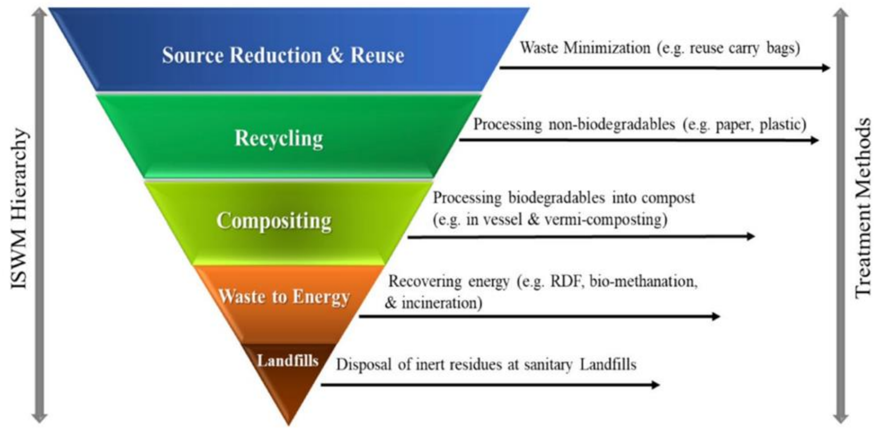
Despite these laws, policies and agencies, difficulties persist in managing waste systems in Ghana. These challenges can mainly be attributed to inadequate financial resources, weak technical and operational capacities at the local level, and inadequate public education and awareness. Limited financial resources have significantly hindered the provision of the necessary infrastructure to facilitate the implementation of a robust waste management system in Ghana. While Ghana's waste management system is jointly financed by the private sector and the government, competing development priorities often divert funds from critical waste management operations (Owusu-Sekyere et al., 2015).

Further, the weak technical and operational expertise, particularly at the MMDA levels, limits the implementation of proposed strategies. Most local government authorities focus on rudimentary waste collection and disposal at non-engineered landfills with limited efforts towards product recovery and recycling (Ministry of Sanitation and Water Resources, 2020). While collection and disposal are essential in the waste management ecosystem, they only represent two stages of an integrated waste management approach. Thus, focus should be shifted towards an integrated Waste Management approach to fully tackle Ghana's waste challenges.

Integrated Solid Waste Management

Integrated Solid Waste Management (ISWM) is a comprehensive and strategic approach to sustainable solid waste management, emphasising environmental impact minimisation and resource recovery maximisation. It covers all the steps of the waste lifecycle, including its generation at the source, separation, transportation, sorting, treatment, recovery, and disposal, dealing with the waste to maximise resource use efficiency (Xiong et al., 2015). The hierarchy of solid waste management is at the centre of the ISWM system. This framework details the principles of prioritisation in waste management to ensure waste minimisation, resource conservation and environmental protection (Iyer, 2017).

Figure 1: Integrated Solid Waste Management (ISWM) Hierarchy



Source: Mushtaq & Ahsan, 2020

As shown in Figure 1 above, the hierarchy prioritises waste reduction and reuse to avoid excessive waste generation. Adopting this approach promotes waste prevention and minimisation while reducing resource extraction. Waste management methods include recycling and composting, transforming waste into valuable products or new raw materials. In recycling, waste categories such as plastic, paper and metals are transformed into valuable raw materials, whereas in composting, organic portions of waste are transformed into nutrient-rich soil enhancers.

When waste cannot be reused or recycled, energy recovery provides an alternative by converting waste into electricity or heat through incineration with energy capture, anaerobic digestion, and biogas production. The final disposal of the waste is still landfill, but if a proper ISWM system is implemented, the fraction of waste that goes to landfill is minimal, as it is just the waste that cannot be reused or treated (Awino et al., 2024).

While waste reduction and reuse should form the baseline of Ghana's efforts towards waste management and, in effect, climate mitigation from the waste sector, the scope of this chapter focuses on composting as a key pillar in Ghana's waste management sector. Given the high organic waste content in the country's municipal solid waste, composting presents a sustainable solution to divert biodegradable waste from landfills while enhancing soil fertility and mitigating climate change. Furthermore, the country's large agricultural industry can reap enormous benefits from converting organic waste into nutrient-rich soil enhancers.

Composting

Composting is the biological decomposition of biodegradable materials under controlled conditions by bacteria and fungi under aerobic conditions. While composting can also occur under anaerobic conditions (i.e., in the absence of oxygen), this process produces methane, a potent GHG, resulting in low-quality compost (Amuah et al., 2022). Compost application enhances soil fertility and serves as a long-term sink, i.e., reducing greenhouse gas emissions by storing carbon that would otherwise be released as carbon dioxide or methane. Additionally, compost supports plant growth, contributing to the natural cycle of carbon capture and environmental sustainability. Its adaptability allows for implementation at both centralised and decentralised levels, making it suitable for varying community sizes and infrastructure capabilities (Bruni, 2020).

Centralised Composting

In the centralised approach, large-scale facilities are established to process organic waste collected from diverse sources, including households, markets, and institutions in a large district, municipality or region. There are four widely used technologies or methods for large-scale composting. Most of these technologies are scalable and can be used even for small-scale composting. These technologies include:

1. **Windrow composting** is a popular technique for creating long, narrow rows of organic matter. It regularly uses equipment such as loaders and turners to aerate the pile (De Wilde & Mortier, 2014). This method is suitable for a wide range of materials and feedstocks (US EPA, 2015).
2. **Static Pile with Active Aeration** is a method that involves using blower systems to circulate air through a pile of organic matter. This method allows large quantities of organic matter to be composted quickly since the pile conditions are controlled.
3. **In-vessel composting,** also called bioreactors, is suitable even for centralised composting when available space is limited (Abdallah et al., 2022). Materials are fed into a container, such as a silo, trench lined with

concrete, drum, or other enclosed machinery and are mechanically rotated or combined with bulking agents like wood chips in the vessel to ensure aeration (US EPA, 2015)

4. **Mechanical biological treatment (MBT)** combines biological processes like composting with mechanical waste sorting and mixed solid waste treatment plants. While the biological stage stabilizes the organic fraction and produces compost, the mechanical component separates recyclable materials (Cook et al., 2015).

Decentralised Composting Approach

In the decentralised approach, composting occurs at the locations where waste is generated, such as individual homes or institutions. Decentralised composting technologies, also called community composting technologies, are used mainly on a smaller scale. Among these technologies, centralised composting techniques like windrow, in-vessel and active aeration static pile can be easily scaled down for community composting. The following are other composting technologies that are solely applied to decentralised composting:

1. **Vermicomposting** involves using earthworms and micro-organisms to break down organic matter and produce a high-quality soil amendment. These systems are usually done on a smaller scale, and when maintained well, they do not smell or draw pests (US EPA, 2015).
2. **Plastic Bin Reactors** can be operated in batch, continuous or semi-continuous modes with sizes ranging from 100-1000 L plastic bins and are widely used for simplicity and low cost (Bruni et al., 2020).
3. **Rotating drums or inclined composters** are cylindrical containers that employ manual or mechanical rotation to mix and aerate the compost. Internal vanes are incorporated into some drum designs, and when paired with the drum's rotating action, they help reduce feedstock size and mix it (Bruni et al., 2020).

Key Composting Process Control Factors

Critical parameters such as temperature, pH, moisture, aeration and the Carbon-Nitrogen ratio (C/N ratio) are central to every composting approach and technology. These factors determine the quality of the fertiliser produced and the effectiveness of composting as a climate mitigation approach. Composting occurs in four main stages: mesophilic, thermophilic, cooling, and maturation.

Within each stage, micro-organisms decompose substrates into other materials, which serve as substrates for the organisms in the subsequent stages. Considering the complex biological nature of composting, maintaining suitable conditions for microbial activity is crucial (Meena et al., 2021). For instance, aeration ensures the supply of oxygen to micro-organisms during aerobic composting; without regular turning, the organic matter will decompose anaerobically, which may lead to methane emissions, thus defeating the climate mitigation goals associated with the adoption of composting. Table 2 below details the recommended conditions for each critical composting parameter.

Table 2: Key Composting Process Factors

Parameter	**Optimal Range**	**Importance**
Temperature	40–65 °C; ≥55 °C during thermophilic phase	Ensures pathogen destruction and optimal microbial activity
Moisture	45–60%	Promotes microbial activity without waterlogging; >65% may inhibit oxygen flow
C/N ratio	25–30:1	Balances carbon for energy and nitrogen for microbial protein synthesis
pH	6.7–9.0	Affects microbial survival and activity; acidic pH in early stages may cause odour
Aeration	10-15%	Maintains aerobic conditions, prevents anaerobic odours and methane formation
Retention Time	≥3 months (electromechanical); ≥6 months (static piles)	Ensures full microbial decomposition and compost stabilisation
Particle Size	5 – 30 cm	Influences porosity and decomposition rate

Sources: Bruni et al., 2020 and Meena et al., 2021

Composting As a Climate Solution in Ghana

Considering the highly organic nature of waste generated in Ghana, composting presents a practical and scalable solution for treating organic waste while providing valuable fertiliser products. Employing composting is a viable approach to diverting waste from non-engineered landfills and effectively preventing methane emissions from decomposing organic waste. Furthermore, composting will reduce the country's dependence on synthetic fertilisers, which may pose environmental concerns and are often costly.

According to Ghana's Updated Nationally Determined Contributions (NDCs) under the Paris Agreement, the country seeks to adopt an alternative urban solid waste management to reduce its emissions by 21.3 MtCO2 by 2030 (Ministry of Environment, Science, Technology and Innovation [MESTI], 2021). Recognising the significant environmental and economic advantages of turning organic waste into compost, Ghana has mainstreamed composting in achieving the goal of developing 16 integrated recycling and composting facilities across the country's 16 regions (Environmental Protection Agency Ghana, 2023). While these efforts mark significant progress, challenges remain, including limited public awareness and participation in composting programs.

Additionally, the restricted capacity of existing composting plants, such as the Accra Composting and Recycling Plant and the Kumasi Composting and Recycling Plant, along with the ongoing developments, can collectively process only 35% of the waste generated in Ghana. This leaves approximately 65% of waste disposed of in non-engineered landfills, exacerbating environmental and climate-related challenges. Therefore, this chapter explores pathways for implementing centralised and decentralised composting models while proposing policy recommendations to enhance waste diversion efforts, improve composting infrastructure, and significantly reduce waste-related emissions.

Methodology

This study adopted two key tools. The first is *a* preliminary engineering design of a selected composting technology under each approach to assess the technical feasibility*. Secondly, a* case study *was conducted* to identify insights and assess the practical performance of such applications in other jurisdictions. These tools provide a comprehensive evaluation, enabling informed decision-making regarding the most effective and sustainable composting solutions. The respective assumptions taken during the *p*re-engineering design are outlined below:

Pre-engineering Design for the Centralised Approach

Windrow composting was selected based on an assessment of the different composting technologies available because it best suits the Ghanaian context. Windrow composting is the most used composting technology as it is a simple method requiring low investment costs and a low process control requirement (De Wilde & Mortier, 2014). Standard input parameters were considered for the windrow composting design in Table 3 below. With the information required, the optimised composting area and the total daily produced compost were calculated.

Table 3:Input Parameters for the Centralised Composting System

Parameters	Values	References
Organic Waste	1000 tons/day	Estimate
Windrow width	3.0 m	FAO, n.d.
Windrow height	1.65 m	FAO, n.d.
Windrow intra-space	2.5 m	FAO, n.d.
Composting cycle days	60 days	BioCycle, 2022
Manoeuvring area length	5 m	Vermont DEC, n.d.
Initial waste density	0.65 ton/m (linear meter)	Tchobanoglous et al., 1993
Waste C: N ratio	20	Compost Magazine, n.d.
Final compost C: N ratio	30	Compost Magazine, n.d.
Brown materials C: N ratio	100	Compost Magazine, n.d.
Sieving losses	1%	Estimate
Compost volume reduction	50%	Vermont DEC, n.d.
Storing facilities	10% of area	Estimate

Preliminary Design of the Decentralised Composting Technology

The design aims to be simple, cost-effective, and easy to manage while ensuring efficient composting of organic waste at the point of generation. Merging the plastic bin and rotating drum composting technology is considered for the decentralised composting technique. This merge combines the simplicity and easy accessibility of plastic bins with mechanical rotation to produce a technology that is cost-effective and efficient at composting. The following design parameters have been calculated based on typical waste generation and decomposition rates. The technology can be easily scaled to meet the needs of the user. The design of the decentralised composting system takes decomposition dynamics and organic waste generation rates into account. The suggested bin allows for effective waste breakdown and is designed for households producing 1 kg of organic waste daily. Its dimensions are ideal for controlling moisture and aeration, guaranteeing the production of high-quality compost. Different waste capacities can be accommodated by simply scaling the design.

Table 4: Input Parameters and Design Assumptions, Decentralised Composing System

Vessel Calculation Inputs	Quantity	Unit	Additional Information
Amount of waste	1	kg/day	Assumed daily volume of household waste to be composted. This figure determines the scale of the composting system.
Composting Duration	40	day	The assumed period over which composting will occur **(Source: Natural Resources Defense Council, n.d.**)
Density of organic waste	200	kg/m³	Mass per unit volume of organic material **(Source: Liu et al., 2023**)
Compost mass reduction	50	%	Estimated percentage of mass loss during composting. This could be due to decomposition or moisture loss
L/D ratio	2		The ratio of the vessel's length to its diameter ratio. This is important for determining its shape and dimensions
Headspace	50	%	Additional reserved space above the waste level to facilitate aeration and mixing

Results and Discussions

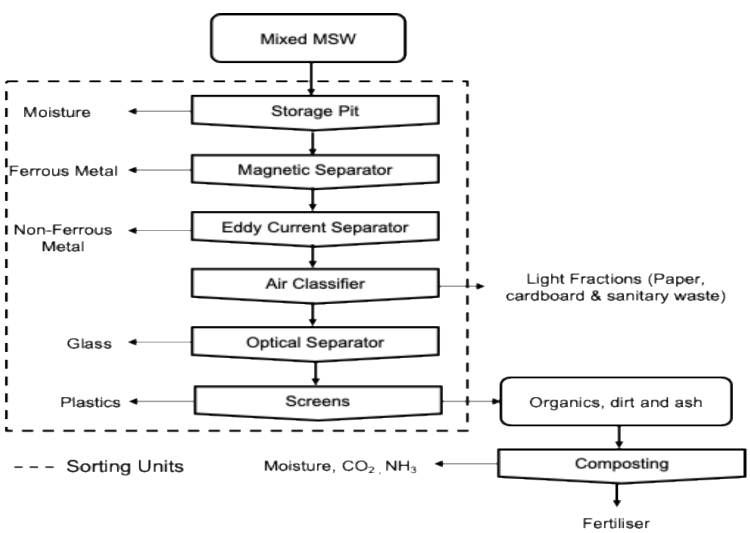
Pre-engineering Design for Centralised Composting

The preliminary design of the centralised composting system includes a flow chart for centralised composting. Figure 2 illustrates Ghana's current state of centralised composting, i.e., without adequate source segregation. Under this approach, mixed waste is first collected and stored before sorting. Waste is manually or mechanically separated during sorting into organic matter and non-biodegradable materials. The organic matter is processed to produce organic fertiliser, while non-biodegradable materials are either sent for recycling or disposed of in landfills.

On the other hand, Figure 3 illustrates the source segregation process in centralised composting, where MSW is divided at the point of generation into non-biodegradable and organic matter categories. Non-biodegradable waste is further classified into recycled materials, which are processed for reuse, and other materials, which are disposed of in landfills. The organic matter is directed towards composting producing fertilizer for agricultural use. This clear separation streamlines waste processing and ensures each type follows an appropriate and sustainable treatment pathway.

Comparatively, the approach in Figure 2 is less efficient. First, this process is more resource-intensive due to the additional step of sorting organics from non-biodegradables. This separation is challenging as organic waste often lacks distinct physical properties that make it easy to isolate. For instance, physical properties such as magnetism and conductivity may be used to separate metals. However, organic waste lacks such easily identifiable characteristics, making it harder to isolate.

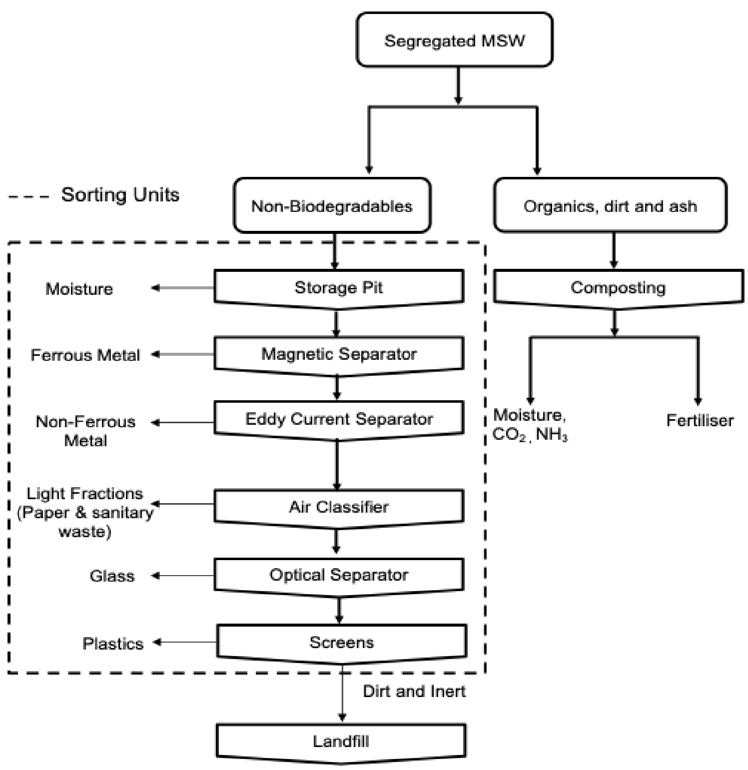
Figure 2: Centralised Composting Flow Chart, No Source Segregation



As a result, it is often collected as residual waste after other materials have been removed. Consequently, the risk of contamination is increased, reducing compost quality and increasing the complexity of waste processing. Moreover, sorting mixed waste also requires more time, labour, and financial resources, leading to higher operational costs. Improperly sorted waste can also result in more materials being landfilled, increasing environmental impacts such as methane emissions.

Therefore, source segregation is essential to ensure the production of cleaner, more nutrient-rich compost and to reduce the need for labour-intensive sorting. Source segregation would enhance the efficiency of composting operations and reduce methane emissions from landfills. To achieve this, Ghana requires policies that engender public education on waste separation and provide colour-coded bins for households, markets, and businesses. Clear regulations mandating organic waste separation and incentives such as reduced waste collection fees can drive compliance.

Figure 3: Centralised Composting Flow Chart with Source Segregation



Pre-Engineering Design for Windrow Composting

The windrow design is provided in Figure 4, and the input parameters are summarised in Table 5, illustrating the facility layout, which is designed to handle large-scale organic waste processing through open-air windrows. The facility is equipped to process 500 tons per day (TPD) of source-separated organic waste, which is arranged into 32 parallel windrows with a 3-meter spacing for proper aeration and equipment access. A 5-meter-wide manoeuvring area ensures the effective turning and management of the windrows using mechanical equipment.

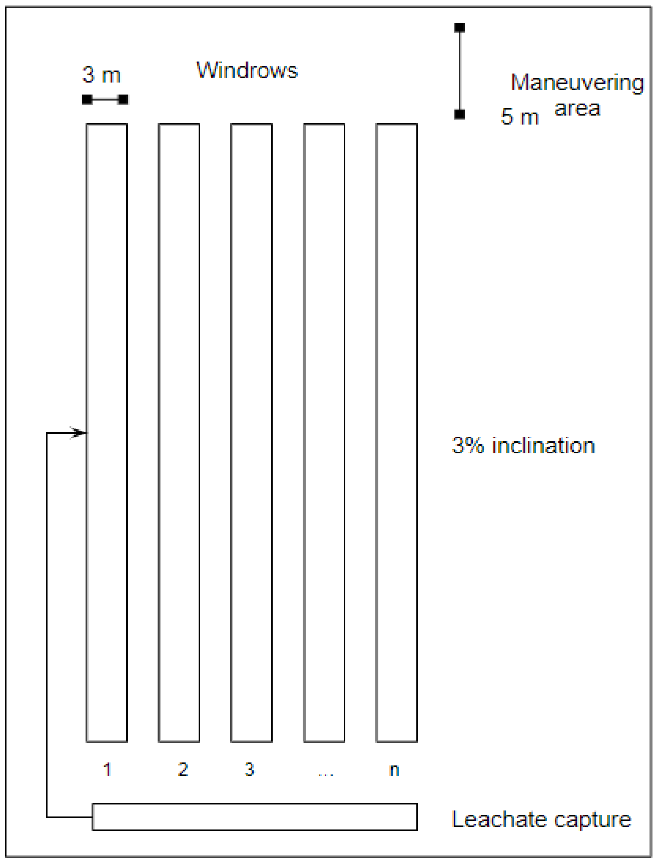
The composting platform features a 3% slope to facilitate the natural flow of leachate (liquid produced during decomposition) towards a leachate capture system at the lower end. This system helps prevent contamination while maintaining moisture control. Since the composting cycle lasts about 60 days, the facility manages about 30,000 tons of organic material in various stages of decomposition at any given time, referred to as composting cycle waste. This volume represents the total amount of waste under active processing.

To optimise composting conditions, 4,285 tons of brown (carbon-rich) materials, such as sawdust or dry leaves, are added to balance the nitrogen-rich food waste. The system generates about 283 TPD of finished compost (56.6% composting efficiency), with the entire operation spanning 31 acres.

Table 5: Windrow Design Parameters

Parameters	Source separation	Comments
Incoming organic waste	500 TPD	This is the total quantity of organic waste received per day.
Composting cycle waste	30,000 tons	The total quantity of organic waste undergoing composting at any given time.
Brown complement	4285 tons	Carbon-rich materials (e.g., dry leaves, sawdust, straw, or wood chips) are required to balance the compost mix.
Daily Compost output	283 TPD	The final compost yield.
Area required	31 acres	The total land area needed for the composting site.
Number of burrows	32	The total number of windrows.

Figure 4: Schematic Design of Windrows Designed



Pre-engineering Design of the Decentralised Composting unit

A preliminary engineering design was carried out to estimate the dimensions of a decentralised bin-type composting unit. Depending on space availability and daily organic waste production, this design can be easily scaled up or down. The design reduces the effort required to aerate the compost pile and makes producing high-quality compost easier. Per this design, organic matter is estimated to fully decompose after 40 days with about a 50% reduction in the mass of the feed. Table 6 details the design dimensions.

Table 6: Bin Dimensions Parameters

Parameter	Value	Unit	Additional Information
Volume of waste	0.2	m^3	Calculated from density and mass
Length of Vessel	1	m	Estimated from L/D ratio and volume
Diameter of vessel	0.5	m	Estimated from L/D ratio and volume
Volume of vessel	0.2	m^3	Calculated
Compost Produced	0.5	kg/d	First compost produced after 40 days

A scalable, user-friendly composting bin designed for decentralised waste management is featured in the preliminary design. The design, which is shown below, minimises odours and methane emissions while ensuring adequate aeration and moisture control, accelerating decomposition. Figure 5 shows a 3D drawing of the proposed technology. The drawing shows a tumbling bin composting technology that operates under the normally open state. The bin is designed to be revolved every two to three days to ensure proper aeration and mixing. Figure 6 shows a first-angle projection of the 3D object along with the dimensions. The drawings have a scale of 1:2 (centimetres), implying the dimensions need to be doubled.

Figure 5: Innovative Tumbling Bin Composting Technology

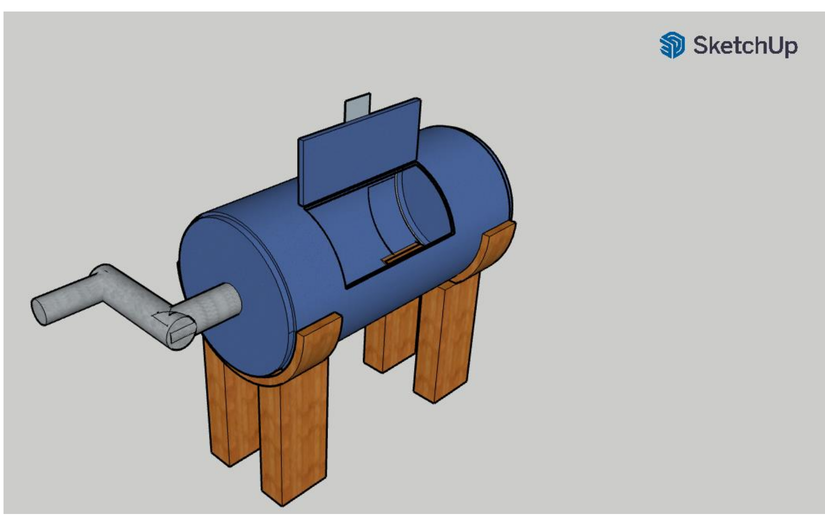
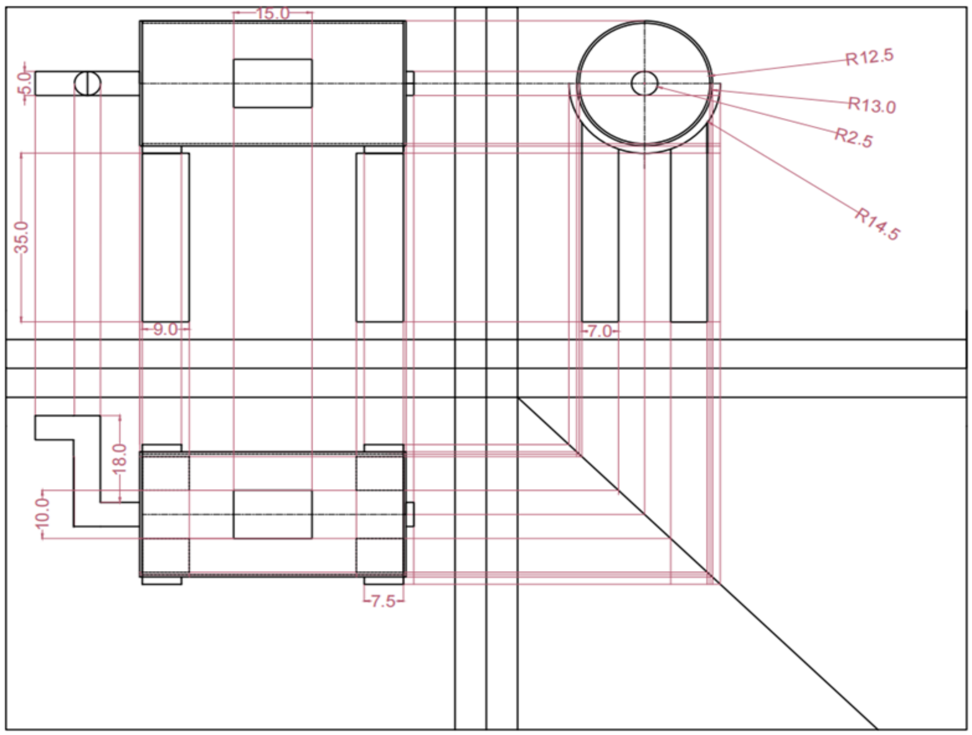


Figure 6: First-Angle Projection (Scale is 1:2)



Case Study Analysis

This session presents four case studies, two on each composting approach, to further illustrate the real-world applications of both composting regimes. These assessments focus on operational strategies, challenges, benefits, and key insights from implementing these composting approaches in other jurisdictions. The case studies demonstrate the potential benefits of composting as a strategy for protecting public health and mitigating climate change cost-effectively. They highlight that the centralised and decentralised approaches to composting offer unique opportunities for effective waste management. While both approaches present significant benefits, the case studies also establish that the success of any strategy is dependent on key factors such as community engagement, policy alignment and financial support.

The centralised composting facilities in Sri Lanka demonstrate the efficiency of large-scale composting in waste reduction, with an 85% reduction in landfill waste at the Environmental Preservation Centre in Kuliyapitiya. Notwithstanding the significant challenges, such as capital and operational costs, difficulties in implementing segregation programs, and revenue generation challenges, these centralised facilities have proven effective through strategic policies. For instance, introducing the waste segregation policy at Sri Lanka's Kuliyapitiya composting plant resulted in a 50% reduction in labour requirements, thereby reducing operating costs. Furthermore, Sri Lanka's Mihisaru Compost Facility benefited from strict waste segregation laws and tipping fees, which ensured financial sustainability and reduced waste contamination.

In the case of the decentralised approach, the models in Pontevedra, Spain, and Surabaya, Indonesia, highlight citizen and community-led solutions to waste reduction and environmental protection. While the decentralised approach leverages community-led action to implement cost-effective, resource recovery-centred and environmentally beneficial waste management solutions, its success hinges on continuous and well-targeted public engagement, which can be challenging to maintain.

Nonetheless, the two case studies demonstrate the success of the decentralised approach through effective policy implementation, consistent community engagement and strategic collaborations. The Revitaliza Program in Spain successfully implemented decentralised composting across multiple municipalities by integrating composting into households and public spaces, significantly reducing reliance on landfilling and incineration. Similarly, Surabaya's initiative focused on household and local composting centres, cutting waste generation by over 20% while keeping operational costs low.

These examples provide valuable lessons for Ghana, considering the challenges associated with waste collection and management in peri-urban and rural areas. In most areas, inhabitants resort to non-engineering landfilling or open burning due to the unavailability of proper waste management collection and treatment infrastructure. District Assemblies and local governments could replicate the models from Indonesia and Spain by promoting household composting, community composting hubs, and partnerships with NGOs to enhance public participation. While behavioural change may initially be challenging, as was observed in the Revitaliza program, sustained public awareness and training can ensure long-term success.

Centralised Approach

Table 7: Case Studies under the Centralised Approach

Facility & Location	Implementation	Challenges	Advantages	Key Insights
Environmental Preservation Centre, Kuliyapitiya (Single Municipal Operation)[1]	1. An integrated composting, recycling and landfilling facility was established in 2009. 2. Windrow composting for 10 MTPD. 3. Waste segregation was implemented in 2016. 4. Mainly recruited locals and community members.	1. High labour costs due to manual sorting. 2. Initial difficulty in enforcing source segregation. 3. Maintenance costs for machinery.	1. Effective source segregation reduced sorting effort. 2. Reduced landfill waste by 85%. 3. Compost meets national quality standards.	1. Early investment in awareness campaigns is key for source segregation. 2. Diversifying revenue (e.g., tipping fees, compost sales) can improve financial sustainability. 3. Recruitment of locals and community members gave a sense of public ownership. 4. Waste segregation reduced manual labour requirements by almost 50%.
Mihisaru Compost Facility, Kalutara (Provincial Government Operation)[2]	1. Large-scale facility (22-38 MTPD) built in 2011. 2. Managed by the Waste Management Authority-Western Province. 3. Source segregation is enforced by law with tipping fees.	1. Initial public protests due to facility location. 2. High soil & plastic contamination from market waste. 3. Challenges in selling compost due to seasonal demand.	1. High-quality compost achieved through strict sorting and source segregation policies. 2. Effective revenue model via tipping fees and exports.	1. Provincial oversight helps ensure sustained funding and enforcement. 2. Legal mandates on waste segregation can significantly improve compost quality.

[1] (IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) & University of Peradeniya, 2020)
[2] (IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) & University of Peradeniya, 2020)

Decentralised Approach

Table 8: Case Studies under the Decentralised Approach

Facility & Location	Implementation	Challenges	Advantages	Key Insights
"Revitaliza"Program, Pontevedra, Spain (Condamine, 2019)	1. Transition from centralised incineration/landfilling to local composting. 2. Over 44 out of 60 municipalities adopted decentralised composting. 3. Composting units installed in households, communities, and public spaces. 4. Managed by local municipalities with public participation	1. Initial resistance to behavioural change. 2. Need for continuous public education on waste separation. 3. Infrastructure development required at the community level.	1. 2,000+ tonnes of biowaste composted locally. 2. Reduced waste transportation and reliance on incineration/landfilling. 3. Strong community engagement leading to social and environmental benefits.	1. Decentralised composting can be scaled up successfully with municipal leadership. 2. Community involvement is crucial for sustainability. 3. Reduces costs and emissions associated with centralised waste processing.
Surabaya City Composting Initiative, Indonesia (Maeda, 2009)	1. Established over a dozen composting centres across the city. 2. Distributed thousands of compost baskets to residents for at-home composting. 3. Collaborated with NGOs, private companies, and media to organise city-wide cleanup campaigns.	1. Community involvement requires significant effort. 2. Ensuring adequate resources and training for effective composting practices.	1. A reduction of over 20% in waste generation within a few years. 2. Expenses accounted for only 1-2% of the total solid waste management budget. 3. Awarded the Adipura (Clean City) Award for three consecutive years since 2006.	1. Active involvement of residents, community groups, NGOs, and private companies is crucial for success. 2. The model's success in a large city like Surabaya indicates its potential applicability to other urban areas.

Ultimately, the case studies under both approaches affirm the need for a hybrid model that accounts for the peculiarities and varying conditions of urban, peri-urban and rural areas. High-density urban areas can leverage centralised composting while rural and peri-urban areas can adopt the decentralised approach; however, the final decision should be made by the MMDAs as the law assigns them the responsibility of waste management. This can only be achieved with strategic policy planning and implementation that aligns with the integrated solid waste management hierarchy. Recognising the limited focus of most MMDAs on rudimentary collection and disposal with minimal emphasis on material recovery (Ministry of Sanitation and Water Resources, 2020), mainstreaming ISWM at the local government levels is essential to implementing any composting strategies.

The Ministry of Sanitation and Water Resources (2020) developed the National Solid Waste Management Strategy to address Ghana's growing waste management challenges by emphasising the ISWM. The strategy promotes a comprehensive approach that includes waste minimisation, recycling, composting, and energy recovery while also strengthening institutional capacities through the training of Metropolitan, Municipal, and District Assemblies (MMDAs). Furthermore, the policy promotes public-private partnerships (PPPs) to enhance waste collection efficiency and incentivise investment in waste treatment infrastructure. Despite these well-structured initiatives, the implementation of the strategy has been limited mainly due to weak enforcement mechanisms and poor stakeholder coordination; hence, improper waste disposal, low recycling rates, and environmental pollution persist. Therefore, addressing these challenges will require a renewed political will to implement existing and newly passed policies.

Conclusions and policy recommendations

The study introduces composting as a viable strategy to reduce methane emissions and treat waste while producing nutrient-rich compost for agricultural use. This paper examines two composting strategies—centralised and decentralised—for waste management in Ghana. The results show that centralised composting reduces landfill waste and methane emissions. Even though source segregation can significantly reduce composting costs, centralised facilities can be costly for local governments. Decentralised composting is a cost-effective way for communities to manage waste sustainably. However, the success of this strategy depends on community involvement and supportive policies.

Based on these findings, the study recommends a hybrid approach, advocating for centralised composting in urban areas where large-scale waste processing is feasible and decentralised composting in peri-urban and rural areas to promote community-led waste management and resource recovery. However, MMDAs should decide on the most suitable approach, considering local conditions, available resources, and community needs. To strengthen the implementation of both methods, specific recommendations are outlined to ensure their effective implementation upon deployment.

Recommendation for Centralised Composting Approach

1. **Leverage public-private partnerships:** To attract investment in centralized composting, the Government of Ghana, through the Ministry of Finance, Ministry of Local Government and the Environmental Protection Agency should focus on creating a strong enabling environment. This includes establishing clear regulations on organic waste management and compost quality standards, introducing fiscal incentives, and offering risk-sharing mechanisms like guarantees or blended finance. Promoting compost use through public procurement and integrating it into national fertilizer subsidy programs can help develop reliable markets. These measures will improve project bankability, reduce investor risk, and encourage sustainable private sector participation in composting infrastructure.
2. **Establish an organic waste segregation program:** The efficiency and cost effectiveness of composting facilities depend on a reliable supply of clean organic waste. To achieve this, the Ministry of Local Government and its MMDAs should launch and implement pilot organic waste segregation programs across high waste-generation zones such as markets, schools and other public institutions. This initiative can be supported by providing source segregation equipment (e.g. bins, signages etc.) along with public education campaigns.
3. **Strengthen waste transport systems:** A key barrier to effective composting in Ghana is the breakdown of waste segregation during transport. The Environmental Protection Agency, working with MMDAs and private waste contractors, should enforce waste-type-specific collection by requiring separate trucks or compartments for organic waste. Waste haulage

contracts should include clear clauses on maintaining segregation, with penalties for non-compliance and incentives for adherence. Investing in simple upgrades, such as modifying trucks with dividers, and partnering with logistics providers that offer tracking systems can further support compliance.

4. **Engage their constituents in waste management activities:** To enhance public involvement and cooperation, MMDAs should include citizens in waste management-related decision-making processes. For instance, before any waste segregation policies are enacted, local and national authorities should engage in widespread and effective public engagement. Furthermore, continuous advocacies will be required to sustain a segregation initiative.
5. **Promote compost as a social enhancer:** To make composting commercially viable, demand for compost must be expanded beyond current levels. The Ministry of Food and Agriculture (MOFA), in collaboration with compost producers and distributors should integrate compost into the national fertilizer subsidy and distribution programs. MOFA should also sstablish demonstration farms to showcase compost's effectiveness in improving soil health and yield, and promote compost as part of climate-smart agriculture and regenerative farming initiatives. These initiatives can unlock access to green finance and rural development funds.

Recommendation for Decentralised Composting Approach

1. **Strengthen Community Education and Awareness Campaigns**: The Ministry of Environment, Science and Technology and the EPA must launch nationwide educational campaigns across media platforms and in schools. These campaigns should focus on the impacts of climate change in Ghana and the role of composting in mitigation. Additionally, The Ministry of Local Government should collaborate with Metropolitan, Municipal, and District Assemblies (MMDAs) to organise community workshops and meetings, highlighting the environmental, economic, and agricultural benefits of composting.
2. **Integrate Composting into Agricultural Practices**: Through its agricultural extension services, the Ministry of Food and Agriculture (MoFA) should promote composting as an alternate source of fertiliser application. They must train farmers on composting techniques and connect urban compost producers with rural farming communities to ensure steady supply and

demand. MoFA should also facilitate the development of localised compost markets and provide technical support to farmers transitioning to compost use, ensuring composting becomes an integral part of sustainable agricultural practices.

3. **Empower Youth and Women in Composting Initiatives**: The Ministry of Gender, Children and Social Protection (MoGCSP), in partnership with MMDAs and local NGOs, should design programs to educate and empower women and youth as champions of decentralised composting. These programs should provide access to resources, micro-grants, and training to encourage women and youth-led composting initiatives.
4. **Establish Monitoring and Feedback Mechanisms:** The EPA, in collaboration with MMDAs and community-based organisations, should develop monitoring systems to track participation rates, compost production levels, and environmental outcomes. Community media platforms should be used to share success stories and encourage further adoption. Feedback channels, such as community forums and digital platforms, should be established to allow participants to voice concerns, suggest improvements, and report challenges. The EPA should conduct periodic reviews of composting initiatives to refine approaches, sustain participation, and promote best practices.

References

Accra Compost and Recycling Plant. (2024). Products Destruction – Accra Compost and Recycling Plant (acarpghana.com), Accessed: 3rd September 2024.

Amuah, E.E.Y., Fei-Baffoe, B., Sackey, L.N.A. *et al.* (2022). A Review of the Principles of Composting: Understanding the Processes, Methods, Merits, And Demerits. *Org. Agr.* **12**, 547–562. https://doi.org/10.1007/s13165-022-00408-z

Awino, F. B., & Apitz, S. E. (2024). Solid waste management in the context of the waste hierarchy and circular economy frameworks: An international critical review. *Integrated Environmental Assessment and Management*, *20*(1), 9-35.

BioCycle. (2022). *Calculating a composting facility footprint*. Retrieved from https://www.biocycle.net/calculating-a-composting-facility-footprint/

Bruni, C., Akyol, Ç., Cipolletta, G., Eusebi, A. L., Caniani, D., Masi, S., ... & Fatone, F. (2020). Decentralized community composting: past, present and future aspects of Italy. *Sustainability*, *12*(8), 3319

Compost Magazine. (n.d.). *Carbon-Nitrogen Ratio List & Calculator*. Retrieved March 23, 2025, from https://www.compostmagazine.com/carbon-nitrogen-ratio-tables/

Condamine P (2019) The Story of Pontevedra–Case Study #13. Zero Waste Europe. https://zerowasteeurope.eu/downloads/the-story- of-pontevedra/

Cook, E., Wagland, S., & Coulon, F. (2015). Investigation into the non-biological outputs of mechanical-biological treatment facilities. *Waste Management*, *46*, 212–226. https://doi.org/10.1016/j.wasman.2015.09.014

Dandeniya, W. S., & Caucci, S. (2020). Composting in Sri Lanka: Policies, practices, challenges, and emerging concerns. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 61-90). Springer.

De Wilde, B., & Mortier, N. (2014). Review on centralized composting Public. *Open-BIO*. www.ows.be

Environmental Protection Agency. (2022). *Ghana's Fifth National Greenhouse Gas Inventory.*

Environmental Protection Agency Ghana. (2023). *Article 6 annual progress report, 2023*. https://cmo.epa.gov.gh/wp-content/uploads/2024/02/Article-6-Annual-Progress-Report-2023_final.pdf

FAO (Food and Agriculture Organization of the United Nations). (n.d.). *Large-scale composting*. Retrieved from https://www.fao.org/4/y5104e/y5104e07.htm

GAIA. (2022). Zero-waste-to-zero-emissions, full-report, 51 pp. Zero Waste to Zero Emissions - GAIA (no-burn.org). Accessed: 23rd August 2024.

Ghana Statistical Service. (2022). *Population of Regions and Districts Report.* Ghana Statistical Service.

Hannah Ritchie, Pablo Rosado and Max Roser. (2020). "Greenhouse gas emissions" Published online at OurWorldInData.org. https://ourworldindata.org/greenhouse-gas-emissions. Accessed: 23rd August 2024.

IEA (2022). Sources of methane emissions, 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/sources-of-methane-emissions-2021, Licence: CC BY 4.0

IEA (2024), Renewables 2023, IEA, Paris https://www.iea.org/reports/renewables-2023, Licence: CC BY 4.0

IGES Centre Collaborating with UNEP on Environmental Technologies (CCET) & University of Peradeniya. (2020). Towards sustainable operation and management of centralised composting in Sri Lanka.

Iyer, V. G. (2017, February). Solid waste minimization hierarchy of waste management for sustainable development. In *Twelfth Biennial Conference on Entrepreneurship* (pp. 22-24).

Krause, A. (2020). Valuing waste: A multi-method analysis of the use of household refuse from cooking and sanitation for soil fertility management in Tanzanian smallholdings. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 91-122). Springer.

Xin Liu, Yuancheng Xie, Hu Sheng, (2023), Green waste characteristics and sustainable recycling options, Resources, Environment and Sustainability, Volume 11, 100098, ISSN 2666-9161, https://doi.org/10.1016/j.resenv.2022.100098.

Machado, C. R., & Hettiarachchi, H. (2020). Composting as a municipal solid waste management strategy: Lessons learned from Cajicá, Colombia. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 17-38). Springer

Maeda T (2009) Reducing waste through the promotion of composting and active involvement of various stakeholders: Replicating Surabaya's solid waste management model. Institute for Global Environmental Strategies.
https://www.iges.or.jp/en/publication_documents/pub/policy/en/1712/policy+brief+no9-e_final_dec09.pdf

Mandpe, A., Kumari, S., & Kumar, S. (2020). Composting: A sustainable route for processing of biodegradable waste in India. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 39-60). Springer.

Marmolejo-Rebellón, L. F., Oviedo-Ocaña, E. R., & Torres-Lozada, P. (2020). Organic waste composting at Versalles: An alternative that contributes to the economic, social and environmental well-being of stakeholders. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 147-164). Springer.

Meena, A. L., Karwal, M., Dutta, D., & Mishra, R. P. (2021). Composting: phases and factors responsible for efficient and improved composting. *Agriculture and Food: e-Newsletter*, *1*, 85-90.

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., & Mensah, M. Y. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management, 46*.

Ministry of Environment, Science, Technology and Innovation (MESTI). (2021). *Ghana: Updated Nationally Determined Contribution under the Paris Agreement (2020–2030)*. https://unfccc.int/sites/default/files/NDC/2022-06/Ghana%27s%20Updated%20Nationally%20Determined%20Contribution%20to%20the%20UNFCCC_2021.pdf

Ministry of Sanitation and Water Resources. (2020). *National Solid Waste Management Strategy for Ghana*. Retrieved from https://ghanawasteplatform.org/wp-content/uploads/2021/11/National-Solid-Waste-Management-2020.pdf

Mushtaq, J., Dar, A. Q., & Ahsan, N. (2020). Spatial–temporal variations and forecasting analysis of municipal solid waste in the mountainous city of north-western Himalayas. *SN Applied Sciences*, *2*, 1-18.

Natural Resources Defense Council. (n.d.). *Composting 101*. NRDC. Retrieved April 16, 2025, from https://www.nrdc.org/stories/composting-101

Owusu-Sekyere, E., Bagah, D. A., & Quansah, J. Y. (2015). The Urban Solid Waste Management Conundrum in Ghana: Will It Ever End? *World Environment*, 52-62.

Reetsch, A., Kimaro, D., Feger, K.-H., & Schwärzel, K. (2020). Traditional and adapted composting practices applied in smallholder banana-coffee-based farming systems: Case studies from Kagera and Morogoro regions, Tanzania. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 165-184). Springer.

Snabes, Alexandria, "The Scoop on Composting: A Comprehensive Literature Review on Composting with a Focus on Grand Valley State University" (2021). *Honors Projects*. 865. https://scholarworks.gvsu.edu/honorsprojects/865

Tautges, N.E.; Chiartas, J.; Gaudin, A.C.M.; O'Geen, A.T.; Herrera, I.; M. Scow, K. (2019). *Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and sub-surface soils. Global Change Biology, (), gcb.14762–.* doi:10.1111/gcb.14762

Tchobanoglous, G., Theisen, H., & Vigil, S. (Eds.). (1993). *Integrated solid waste management: engineering principles and management issues* (pp. xxi+-978).

UNDP, 2023a, Composting in Ghana: Turning Waste Challenges into Climate Victories Composting in Ghana: Turning Waste Challenges into Climate Victories | United Nations Development Programme (undp.org). Accessed: 23rd August 2024.

UNDP, 2023b Ghana authorizes second project to transfer mitigation outcomes to Switzerland, Ghana authorizes second project to transfer mitigation outcomes to Switzerland | United Nations Development Programme (undp.org). Accessed: 25th August 2024.

UNDP, 2022, MADD Ghana – Integrated Waste Recycling and Composting for Methane Reduction in Ghana. 46 pp.

United States Environmental Protection Agency, 2024, Global Greenhouse Gas Overview, Global Greenhouse Gas Overview | US EPA. Accessed: 23rd August 2024.

US EPA, O. (2015). Approaches to Composting. [online] www.epa.gov. Available at: https://www.epa.gov/sustainable-management-food/approaches-composting. Accessed: 20th March, 2025.

US Composting Council. (2008). USCC factsheet: Using Compost Can Reduce Water Pollution. www.compostingcouncil.org.

World Bank Group, 2022, Solid Waste Management, Solid Waste Management (worldbank.org). Accessed: 23rd August 2024.

World Economic Forum, 2022, Climate Action, https://www.weforum.org/agenda/2022/11/waste-emissions-methane-cities/. Accessed: 23rd August 2024.

World Bank (2024). *Data Catalog*. [online] datacatalog.worldbank.org. Available at: https://datacatalog.worldbank.org/search/dataset/0039597/What-a-Waste-Global-Database. Accessed: 29th October, 2024.

Vermont Department of Environmental Conservation (Vermont DEC). (n.d.). Turned windrow composting: Sizing your composting pad. Retrieved from https://dec.vermont.gov/sites/dec/files/wmp/SolidWaste/Documents/ANR%20Sizing%20Your%20Composting%20Pad.pdf

Yirenya-Tawiah, D., Annang, T., Ofori, B. D., Fosu-Mensah, B. Y., Tweneboah-Lawson, E.,

Xiong, J., Ng, T. S. A., & Wang, S. (2015). Integrated Solid Waste Management System Design under Uncertainty. In Proceedings of the 18th Asia Pacific Symposium on Intelligent and Evolutionary Systems-Volume 2 (pp. 151-165). Springer International Publishing.

Yeboah, R., Owusu-Afriyie, K., Abudey, B., Annan, T., Datsa, C., & Gordon, C. (2020). Urban waste as a resource: The case of the utilisation of organic waste to improve agriculture productivity project in Accra, Ghana. In H. Hettiarachchi, S. Caucci, & K. Schwärzel (Eds.), *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends* (pp. 123-146). Springer.

Climate Policy, Sustainable Financing, and Business Models

7

Gender and Climate Change Policies in Sub-Saharan Africa

Ama Afriyie-Jenkins

Abstract

This study utilised the gender-responsive criteria to analyse how national climate policies, specifically the Nationally Determined Contributions (NDCs), address the intersection of gender equality and climate change policies in sub-Saharan Africa. A systematic review showed that, while some countries acknowledge the importance of this connection, their approaches lack full gender responsiveness, with some key elements either missing or inadequately addressed. This chapter recommends promoting gender diversity in political representation, integrating gender considerations into climate policy development, leveraging women's agency for gender-responsive and sustainable climate action, integrating women and girls into climate change planning and including women's voices in climate negotiations. This chapter provides valuable insights to policymakers, researchers, and stakeholders to help shape climate policymaking in sub-Saharan Africa.

Keywords: Gender equality, climate policies, sub-Saharan Africa, gender-responsive criteria, Nationally Determined Contributions (NDCs)

Introduction

In the wake of global development, the fight for gender equality and climate change is no longer peripheral. The advancement of women's rights and climate action has gained important recognition and accentuated as Sustainable Development Goals (SDG 5) and (SDG 13), which target “gender equality” and “climate action” respectively.

Lockwood (2013) argued that sub-Saharan Africa (SSA) has been disproportionately affected by the consequences of climate change, despite having minimal responsibility for its causes. This disproportionate impact is particularly severe for vulnerable groups, especially women, who face heightened risks to their livelihoods, rights, health, and safety. These concerns have contributed the recent momentum in climate change research, emphasising its impact on livelihood, rights, health and safety of women, as well as the growing need to develop competent solutions for women, generated by women.

In 1994, sub-Saharan African countries ratified the United Nations Framework Convention on Climate Change (UNFCCC) and integrated it into their national climate strategies for adaptation and mitigation. At COP 3 in December 1997, the Kyoto Protocol, which aligns with the UNFCCC's objectives, was adopted as an extension of the 1992 convention. The Protocol came into force in 2005 with broad ratification, except for the United States, and required industrialised and transitioning nations to meet specific greenhouse gas (GHG) emissions reduction targets. In contrast, the UNFCCC only urged these countries to adopt mitigation policies and report on their efforts (UNFCCC, 2015).

UNFCCC (2015) stressed that effective climate adaptation and mitigation require a gender-sensitive approach, as climate change impacts both women and men differently. The UNFCCC also warned that failing to address barriers to integrating gender in National Adaptation Plans (NAPs) could worsen existing gender inequalities or create new ones. In December 2015, the Paris Agreement was adopted to promote global efforts in fighting climate change and pursuing sustainable, low-carbon practices. Its preamble highlights the importance of gender equality and empowering women (UN Women, 2018). Articles 7 and 9 of the Agreement, as noted by UN Women (2018), advocate for gender-responsive adaptation. Specifically, Article 7.5 calls for inclusive, transparent, and knowledge-based adaptation efforts, considering vulnerable groups and ecosystems while promoting active participation.

At the global level, international frameworks for climate policy, such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and Paris Agreement emphasise the importance of integrating gender considerations into climate change interventions among their member parties (Bodansky, 2016). More recently is the 5-year enhanced Lima work programme on gender and its gender action plan agreed on by parties at COP 25 in December 2019. The parties stressed the importance of integrating gender considerations to enhance climate action and acknowledged that men and women face different climate impacts due to gender disparities, especially in developing regions. A consensus was reached on promoting women's leadership and participation in UNFCCC processes and climate policies to achieve lasting climate goals (UNFCCC, 2022). Other notable initiatives include the UN Secretary-General's Gender and Climate Change initiative launched at the Global Climate Action Summit 2019 and the Feminist Action for Climate Justice action coalition under the Generation Equality Forum.

In Africa, the African Union (AU) is dedicated to addressing climate change with a gender perspective. In 2014, the Union reaffirmed its commitment to addressing climate change with a gender focus. This commitment was demonstrated during the twenty-third ordinary session in Malabo, where African heads of state, through the Committee of African Heads of State and Governments on Climate Change (CAHOSCC), agreed to establish the CAHOSCC Women and Gender Program on Climate Change (CWGPCC) to involve women and gender in climate-related actions (Herman, 2016). This initiative, alongside broader global and regional advocacy efforts, has contributed to African nations developing climate policies, strategies, and green growth plans that aim to integrate gender considerations into development frameworks (Aura et. al., 2017).

At the sixty-sixth session of the Commission on the Status of Women (CSW66) Africa consultations in 2022, AU member countries adopted the Common Africa Position. This position urged stakeholders to enhance national data systems for gender-focused climate analysis. It also called for the provision of technical support for gender-responsive climate and disaster plans. Additionally, countries emphasised the need to strengthen coordination between gender and environment ministries. They also advocated for investments in early childhood protection and community childcare to support women and girls, particularly those in agriculture affected by climate change (African Union, 2022).

Despite global and regional frameworks emphasizing the integration of gender considerations into climate strategies, there is limited understanding of how effectively these commitments have been reflected in the Nationally Determined Contributions (NDCs) of sub-Saharan African (SSA) countries. In many cases existing climate policies fall short in addressing gender-specific needs and promoting women's active participation in climate action. These inadequacies undermine the effectiveness of climate adaptation and mitigation efforts and present a challenge for evaluating progress and identifying gaps in gender-responsive climate action. Addressing these gaps are essential for ensuring that climate strategies are inclusive and aligned with broader gender and development objectives.

The main objective of this chapter is to examine the extent to which gender considerations have been incorporated into the Nationally Determined Contributions (NDCs) of sub-Saharan African countries. Specifically, the chapter raises the following research question: How many countries, and to what extent, have these countries incorporated gender considerations into their climate plan, i.e., the Nationally Determined Contributions (NDCs)?

In response to the question raised, the chapter aims to examine the extent to which gender considerations have been incorporated into the NDCs of SSA countries through a review approach. The remainder of the paper is structured as follows: Section 2 covers the literature review, Section 3 details the methodology, Section 4 presents the results and discussion, and Section 5 concludes the paper, followed by policy recommendations and references.

Literature Review

Gender Responsive Criteria for Climate Change Policies

This section delves into the research on key ideas and methods that aid in understanding the theory behind gender-sensitive climate change policies. The review adopts the five concepts, developed by Fawad (2019), namely, Human Rights, Gender Equal Participation, Gender Mainstreaming, Power Relations, and Budgeting. These five concepts form the basis of the gender-responsive criteria – an overall criterion used to analyse national climate policies and assess their alignment with gender commitments. All concepts emphasize the significance of including gender considerations in climate governance. While these five concepts play a crucial role in the development of gender-responsive climate policies promoting gender equality, it is important to note that they do not represent an exhaustive list and should not be considered as such.

Human Rights and Gender Equality in Climate Change Policies

Extensive research on gender and climate change highlights the heightened vulnerability of women and girls to its impacts (UN Women, 2018). In sub-Saharan Africa, this vulnerability is compounded by various forms of discrimination deeply rooted in societal norms, values, and legal systems (Tschakert & Machado, 2012). Scholars argue that such discrimination hinders women's rights (Arora-Jonsson, 2014), making it harder for them to cope with climate change effects. This underscores the need to empower women who have been historically marginalized in political, economic, and social domains (Habetzion, 2013).

However, some scholars also contend that, merely incorporating gender and human rights language into agreements and laws risks overlooking the deeper power dynamics and social injustices (MacGregor 2010). While integrating these principles into policies is crucial for promoting fairness, there is a concern that such inclusion may lead to a superficial compliance culture, rather than genuine progress. Thus, these principles might be added for compliance rather than to inform actual policymaking and planning processes.

Gender Equal Participation in Climate Change Policies

The fundamental principle of gender equality asserts that all individuals are equal and deserve equal rights, including equitable decision-making processes and inclusion in policy discussions. Despite this premise, women's participation in political and economic spheres, especially at high levels of decision-making in climate-related institutions remains limited (Hemmati and Rohr 2009). Women are still underrepresented in negotiations and delegations of many countries, including those most prone to climate impacts, and their presence is notably low in decision-making positions.

According to UNFCCC data from May 2018, although women made up 47 percent of non-governmental participants at COP 23 in 2017, women leading government delegations remained below 30 percent. Observers at the 2017 UN Climate Conference highlighted the lack of women in key roles and urged officials to increase female representation for COP 24 (UNFCCC, 2022).

However, measuring women's involvement solely by counting their numbers in political arenas could overlook issues concerning the unequal power dynamics within institutions and among policy makers. For instance, even when women are present in decision-making spaces, they may be marginalised through limited access to influential networks, exclusion from informal decision-making platforms, or being assigned roles with less authority or influence. Additionally, prevailing institutional cultures can undervalue women's contributions, reinforcing stereotypes that sideline women's voices or limit their participation to specific gender-focused issues rather than broader policy concerns. Addressing these deeper issues requires not only enhancing women's access to decision-making spaces but also transforming institutional structures and norms to ensure that their contributions are valued and integrated into policy processes.

Gender Equality and Power Relations in Climate Change Policies

Gender dynamics illustrate the power relations between women and men, as well as between boys and girls, which greatly influence access to and control over environmental resources and opportunities (Kronsell, 2018). Because of societal gender norms and stereotypes, men and women engage in different tasks, have uneven access to resources and information, and experience the effects of climate change in distinct ways (Denton, 2002).

For instance, in many rural households in sub-Saharan Africa, women typically manage water and waste due to traditional family and domestic duties. However, their limited presence in male-dominated political and public spheres restricts their influence over water and waste management systems. Despite numerous women's movements and alterations in international and national legislations, persistent traditional stereotypes perpetuate gender disparities through customs, social norms, and economic structures. Women continue to be marginalized, lacking access to financial, material, and technological resources, as well as rights and decision-making authority. These issues exacerbate their susceptibility to the impacts of climate change as their societal roles often limit their ability to adapt or mitigate its effects (Kronsell, 2018).

Gender Mainstreaming in Climate Policies

Gender mainstreaming was introduced during the UN's Fourth World Conference on Women in Beijing in 1995, and it became the official approach for all policies and programs within the UN system in 1997 (WEDO, 2015). Since then, it has become increasingly popular as a way to improve the integration of gender perspectives into climate policies and actions. Many supporters of gender and climate change emphasize the importance of incorporating a gender equality perspective throughout all stages of climate-related processes, including policy formation, decision-making, and the implementation of mitigation and adaptation strategies, at every level (UN Women, 2018).

As women in sub-Saharan Africa remain underrepresented and have less power and influence in all aspects of climate change policies, information, and funding compared to men, they're unlikely to contribute meaningfully or gain from climate change solutions (Otzelberger, 2011). Women's organisations and advocacy groups stress that climate policies and initiatives might lack effectiveness and equity unless they incorporate and embrace gender perspectives and equality approaches across all sectors, even those historically dominated by men (Otzelberger, 2014).

Budgeting in Climate Policies

There is a growing need to address the oversight of gender concerns in climate financing. For example, Williams (2015) discusses factors leading to gender unawareness in climate change financing, focusing on how funding often prioritises mitigation over adaptation. Cohen's 2018 review of Williams' work highlights this point, noting the tendency of climate finance to emphasize mitigation strategies rather than adaptation measures that are more directly relevant to addressing gender-specific needs. The majority of policies regarding mitigation actions, which hold the greatest potential for reducing greenhouse gases and mitigating climate change impacts, typically prioritise fields such as science and the economy, which are predominantly steered by male interests. Consequently, these policies often offer minimal consideration for gender aspects (Djoudi et al. 2016).

Kronsell (2018) contends that climate change is often portrayed as a technical issue demanding technological solutions, which frequently overlooks or superficially addresses gender considerations. To enhance gender considerations in climate policy, especially in finance, international organizations, including the UNFCCC, must advocate for and support Gender Responsive Budgeting (GRB). In the 1990s, GRB gained prominence at the Fourth World Conference on Women in Beijing (1995), calling for the inclusion of a gender perspective in budgetary decisions. This approach entails gender-based assessments of budgets to achieve equality in decision-making and the distribution of benefits and burdens. Making GRB a permanent part of the system has great potential to tackle structural inequalities and reduce gender-based climate impacts. However, its effectiveness depends on fair access to climate finance, with specific funding set aside for women, and ensuring that gender aspects are included at every stage of designing and implementing climate finance (WEDO, 2015).

Methodology

This study utilizes systematic review, specifically thematic analysis to identify gender-related considerations within the Nationally Determined Contributions (NDCs) of sub-Saharan African countries. The NDCs are used as the key document for scrutiny because they form the basis of climate action targets for many countries. Secondly, the NDCs have targets that are multisectoral, covering sectors such as energy, agriculture, transport, land use. These characteristics make the NDCs a holistic policy document whose scrutiny can reflect the climate action priorities of countries.

The research focuses specifically on pinpointing which countries are actively addressing the connections and representation of gender in the context of climate change policy. Thematic analysis, commonly employed in qualitative studies, involves systematically identifying, examining, and detailing patterns or themes inherent in the data, as described by Braun and Clarke (2006). Qualitative research, being inherently exploratory, aims to uncover nuanced meanings and achieve a deep understanding of the phenomenon being studied. Organizational and institutional documents, according to Bowen (2009), play a crucial role in qualitative research, offering insights into the historical origins of specific issues. The steps in thematic analysis, outlined by Castlebury and Nolen (2018), provide a valuable framework for recognizing, examining, and presenting themes found within the data.

Sampling

The study utilised criterion sampling, a method selected from purposive sampling. Purposive sampling involves the researcher choosing cases for the sample based on their judgment of their typicality or possession of specific relevant characteristics. Criterion sampling, a subtype of purposive sampling, allows the researcher to apply specific criteria when specifying the sample (Patton, 1990). According to Ritchie et al. (2003), this approach involves selecting sample members with a purpose, enabling the researcher to carefully define sample parameters at an early stage. The research resulting in this chapter adopted countries which demonstrate a strong commitment to gender-related concerns in their Nationally Determined Contributions (NDCs). This decision aimed to explore how women's rights concerns are interpreted and constructed by Parties in climate policies. Criterion sampling was applied to all 49 sub-Saharan African countries to exclude those with weak or absent gender policies - resulting in a smaller sample that offers cases rich in information, providing valuable insights into issues central to the research's objectives (Patton, 1990).

As stated above, evaluating all NDCs was not practical. To ensure rigor and precision, the selection of countries followed a specific process. This method was crucial to minimize selection bias and offered a clear framework for choosing only those countries that met the following specified criteria:

1. Countries should have formally ratified the Paris Agreement.
2. Countries should have submitted their updated NDCs to the UNFCCC website.
3. NDCs should be submitted in English.
4. NDCs should be submitted in or after 2021.
5. Countries should have a population above 10 million.

After applying five purposive criteria to the 49 sub-Saharan African countries, the sample was reduced to 13, all of which demonstrated the presence of gender-related language in their updated NDCs. However, for the in-depth critical discourse and document analysis central to this study, it became necessary to further narrow the sample to four countries (i.e., Ghana, Malawi, South Sudan, and Zimbabwe). This decision was driven by both analytical depth and representational diversity.

On the analytical approach, Altheide (2000) emphasises contextual richness over breadth. Critical discourse analysis is highly interpretive and demands close reading of text, attention, and engagement with the socio-political context in which the discourse is produced. The reduction also reflects pragmatic research considerations, including time and resource constraints, which are common in qualitative document-based research. Second, the four selected countries were chosen to ensure diversity in regional representation, political context, and gender policy framing. These cases reflect variation across key dimensions:

- **Geographical diversity**: West (Ghana), Southern (Zimbabwe, Malawi), and East/Central Africa (South Sudan);

- **Institutional capacity and stability**: From relatively stable democracies (Ghana, Malawi) to more fragile or post-conflict states (South Sudan), allowing for comparative insight into how institutional environments shape gender discourse;

Table 1: Sub-Saharan African countries selected based on specified criteria.

Country	NDC Availability	Most Recent Population
Ghana	2021	32,833,031
Malawi	2021	19,889,742
South Sudan	2021	10,748,272
Zimbabwe	2021	15,993,524

Source: Author's construct (2023)

Data Analysis Techniques

Altheide (2000), perceives discourse analysis as a social constructivist approach and suggests that knowledge, meaning, and reality are actively shaped by individuals within a social context. Bowen (2009) defines document analysis as a methodical procedure for reviewing or evaluating both printed and electronic data. The data was, therefore, extracted, scrutinized, and interpreted to extract meaning in order to build empirical knowledge. The objective was to assess how 'gender' and 'women' were integrated into these policies. As mentioned earlier, the selection process was purposive, guided by the availability of policies online in English. Altheide (2000) suggests that tracking discourse and employing qualitative document analysis is suitable for widely accessible policies and documents. In this case, the online accessibility of the NDCs from the UNFCCC website was a key criterion for selection. The initial analysis involved a frequent count of the words 'gender' and 'women', followed by a description of instances where women and gender were included in the policies. These terms were chosen because they are relevant to the research topic and their foundational role in gender-responsive concepts.

Document analysis offers several advantages, including efficiency, availability, cost-effectiveness, non-intrusiveness, stability, precision, and broader coverage (Bowen, 2009). However, some weaknesses, as outlined by Bowen (2009), include insufficient detail, low retrieval rates, and selection bias. The five principles of gender-responsive criteria (human rights, gender equal participation, power relations, gender mainstreaming and budgeting) act as a tool to recognize notable features in the data and guide observations across the dataset, helping to define detailed characteristics of gender-responsive implementation of climate policies.

A notable constraint arises from the bias introduced by the criteria employed to reduce the sample size. Choosing countries based on particular criteria, such as solely using English texts, submissions within the 2020 – 2021 timeframe, and countries with a population exceeding 10 million, led to the omission of a substantial number of countries that could have offered valuable insights into gender and climate change policy. However, including all countries with documents submitted in multiple languages would have demanded significant resources and multiple researchers, which goes beyond the scope of this study.

Results and discussion

This research explores five main concepts forming the gender-responsive criteria—human rights, gender-equal participation, gender mainstreaming, power relations, and budgeting—as identified in the literature review, to assess how gender equality is represented in NDCs.

Human Rights:

The data extracts presented below demonstrate evidence of recognizing and respecting women's agency and rights as equal to those of men.

Table 2: Recognition of human rights in the NDCs

Document	Data Extract(s)	Chapter, Section and Page Number
Ghana's NDC (2021)	Absent	-
Malawi's NDC (2021)	Absent	-
South Sudan's NDC (2021)	"The Ministry of Gender, Child and Social Welfare is responsible for developing and implementing policies that promote gender equality, social inclusion and justice, and **safeguard the rights of women, children and other vulnerable groups**". "Strengthen adaptive capacity of communities **using a gender and human rights approach.** This will involve making information, training and technologies for climate change adaptation and mitigation accessible to and relevant for all stakeholders".	8.2.1 Major administrative bodies for climate change, p.136 Table 39: Strategies for gender inclusion in the NDC, p.149
Zimbabwe's NDC (2021)	Absent	

Source: Author's construct (2023)

While Ghana, Malawi, and Zimbabwe's NDCs largely overlook the crucial link between gender equality and human rights, South Sudan presents a notable exception. South Sudan's NDCs emphasise the role of the Ministry of Gender, Child and Social Welfare in enhancing community resilience. This role is achieved through a gender and human rights approach encompassing awareness creation, training on climate change adaptation, mitigation, and disaster risk management. These approaches are ultimately aimed to ensure inclusive representation and participation in the revised NDC development and implementation.

However, as Jonsson (2012) argues, merely referencing gender equality within policy documents is insufficient. True progress necessitates addressing the root causes of gender inequality. To genuinely advance gender equality and women's empowerment as fundamental human rights, Parties must actively support implementation by recognizing and respecting women's agency and rights as equal to those of men.

Gender Equal Participation

According to the results below, these Parties support gender equality in politics to assist women in reaching leadership positions in climate decision-making, alongside ensuring active involvement of women empowerment groups in shaping national climate policies through participatory planning.

Table 3: Recognition of gender equal participation in the NDCs

Document	**Data Extract(s)**	**Chapter, Section and Page Number**
Ghana's NDC (2021)	Absent	-
Malawi's NDC (2021)	Absent	-
South Sudan's NDC (2021)	"Integrate **a gender perspective** into national level climate change policies and strategies. South Sudan will **target 35% representation of women in decision-making related to climate change** – as per the Revitalised Agreement on the Resolution of the Conflict in the Republic of South Sudan". "Consider **inclusion of women and other vulnerable groups** when carrying out vulnerability assessments to ensure that evaluations do not focus solely on economic sectors dominated by men"	Table 39: Strategies for gender inclusion in the NDC, p.149
Zimbabwe's NDC (2021)	"Zimbabwe Gender Commission will promote, protect and advance **gender equality** in the NDC".	4.5 Co-benefits of identified mitigation measures, p.23

Source: Author's construct (2023)

The NDCs of South Sudan and Zimbabwe demonstrate a commitment to enhancing women's involvement in climate change decision-making. South Sudan has set a target of 35% representation of women in climate-related decision-making. This target demonstrates the recognition of women's diverse roles, contributions and collective efforts towards gender equality. Similarly, Zimbabwe's Gender Commission advocates for gender equality within their NDC – emphasizing the significance of providing platforms for national and regional women's organizations to voice their concerns and perspectives. Both Parties prioritise participatory planning and collective action in climate decision-making. On the other hand, Ghana and Malawi do not mention their approach to gender-equitable participation in their NDCs.

While increasing the number of women in climate decision-making is a positive step, it does not automatically translate to meaningful influence. Institutional barriers, limited access to financial resources, and deeply ingrained cultural norms often restrict women's ability to shape climate policies, even when they hold leadership positions. Research highlights that without deliberate efforts to address these structural challenges, women's involvement may remain symbolic rather than transformative (Kabeer, 2020; Jonsson, 2012).

Power Relations

This section outlines evidence of policies that address inequalities in resource access and opportunities, and involving women in climate policies as vulnerable groups, not just as vulnerable groups, but also as agents of change, decision-makers, and stakeholders. Additionally, it highlights the aspects of the NDCs that support structural shifts in gender roles, challenging traditional power dynamics to enable more equitable climate governance and action.

The data presented indicates that while Ghana's NDCs recognises the vulnerability of women and youth in climate-vulnerable agricultural landscapes, it fails to explicitly recognize the unequal access to and control over resources that create this vulnerability. The framing does not directly confront the power asymmetries between men and women, particularly in access to land, finance, and decision-making. This omission limits its potential to challenge existing structures of inequality.

Table 4: Recognition of power relations in the NDCs

Document	Data Extract(s)	Chapter, Section and Page Number
Ghana's NDC (2021)	"Build resilience and promote livelihood opportunities for the **youth and women** in climate-vulnerable Agriculture landscapes and food systems".	6.2 Annexe 2: Adaptation and Mitigation Contribution Table, p. 25, 26
Malawi's NDC (2021)	Absent	-
South Sudan's NDC (2021)	Absent	-
Zimbabwe's NDC (2021)	Absent	-

Source: Author's construct (2023)

On the other hand, the NDCs presented by Malawi, South Sudan and Zimbabwe overlook the role of gendered power relations in shaping climate vulnerability and response. Without addressing the structural barriers that limit women's participation in climate action, these NDCs risk reinforcing the status quo rather than driving transformative change.

Literature suggests that women are disproportionately affected by climate change due to deeply entrenched social roles and responsibilities, and institutional barriers that limit their ability to adapt (Habtezion, 2013). These barriers include restrictive land tenure systems, exclusion from climate finance, and underrepresentation in governance structures—all of which stem from gendered power dynamics. However, overly concentrating on women's vulnerability, without addressing why they are vulnerable, may perpetuate women as helpless victims in need of rescue, rather than agents of change. This perception often results in policies that prioritize women's adaptive capacity rather than ensuring structural shifts in power, control, and resource distribution.

For NDCs to be genuinely gender-responsive, they must go beyond general commitments to resilience-building and actively address who holds power, who makes decisions, and who has access to resources. This requires explicit policy commitments to secure women's land rights, expand their access to climate finance, and ensure their leadership in climate governance. Without these measures, climate policies risk maintaining existing inequalities rather than transforming them.

Gender Mainstreaming

The findings show any reference to gender or women in policies and proof that gender is incorporated throughout all aspects of national climate policies, particularly in areas related to mitigation, financing, and technology (non-traditional sectors).

The excerpts from national climate policies indicate varying levels of gender mainstreaming across Ghana, Malawi, South Sudan, and Zimbabwe. While all four countries acknowledge gender in some capacity, their commitments differ in scope, focus, and depth of integration into climate action.

For example, Ghana's approach to gender mainstreaming is framed within a broader vision of a low-carbon, socially inclusive economy. While it mentions women's empowerment and social inclusion, it does not clearly outline how gender will be mainstreamed across different climate action areas or address institutional mechanisms for gender-responsive implementation. The lack of specificity raises concerns about whether gender is fully integrated into Ghana's climate policies or remains a broad development goal.

Malawi and Zimbabwe incorporate gender considerations into climate actions, these efforts primarily focus on adaptation, capacity building, policies, and strategies. Malawi's focus on mainstreaming gender in policies, programs, and projects suggests an institutional commitment to gender inclusion, but without explicit reference to climate-specific actions, its direct impact on climate mitigation and adaptation remains unclear. Similarly, Zimbabwe's National Gender Policy includes climate change as a thematic area, but there is little indication of how this mainstreaming extends beyond policy statements into concrete climate interventions.

South Sudan explicitly integrates gender into both mitigation and adaptation efforts, as well as climate financing. The country demonstrates a higher level of commitment to gender mainstreaming by integrating a gender perspective into climate change mitigation and adaptation interventions. However, the extent to which these commitments translate into actionable policies, funding allocations, and implementation mechanisms remains an open question.

Table 5: Recognition of gender mainstreaming in the NDCs

Document	Data Extract(s)	Chapter, Section and Page Number
Ghana's NDC (2021)	"A resilient and low carbon society by promoting economic growth, climate protection and air quality benefits, **youth and women empowerment and social inclusion** in the next decade and beyond".	6.2 Annexe 2: Adaptation and Mitigation Contribution Table, p. 25
Malawi's NDC (2021)	"Promotion of **gender mainstreaming** in policies, programmes and projects".	Implementation plan measures, p.82
South Sudan's NDC (2021)	"Integrate **a gender perspective** into climate change mitigation and adaptation interventions. Principles of **gender equality and women empowerment** will be included in climate financing".	Table 39: Strategies for gender inclusion in the NDC, p.149
Zimbabwe's NDC (2021)	"In 2017, Zimbabwe adopted a revised National Gender Policy that includes a specific thematic area on gender and climate change and promotes the **mainstreaming of gender** in environmental and climate change policies and strategies".	2.1 National Context & Vision, p.5

Source: Author's construct (2023)

While addressing gender issues in adaptation is crucial, it is imperative to diversify gender concerns into other areas, particularly in climate mitigation activities. Gender mainstreaming, as discussed in literature, demands a transformative shift in behaviours and attitudes across organizations to be fully effective (Pollack and Hafner, 2002). Selectively choosing where to mainstream gender concerns detracts from its fundamental principles (UN, 2002).

Budgeting

By implementing gender-responsive budgeting to tackle the impacts of climate change and address the needs of all genders, we can verify monitoring mechanisms to track progress on gender equality in climate policies. This includes allocating funds for collecting and analysing gender-disaggregated data.

Table 6: Recognition of budgeting in the NDCs

Document	Data Extract(s)	Chapter, Section and Page Number
Ghana's NDC (2021)	Absent	-
Malawi's NDC (2021)	Absent	-
South Sudan's NDC (2021)	Absent	-
Zimbabwe's NDC (2021)	Agricultural value-chains largely employ women. Implementing this measure thus requires actions that consider **gender barriers** to accessing information and resources (such as lack of collateral, illiteracy, etc), as well as actions that directly address **gender inequalities** (i.e. **supporting women** in accessing collateral and finance, reducing the burden of work, etc).	Table 2: Priority adaptation measures, p.15

Source: Author's construct (2023)

The findings reveal that only Zimbabwe's NDCs make explicit commitment to climate financing and budgeting. Zimbabwe acknowledges that agricultural value chains, which employ a large number of women, require targeted actions to overcome gender-specific barriers to accessing financial resources and information. This recognition of gender disparities in financial access is an important step toward gender-responsive climate budgeting. However, Zimbabwe's NDC does not outline a specific funding mechanism or dedicated budget allocation to support these gender-focused interventions.

In contrast, Ghana, Malawi, and South Sudan's NDCs make no mention of gender-responsive climate financing or budgeting. This absence suggests that climate finance policies in these countries may not be designed to address gendered barriers in accessing funding, support services, or economic opportunities within climate-related sectors.

Notably, gender considerations are lacking in policies promoting emissions mitigation through scientific and technological research. This absence suggests that climate issues are often seen as primarily technical, overlooking gender implications. Overall, the data indicates a tendency to view climate challenges as best addressed through technological solutions, potentially underestimating the importance of gender (MacGregor, 2010).

Conclusions and Policy Recommendations

Gender and climate change policies have gained recognition as crucial areas for academic inquiry. This book chapter utilised gender-responsive criteria developed by Fawad (2019) to analyse how national climate policies, specifically the NDCs, address the intersection of gender equality and climate change. Findings from a thematic analysis conducted on Ghana, Malawi, South Sudan and Zimbabwe revealed that, while all four Parties acknowledge the importance of this connection, their approaches lack full gender responsiveness, with some key elements either missing or inadequately addressed. Gender equality discussions in the NDCs were limited, with significant gaps in climate finance, mitigation, and technology. However, Ghana, South Sudan and Zimbabwe acknowledged a deeper link between gender equality and climate change impacts within their NDCs. Also, discussions on gender equality in the NDCs were superficial, focusing on assumptions about women's vulnerability and poverty in the face of climate change. These findings highlight the partial application of a gender-responsive approach in the NDCs, showing that several important elements for effective gender integration are missing. Overall, to achieve gender equality and advance sustainable development, a deeper understanding and application of gender perspectives across climate policies are essential.

Given the findings, the following recommendations are made:

1. **Integrate gender considerations into national climate policies:** To better integrate gender considerations into national climate policies, countries should adopt the five key gender responsive concepts to evaluate and incorporate gender concerns in climate decision-making (i.e. human rights, equal participation, power relations, gender mainstreaming and gender responsive budgeting). These concepts should guide the review of Nationally Determined Contributions (NDCs) through a gender lens, ensuring that gender equality is addressed in all climate actions. Aligning national policies with international gender equality principles, such as those in the Paris Agreement, is also crucial. Additionally, institutional accountability mechanisms should be established to track and evaluate the effectiveness of gender integration in climate policies, ensuring that commitments translate into tangible outcomes.

2. **Strengthen Research, Data Collection and monitoring on gender and climate action**: To bridge the knowledge gap in gender and climate policymaking, governments and institutions should prioritise continuous research and monitoring mechanisms that capture the gendered dimensions of climate action. These approaches include developing sex-disaggregated data systems to assess disparities in climate adaptation, mitigation, and finance, as well as researching barriers that prevent women from participating in climate-related decision-making and financial opportunities. Continuous research and monitoring are necessary to refine gender-responsive climate strategies and ensure that policies are inclusive and sustainable. Policies should be regularly updated based on evidence from gender-focused research, ensuring that climate strategies remain inclusive, data-driven, and responsive to the specific needs of both men and women. Ongoing research should be prioritised to enhance the development of gender-sensitive and responsive climate policies.
3. **Amplify Women's Voices in Climate Action:** Women's participation in climate policy formulation and governance must go beyond symbolic representation to ensure meaningful involvement in decision-making. Simply increasing the number of women at the negotiation table is inadequate, as it does not necessarily reflect the lived experiences or needs of affected women, especially those in local or marginalized communities. Therefore, the focus should shift to leveraging women's agency and incorporating their unique knowledge, skills, and perspectives, particularly in areas such as food systems, technology, and institutional frameworks. Women's active involvement is crucial for developing more effective and sustainable climate actions.
4. **Ensure Gender Inclusivity in National Climate Policies**: It is essential to conduct a comprehensive gender analysis of national climate documents to ensure that gender commitments from international agreements are fully reflected in national climate policies. Effective climate action involves the active participation of both men and women in decision-making, policy formulation, and implementation. Achieving genuine inclusion of women in climate processes addresses deep-rooted sociocultural barriers, such as economic dependency, limited education access, unequal work opportunities, and time poverty.

Addressing these obstacles will facilitate the meaningful involvement of women in shaping climate policies and actions.

5. **Ensure Gender-Responsive Climate Finance and Budgeting**: Climate finance policies should integrate gender-responsive budgeting to ensure that funding mechanisms promote equitable access to financial resources for both men and women. Governments should establish dedicated funding streams to support women-led climate initiatives, particularly in adaptation and mitigation sectors such as renewable energy, agriculture, and disaster risk reduction. Financial barriers that disproportionately affect women, such as lack of collateral and limited access to credit, should be addressed through targeted microfinance programs and collateral-free loan options. Additionally, ministries and climate-related agencies must incorporate gender considerations into public climate finance frameworks, ensuring that mitigation investments explicitly account for gender disparities and create opportunities for women's economic empowerment.
6. **Address Socioeconomic Barriers to Women's Participation in Climate Action**: Achieving gender equality in climate action requires addressing the underlying socioeconomic barriers that hinder women's full participation. Governments should invest in educational and capacity-building programs that equip women with the necessary skills to engage in climate governance, entrepreneurship, and green job opportunities. Economic dependency should be tackled through financial literacy initiatives and targeted support for women in climate-related industries. Additionally, policies should promote gender-responsive climate solutions that alleviate women's time burdens, such as clean cooking technologies and sustainable water management systems. By addressing these structural barriers, countries can create a more inclusive and equitable climate policy landscape that benefits all members of society.

Reference

African Union (AU). (2022). *African countries adopt common African position to integrate gender equality in climate action agenda.* Retrieved from

https://au.int/en/pressreleases/20220303/african-countries-adopt-common-african-position-integrate-gender-equality

Altheide, D. L. (2000). Tracking discourse and qualitative document analysis. *Poetics, 27*(4), 287–299.

Arora-Jonsson, S. (2014). Forty years of gender research and environmental policy: Where do we stand*? Women's Studies International Forum, 47,* 295–308. doi:10.1016/jgloenvcha.2011.01.005

Aura, S., Nyangaga, J., & Were, K. (2017). "Integrating gender into climate change and green growth policies in Africa: Progress and challenges." *Climatic Change,* 144(2), 231-244.

Bauer, G., & Britton, H. (Eds.). (2006). *Women in African Parliaments.* Boulder CO: Lynne Rienner.

Bodansky, D. (2016). "The Paris climate change agreement: A new hope?" *American Journal of International Law,* 110(2), 288-319.

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal, 9*(2), 27–40.

Castleberry, A., & Nolen, A. (2018). Thematic analysis of qualitative research data: Is it as easy as it sounds? *Currents in Pharmacy Teaching and Learning, 10*(6), 807–815. doi:10.1016/j.cptl.2018.03.019

Cohen, M. G. (2018). Gender and climate change financing: Coming out of the margin*. Feminist Economics, 24*(3), 188–190. Retrieved from

https://doi.org/10.1080/13545701.2017.1421319.

Denton, F. (2002). Climate change vulnerability, impacts, and adaptation: Why does gender matter? *Gender and Development, 10*(2), 10–20. doi:10.1080/13552070215903

Djoudi, H., Locatelli, B., Vaast, C., Asher, K., Brockhaus, M., & Sijapati, B. B. (2016). Beyond dichotomies: Gender and intersecting inequalities in climate change studies. *Ambio, 45(*S3), 248–262.

Fawad (2019). *Examining gender responsive implementation of national climate change policies* [Unpublished thesis].

Habtezion, S. (2013). *Overview of linkages between gender and climate change.* United Nations Development Programme. Retrieved from

http://www.undp.org/content/dam/undp/library/gender/Gender%20and%20Environment/PB1-AP-Overview-Gender-and-climate-change.pdf.

Hemmati, M., & Röhr, U. (2009). Engendering the climate-change negotiations: Experiences,challenges, and steps forward. *Gender & Development, 17*(1), 19–32. https://doi.org/10.1080/13552070802696870

Herman, M. (2016). *Women and climatic changes in Ethiopia: A gendered assessment*. In D. Ambrosetti et al. (Eds.), *Climatic and environmental challenges: Learning from the Horn of Africa*. Centre français des études éthiopiennes. https://doi.org/10.4000/books.cfee.417

Kronsell, A. (2018). *The contribution of feminist perspectives to climate governance*. In S. Buckingham & V. Le Masson (Eds.), Understanding climate change through gender relations. Routledge. Retrieved from

https://www.researchgate.net/publication/326232776_%27The_contribution_of_feminist_perspectives_to_climate_governance%27

Lockwood, M. (2013). "Sub-Saharan Africa and climate change: Adapting to a changing climate." *Wiley Interdisciplinary Reviews: Climate Change*, 4(1), 9-19.

MacGregor, S. (2010). Gender and climate change: From impacts to discourses. *Journal of the Indian Ocean Region, 6*(2), 223–238. doi:10.1080/19480881.2010.536669

Otzelberger, A. (2011). *Gender-responsive strategies on climate change: Recent progress and ways forward for donors.* Institute of Development Studies. Retrieved from https://www.gdnonline.org/resources/BRIDGE_Gender_responsive_strategies_on_CC.pdf

Otzelberger, A. (2014). *Tackling the double injustice of climate change and gender inequality*. CARE International. Retrieved from

https://www.carefrance.org/ressources/themas/1/4442,CARE_COP20_Tackling double injustice.pdf

Patton, M. Q. (1990). *Qualitative evaluation and research methods.* Beverly Hills, CA: Sage Publications.

Pollack, S., & Hafner, B. (2002). *"Mainstreaming Gender in Development: A Critical Review."* In D. Archibugi, M. Kohler, & R. Marchetti (Eds.), Global Democracy: For and Against (pp. 147-171). Cambridge University Press.

Ritchie, J., & Lewis, J. (2003). *Qualitative research practice: A guide for social science students and researchers* (pp. 77–108). Book Section, London: Sage. Retrieved from http://psy.au.dk/fileadmin/site_files/filer_psykologi/dokumenter/CKM/NB36/ritchie.pdf

Tschakert, P., & Machado, M. (2012). Gender justice and rights in climate change adaptation: Opportunities and pitfalls. *Ethics and Social Welfare, 6*(3), 275–289.

UN Women. (2018). *Turning promises into action: Gender equality in the 2030 Agenda for Sustainable Development.* Retrieved from http://www.unwomen.org/en/digital-library/publications/2018/2/gender-equality-in-the-2030-agenda-for-sustainable-development-2018.

United Nations Framework Convention on Climate Change. (2015). Paris Agreement. Paris: United Nations.

United Nations Framework Convention on Climate Change. (2022). Lima Work Programme on Gender. https://unfccc.int/topics/gender/workstreams/the-enhanced-lima-work-programme-on-gender

Women's Environment and Development Organization (WEDO). (2015). *Women's participation in UN climate negotiations*. Retrieved from https://wedo.org/wp-content/uploads/2023/06/WEDO_WomensParticipation_2023_EN.pdf

Williams, M. (2015). *Gender and climate change financing: Coming out of the margins*. Zed Books.

8

Innovative Climate Adaptation Financing Options for Ghana: Focus on the AFOLU Sector

Carlos Kokuvi Tetteh

Abstract

Despite increasing recognition of the critical role of climate finance, a significant funding shortfall persists for climate adaptation in developing economies, particularly in Africa. Ghana, with its largely agrarian economy, exemplifies these challenges, facing severe climate risks that demand substantial financial support to build resilience and promote sustainable development. Ghana's Nationally Determined Contributions reveal a significant climate finance gap, with only 5% of the required $15 billion to meet climate adaptation and mitigation targets. In 2020, public finance constituted most climate finance flows, contributing $722 million (87%), while the private sector accounted for $106 million (13%). The Agriculture, Forestry, and Other Land Use (AFOLU) sector remains the largest recipient of climate finance due to its high vulnerability to climate change. This chapter employs a desk review methodology to explore innovative financing options for climate adaptation in Ghana's AFOLU sector. It highlights three key pathways for mobilising green finance, as identified by the United Nations Environment Programme: government-led initiatives, private-sector investments, and household contributions. The research reveals several innovative financing mechanisms, including disaster risk instruments such as parametric insurance and catastrophe bonds, catalytic instruments like blended finance and pooled investment funds, and outcome-based instruments such as debt-for-nature swaps and adaptation benefit mechanisms. The findings underscore the urgent need to leverage these innovative tools to address Ghana’s adaptation finance deficit, particularly in the AFOLU sector. The chapter recommends prioritising the development of blended finance frameworks to attract private capital by reducing investment risks and increasing returns for private-sector actors. This approach can unlock significant new funding to enhance resilience in the AFOLU sector and ensure sustainable growth in the face of escalating climate impacts.

Keywords: Climate Finance, Adaptation Finance, Innovative, AFOLU, Ghana

Introduction

In the face of escalating climate challenges, Ghana's Nationally Determined Contributions (NDCs) offer a critical roadmap for addressing climate change impacts while pursuing sustainable development. However, achieving these ambitious goals requires significant financial resources, which remain elusive due to Ghana's complex economic context, including high debt burdens and limited private sector participation. The ability to secure and utilise climate finance effectively is not only essential for meeting climate targets but also for fostering sustainable growth and building resilience in key sectors, particularly the Agriculture, Forestry, and Land Use (AFOLU) sector.

Climate finance is a specific category within the broader environmental or green finance framework. Green finance encompasses funding initiatives that address various environmental challenges, including pollution reduction, biodiversity preservation, and climate mitigation efforts. In turn, green finance forms part of an even larger domain known as sustainable finance. Sustainable finance extends beyond environmental concerns to include social, economic, and governance issues. Sustainable finance reflects a holistic approach to fostering sustainability across multiple dimensions (PPIAF, 2023).

According to the United Nations Environment Programme (UNEP), green financing relies on a multi-stakeholder partnership involving governments, businesses, and citizens. Governments play a critical role by establishing regulatory frameworks, creating institutional setups, designing tariffs, and offering subsidies and guarantees to support green initiatives. Businesses contribute by providing financial investments, driving technical innovation, managing operations, leveraging local knowledge, and promoting backward and forward linkages within supply chains (UNEP, 2024). Citizens also play a key role through their willingness to pay for green initiatives and a commitment to adopt environmentally friendly lifestyles that support sustainable development. Therefore, climate finance, a component of green finance, embodies these three contributions (i.e., government or public, private or business and household or citizens).

Climate finance, which spans mitigation and adaptation efforts, is indispensable for Ghana's climate ambitions. Ghana's climate finance covers just 5% of the estimated USD 15 billion needed to implement its NDCs measures. Of this, 87% comes from public sources, while private investment constitutes only 13% (CPI, 2023). Climate finance is distributed almost equally between adaptation and mitigation, with the AFOLU sector receiving the largest share due to its critical role in the country's economy and vulnerability to climate risks. However, challenges in tracking private investments and assessing precise financial needs, particularly for adaptation, exacerbate the financing gap (CPI, 2023).

The Agriculture, Forestry, and Other Land Uses (AFOLU) sector is critical to Ghana's economy. It is a vital sector, employing about one-third of the nation's population (Ghana Statistical Service, 2021). On average, this sector contributes approximately 20% to the GDP (Ghana Statistical Service, 2023). Key outputs from the AFOLU sector, like cocoa and timber, account for an average of 19% of Ghana's merchandise exports (Bank of Ghana, 2024). Despite its importance, the sector is highly vulnerable to climate-related risks such as erratic rainfall, severe flooding, and prolonged droughts, directly threatening livelihoods and food security. Adaptation-centred investments are therefore critical to protecting this vital sector; however, current funding levels remain inadequate, especially from the private sector.

The consequences of inadequate funding for this sector are profound. Without sufficient resources, there is limited capacity to implement robust adaptation strategies, leading to heightened vulnerability to climate shocks. Smallholder farmers, who form the backbone of agricultural production, often lack access to affordable insurance, modern farming technologies, or improved crop varieties, which could help them adapt to changing climatic conditions. This inadequacy worsens poverty, reduces agricultural productivity, and weakens rural economies, with ripple effects on national food security and broader economic stability.

Given these challenges, going beyond traditional public and donor-funded instruments and exploring more innovative financing options is essential. These innovative mechanisms offer opportunities to leverage additional resources from the private sector while ensuring sustainability and scalability. This book chapter examines other innovative means of accessing climate funds to support the AFOLU sector. It explores mechanisms that enhance financial flows from the private sector and communities to bridge the gap between available resources and the investment needs of the sector. The chapter provides actionable insights for policymakers committed to building climate resilience in the AFOLU sector.

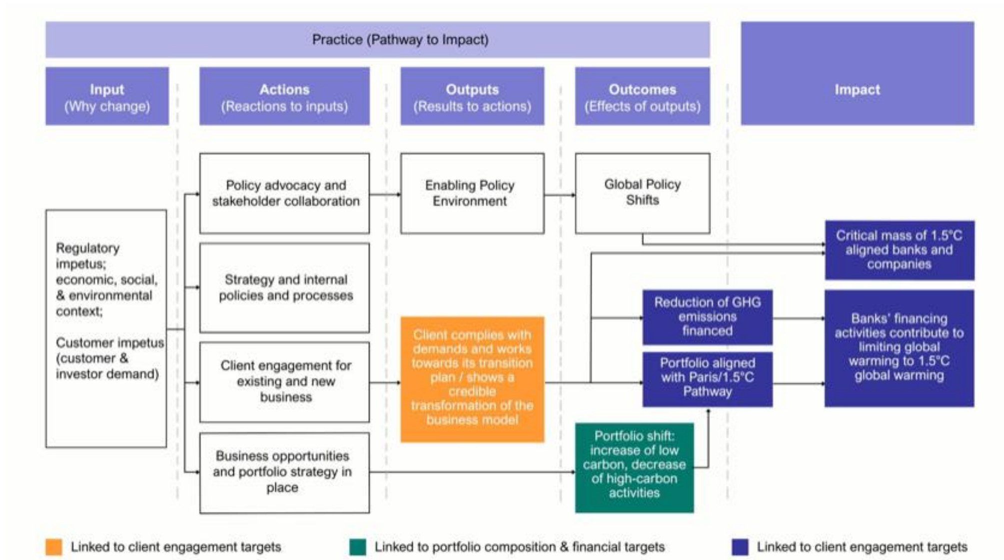
The chapter is organised into three key sections. After the introductory section, the second section provides an overview of climate finance in Ghana, highlighting key trends and gaps. It also examines the updated NDCs and the state of the AFOLU sector, emphasising its importance and vulnerabilities. The subsequent section then discusses climate adaptation measures before presenting innovative financing options for climate adaptation in the AFOLU sector. Finally, the chapter concludes with policy recommendations to enhance climate finance and strengthen Ghana's adaptation strategies.

Literature Review

Climate Finance draws on concepts from multiple disciplines, integrating insights from economics, environmental science, and development studies. Among these, the Theory of Change (ToC) has been widely used in studies on climate adaptation finance (Pringle and Thomas, 2019; Juste, 2023). Juste (2023) highlights the ToC as a robust framework for designing, implementing, and evaluating adaptation finance initiatives. It provides a structured approach for stakeholders to define long-term goals, map the steps to achieve them and establish measurable outcomes. A well-crafted ToC begins with identifying stakeholders (e.g., microfinance institutions or institutional investors) and fostering collaboration among these stakeholders to generate innovative solutions.

The theory requires a thorough analysis of climate vulnerability and its root causes, followed by mapping causal pathways that link specific activities to desired outcomes, such as promoting climate-smart loans to enhance smallholder farmers' resilience. ToC frameworks incorporate realistic assumptions, identify barriers like market competition, and set indicators to track both direct and indirect impacts, such as changes in productivity or community resilience. Communicated effectively through narratives and diagrams (see Figure 1 below), ToC acts as a blueprint for implementation and monitoring, offering a pathway to innovative financial solutions that address gaps in adaptation finance. While challenges remain, the ToC's structured approach can significantly enhance climate resilience, especially in vulnerable communities reliant on climate-sensitive livelihoods (Juste, 2023).

Figure 1: Theory of change for climate mitigation



Source: United Nations Environment Programme (2023)

Climate Adaptation Financing

Climate change adaptation means acting to reduce the risks from current or future climate impacts, such as extreme weather, rising sea levels, loss of biodiversity, and food or water shortages. These actions must happen locally, so rural areas and cities play a key role. Examples of adaptation include growing drought-resistant crops, practising sustainable farming, improving water storage, managing land to prevent wildfires, and building stronger protections against floods and heatwaves.

However, adapting to climate change faces several challenges. The first major challenge is inadequate funding. Developing countries need 10 to 18 times more adaptation finance than what is currently available from public sources. This adaptation finance is required to invest in solutions and scale up successful efforts. It is also essential to empower local communities on the frontlines of climate change to take action that suits their needs. Another challenge is the lack of information. Accurate climate data and local risk assessments are hard to find in many developing countries. Systems for monitoring and learning from adaptation efforts are still incomplete. Without this information, it is difficult for governments, communities, and businesses to plan effectively and decide where to invest. In addition, institutional and governance issues are problems. Poor coordination between government sectors, lack of expertise, and limited experience in climate-risk planning are slowing down effective adaptation in many countries.

Despite gaining more attention, adaptation and resilience are often overshadowed by mitigation in climate discussions, both in terms of focus and funding. As the impacts of climate change become more immediate and climate disasters a lived reality, the role of adaptation and resilience is growing in importance. However, the challenge of securing adequate financing persists, causing the gap in adaptation funding to widen each year. In 2021-2022, climate adaptation and resilience financing hit a record $63 billion, according to the Climate Policy Initiative, with 86% of this provided by development finance institutions (DFIs). However, this is only 20-30% of the estimated annual funding needed, expected to reach $215-387 billion in developing countries by 2030.

The international climate and adaptation finance landscape is highly complex, posing significant challenges for potential recipients seeking funding for individual projects. Navigating this landscape requires understanding different funding sources' varying characteristics, requirements, and access processes. A wide range of actors contribute to adaptation finance, spanning national, international, public, and private sectors.

According to Burmeister et al. (2019), several international sources contribute to adaptation finance. These include Multilateral Development Banks (MDBs) such as the World Bank Group (WBG), Asian Development Bank (ADB), African Development Bank (AfDB), Inter-American Development Bank (IDB), European Investment Bank (EIB), and European Bank for Reconstruction and Development (EBRD). Additionally, multilateral public funds like the Green Climate Fund (GCF), Adaptation Fund (AF), Least Developed Countries Fund (LDCF), Special Climate Change Fund (SCCF), Pilot Program for Climate Resilience (PPCR), and the Adaptation for Smallholder Agriculture Program (ASAP) play a significant role. Other important contributors include members of the International Development Finance Club (IDFC) and international organisations such as the United Nations Development Programme (UNDP), the Food and Agriculture Organization (FAO), and the International Fund for Agricultural Development (IFAD). These entities provide critical financial and technical support to enhance climate adaptation efforts globally.

Public climate finance providers include donor governments and their agencies, multilateral climate funds, and development finance institutions (DFIs). DFIs encompass multilateral development banks (MDBs), regional and national development banks (such as members of the International Development Finance Club), and other financial institutions. National governments also play a crucial role by mobilising resources at national and subnational levels through legislative measures or budgetary allocation to specific instruments like national climate funds. The private sector is another key player in adaptation finance. It includes project developers, corporate entities, households, and commercial financial institutions. Each of these actors brings unique capabilities and resources, further diversifying the potential avenues for adaptation financing. This multifaceted landscape underscores the importance of tailored approaches to align funding sources with project-specific needs and conditions (Burmeister et al., 2019).

Overview of Climate Finance in Ghana

According to the United Nations, climate finance encompasses local, national, and transnational funding from public, private, and alternative financial streams to support actions to mitigate and adapt to climate change (UNFCCC, n.d). Frameworks like the United Nations Convention for Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement emphasise the need for financial assistance from wealthier parties to those less resourced and more vulnerable. This approach acknowledges the varying contributions of nations to climate change and their differing capacities to address its causes and impacts. Significant financial investments are essential for mitigation (i.e. to achieve substantial emissions reductions) and adaptation (i.e. to manage and minimise the adverse effects of a changing climate).

According to the Climate Policy Initiative report, climate finance in Ghana was almost evenly divided between mitigation and adaptation efforts in 2019 and 2020 (see CPI, 2023). Due to the country's high vulnerability to climate change (mainly because many Ghanaian households depend on rainfed agriculture), adaptation measures play a crucial role in its climate finance strategy. Within the period under review, Adaptation finance comprised 49% ($403 million) of the total, funded mainly by public sources, while mitigation finance accounted for 47% ($386 million). Ghana's two largest greenhouse gas (GHG) emissions sources, the AFOLU and energy sectors, received over 53% of the country's total climate finance. The AFOLU sector, driven mainly through public investment, accounted for 28% (USD 235 million) of total climate finance, the highest among all sectors (CPI, 2023).

In the same period (i.e. 2019/2020), adaptation funds were primarily directed toward the AFOLU sector (32%), followed by cross-sectoral projects (30%), and water and wastewater management (28%). Mitigation finance was largely focused on the energy sector, which received 51% ($197 million), followed by AFOLU ($86 million) and cross-sectoral initiatives ($63 million). Mitigation finance in Ghana was distributed through a wider variety of financial instruments, with grants (38%), concessional debt (28%), and balance sheet financing and debt (27%). Adaptation finance, on the other hand, relied primarily on grants (53%) and concessional debt (42%). Attracting private capital to adaptation projects is crucial to boost adaptation finance. This requires developing bankable projects and improving the business environment to facilitate international financial flows, creating favourable conditions for private investment (World Bank, 2022).

Ghana's Updated Nationally Determined Contribution

Ghana's Updated Nationally Determined Contribution under the Paris Agreement (2020-2030) was introduced in 2021, aiming to build a resilient society that can withstand the impacts of climate change while also contributing to reducing global emissions. As part of this strategy, Ghana has outlined 19 policy actions in 10 priority areas to meet its Nationally Determined Contribution (NDC) goals over the next decade. These actions include 13 adaptation and 34 mitigation programs to benefit economic growth and environmental sustainability (Ministry of Environment, Science, Technology and Innovation [MESTI], 2021).

The 19 policy actions are expected to accelerate sustainable energy transitions, build resilient economies and societies, improve early warning and disaster risk management, enhance landscape restoration, promote responsible production and consumption, foster social inclusion focusing on youth and women, and create smart and safe communities. By 2030, Ghana aims to achieve significant results through these policy actions. These include reducing greenhouse gas (GHG) emissions by 64 million tons of CO2 equivalent (MtCO2e), preventing at least 2,900 premature deaths each year by improving air quality, creating over one million decent and green jobs, and benefiting the citizenry, particularly youth and women (MESTI, 2021).

The 13 adaptation measures are split into seven unconditional and six conditional programs. For the 34 mitigation measures, Ghana plans to implement nine unconditional programs to reduce GHG emissions by 8.5 MtCO2e by 2025 and 24.6 MtCO2e by 2030 compared to baseline emissions. Additionally, Ghana could implement 25 conditional programs if financial support from international and private sectors is secured, potentially achieving a further 16.7 MtCO2e reduction by 2025 and 39.4 MtCO2e by 2030. The best way to make the nationally determined contribution (NDC) effective and improve the lives of vulnerable people is by removing institutional, policy, and financial barriers. Thus, the updated NDC must fully support government policy goals, be managed by strong national institutions, and have enough funding and technology from international and private sectors (MESTI, 2021).

According to the Ministry of Environment, Science, Technology and Innovation (2021), Ghana needs between US$ 9.3 and US$ 15.5 billion to carry out its 47 nationally determined contribution (NDC) measures from 2020 to 2030. Of this amount, US$ 3.9 billion is required to implement 16 unconditional programs by 2030. The remaining US$5.4 billion for 31 conditional programs will be raised from public, international, and private sector sources and carbon markets. Additionally, Ghana will need an extra US$ 3 million every two years to support the coordination and international reporting of its NDC.

The AFOLU Sector

Agriculture, Forestry, and Other Land Uses (AFOLU) denote how people use and manage land. This sector is closely studied in climate science and policy because of its impact on global greenhouse gas emissions. The guidelines from the Intergovernmental Panel on Climate Change (IPCC) divide AFOLU into two main parts: one related to emissions from land use and forestry (called “Land Use, Land-Use Change, and Forestry" or LULUCF) and the other related to emissions from farming. The IPCC's Sixth Assessment Report states that the AFOLU sector accounts for about 22% of global greenhouse gas emissions. The Agriculture, Forestry, and Other Land Use (AFOLU) sector includes managed ecosystems and offers many opportunities to reduce environmental impact. It provides essential resources like food, wood, and other renewable materials while also helping to protect biodiversity if it adapts to climate change.

The AFOLU sector is crucial for meeting the Paris Agreement goals because it produces nearly a quarter of global human-caused greenhouse gas emissions (CO_2, CH_4, and N_2O) while being very sensitive to climate change (IPCC, 2019b). Reducing emissions and adapting to climate change are essential to achieving the Paris Agreement's temperature and adaptation goals (UNFCCC, 2016). The AFOLU sector is already highly vulnerable to climate impacts like droughts and floods, and this will worsen as the climate warms, especially if temperatures rise beyond 1.5°C above pre-industrial levels (Hoegh-Guldberg et al., 2018; Jia et al., 2019). Many ecosystems and populations are already suffering from climate impacts, and the risks to both will increase as climate change progresses, with some systems reaching their limits to adapt (Hoegh-Guldberg et al., 2018).

Funding for Africa's AFOLU sector must significantly increase to ensure food security. The AFOLU sector has Africa's highest adaptation finance needs, requiring at least USD 49 billion between 2021 and 2030, with most of the demand coming from Central and West Africa (CPI, 2022a). AFOLU is Africa's second-largest source of greenhouse gas (GHG) emissions and one of the most vulnerable sectors to climate change. Hence, building resilient agricultural systems is crucial for securing food for all Africans and requires substantial climate financing.

Innovative Climate Financing Options for Ghana's AFOLU Sector

This section employs a desk review method to explore innovative financing options for climate adaptation in Ghana's AFOLU sector. The analysis draws on diverse and reputable sources, including academic publications, policy reports, and case studies from international organisations such as the United Nations Environment Programme (UNEP), the World Bank, and the Climate Policy

Initiative (CPI). The reviewed materials were selected to focus on financing mechanisms applicable to developing countries, ensuring that the options identified are contextually relevant to Ghana.

Climate adaptation and resilience are becoming more important in climate change discussions but require greater financial support. The good news is that new and innovative financing tools, such as disaster risk, catalytic, and outcome-based instruments, are emerging. However, these tools are still in the early stages. While investors and development banks are beginning to adopt them, much more effort is needed to make these solutions widely available and close the significant funding gap for adaptation and resilience.

This section outlines some key forms of innovative climate adaptation and resilience financing instruments, each offering new ways to attract capital from the private sector, institutional investors, impact investors, and philanthropists. While some of these tools are still in their early stages, they have great potential to drive significant investments in climate adaptation.

Disaster risk instruments

Disasters, driven by the intensity of extreme weather events, are among the critical consequences of climate change. Various climate policy indices highlight Africa as one of the regions most vulnerable to these impacts. In 2020, Ghana ranked 109 out of 181 countries according to the University of Notre Dame Global Adaptation Initiative's [ND-GAIN] Index (Chen et al., 2024). Given this vulnerability, disaster risk instruments are essential to provide the necessary financial resources to address the impacts of climate change, enabling countries like Ghana to build resilience and respond effectively to climate-induced disasters.

According to the Boston Consulting Group (2024), disaster risk instruments provide rapid financial support to help organisations, governments, and individuals plan for climate-related disasters. Examples include parametric insurance products and regional insurance pools, which help scale up the use of insurance in climate adaptation. These tools provide quick liquidity when specific disasters, such as hurricanes or floods, occur, assisting communities to recover faster. Another example is catastrophe bonds, which are high-yield debt instruments that share the financial risk of climate-related disasters and can be accessed when certain catastrophic events happen. A newer tool, climate-resilient debt clauses, allows countries to pause their loan repayments if a climate disaster hits them. This approach gives them temporary financial relief in times of crisis. In late 2023, the World Bank expanded these clauses, allowing vulnerable countries to defer loan payments during climate disasters, providing crucial support that was previously unavailable.

In 2018, the African Development Bank established the Africa Disaster Risk Financing Programme (ADRiFi) to enhance resilience and response to climate-related shocks by improving the management of climate disaster risks. The fund received about $100 million in contributions from donors such as Canada, the United Kingdom, Switzerland, Norway, the Netherlands, and the United States. The MDTF has since provided financial protection to millions in 16 countries exposed to climate risks like droughts, cyclones, and floods. The program has promoted ex-ante climate risk management by encouraging governments to allocate domestic budgets toward climate risk financing while strengthening regional risk pools managed by the African Risk Capacity.

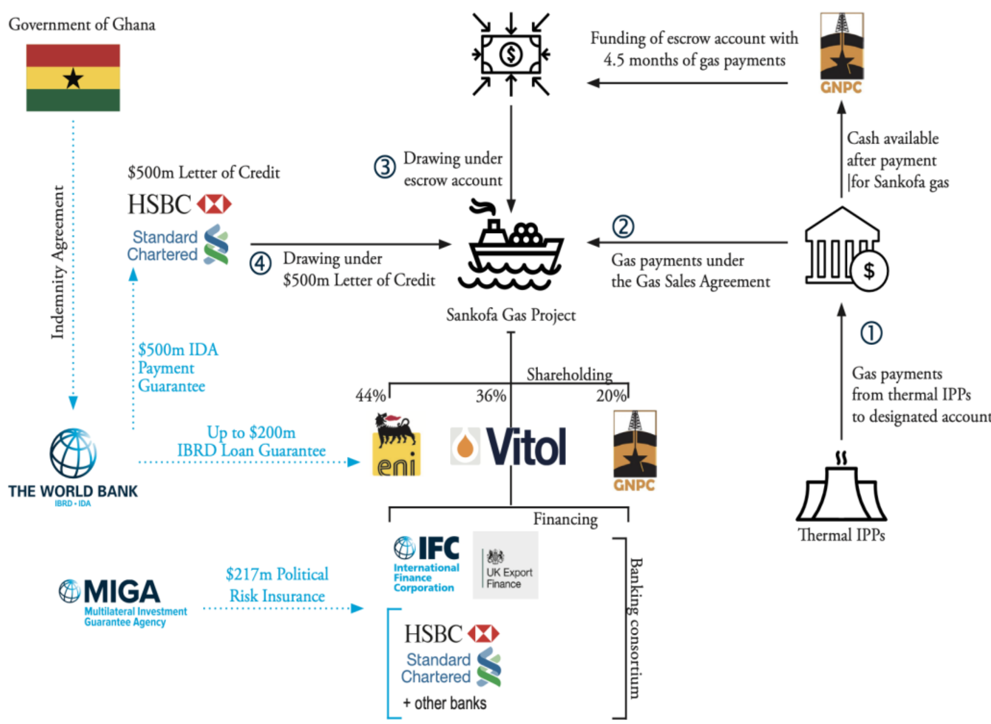
Disaster risk instruments will be crucial for Ghana's AFOLU in providing financial mechanisms to mitigate the impacts of climate-related disasters such as droughts, floods, and extreme weather events. Insurance products and contingent credit facilities can offer timely payouts to farmers, forest managers, and other stakeholders, enabling them to recover quickly and sustain their operations. Additionally, financial packages can incentivise the adoption of drought-resistant crops or agroforestry practices. These tools build financial resilience and contribute to sustainable land use and carbon sequestration, aligning with Ghana's commitments to climate adaptation and mitigation under its Nationally Determined Contributions (NDCs).

Catalytic Instruments

Catalytic instruments are designed to attract commercial capital by combining them with concessional capital, which reduces the financial risks for commercial investors. One example is risk guarantees, where institutions like multilateral development banks (MDBs) promise to cover loan repayments if borrowers default due to specific reasons, such as a government failing to meet its financial obligations.

These guarantees give commercial lenders the confidence to invest in projects with higher risks, such as those focused on climate adaptation. Ghana has successfully utilised such guarantees for several high-value investments, although they are not strictly climate adaptation initiatives. For instance, the $7.9 billion Sankofa Gas Project, a major investment paid for through revenues generated from gas-powered electricity, highlights the effectiveness of guarantees in securing funding. In this case, the World Bank supported the project with approximately $700 million in guarantees, including a $500 million IDA payment guarantee and a $200 million IBRD loan guarantee.

Figure 2: Guarantee Structure of Ghana's Sankofa Gas Project



Source: World Bank (2018)

It is equally important to ensure that such projects are designed to generate sufficient value to cover their costs and minimise drawdowns on the guarantees by investors. Excessive drawdowns could signal weaker creditworthiness on the part of the government, potentially limiting its ability to access further credit from capital markets or institutional investors. Therefore, incorporating mechanisms that enhance project viability and long-term value creation is critical to leveraging these guarantees effectively and sustaining access to financial markets for future initiatives.

Another example of a catalytic instrument is pooled investment funds, which bring together money from different sources. These funds then invest in projects with clear climate adaptation and resilience goals, dividing the investment into varying levels of risk and return to suit various investors. This approach helps mobilise more private sector involvement in climate finance.

These financing tools could be deployed to unlock finance for Ghana's AFOLU sector, which remains central to Ghana's climate adaptation and mitigation agenda yet often struggles to attract commercial investment due to high perceived risks and long investment horizons. Catalytic instruments such as risk guarantees and blended concessional loans could improve the bankability of AFOLU-related projects by absorbing early-stage risks and incentivising private sector participation. For example, a development bank or climate fund could provide a partial risk guarantee to a commercial lender financing a forest landscape restoration or a sustainable cocoa farming project. This guarantee will cover potential losses if the project underperforms due to natural events or market fluctuations.

However, to ensure a successful application and avoid misuse of catalytic capital, several safeguards must be in place:

1. **Project Viability**: Projects should demonstrate a credible path to generating returns, either through monetisable co-benefits (e.g., carbon credits, sustainable timber, certified organic produce) or significant cost savings over time. This requirement does not preclude adaptation-focused projects from receiving support. Instead, it emphasises that projects that demonstrate multiple benefits are particularly attractive to investors.
2. **Policy and Institutional Stability**: For catalytic finance to be adequate in the AFOLU sector, investors need a predictable and secure operating environment. AFOLU projects, such as afforestation, agroecology, or sustainable land management, often require long time horizons to become profitable or deliver measurable climate and environmental

benefits. When catalytic instruments are applied in a stable environment, the blended finance structure becomes more effective since the underlying risks are lower and more predictable. Conversely, in unstable settings, even concessional finance may struggle to attract commercial players.

Outcome-based instruments

Outcome or results-based instruments focus on rewarding projects for achieving specific, measurable outcomes, often tied to long-term climate objectives such as reducing greenhouse gas (GHG) emissions. Unlike traditional market-based instruments that require loan repayments, results-based instruments provide funding without repayment obligations as long as beneficiaries meet agreed-upon targets. In climate finance, these mechanisms aim to achieve verified and sustained reductions in GHG emissions, contributing to global and national climate goals.

One notable example of the outcome-based mechanism is the carbon markets. These markets enable the trade of carbon credits, representing verified emissions reductions from specific projects or activities. Entities that reduce emissions below their targets can sell excess credits to those who need them to meet regulatory or voluntary obligations. Carbon markets incentivise emission reductions and provide financial support for initiatives like reforestation, renewable energy projects, or improved agricultural practices.

Ghana's efforts to leverage carbon markets under the Article 6 Framework present a significant opportunity to drive sustainable development within the AFOLU sector. The Ghana Carbon Market Office, established to support the country's participation in international carbon markets, reports receiving 35 project requests in 2023, with nine successfully onboarded onto the Ghana Carbon Registry (GCR). This registry manages critical data and activities related to carbon markets and ensures transparency in implementing carbon finance mechanisms. Two onboarded projects have received formal authorisation, including an initiative in the AFOLU sector focused on sustainable rice cultivation.

Beyond rice cultivation, carbon markets can support reforestation, agroforestry, and improved livestock management projects, aligning economic incentives with environmental benefits. For example, the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program leverages carbon markets as a key mechanism to finance efforts to reduce greenhouse gas (GHG) emissions while promoting sustainable forest management and enhancing community livelihoods.

Other outcome-based measures include Debt-for-nature swaps, which enable countries to alleviate their debt burdens by achieving specific conservation or environmental protection targets. Under these agreements, a portion of a country's debt is forgiven or restructured in exchange for commitments to implement tangible conservation efforts, such as protecting forests, restoring ecosystems, or enhancing biodiversity. This approach provides financial relief and ensures measurable environmental outcomes, aligning monetary incentives with sustainable development goals.

Another example of outcome-based climate finance is the Adaptation Benefits Mechanism (ABM) introduced by the African Development Bank. This mechanism rewards projects that achieve verified adaptation results, such as improved resilience to climate impacts or enhanced food security, by providing financial credits. These credits increase the bankability of adaptation projects, making them more attractive to investors and fostering broader participation in climate resilience initiatives. Debt-for-nature swaps and mechanisms like the ABM exemplify how linking finance to measurable results can drive progress toward long-term climate and environmental objectives.

Market-based debt

Market-based debt is a common tool used to raise adaptation finance worldwide. These are financing mechanisms that are raised through loans at prevailing interest rates. Market-based debt is usually sourced from commercial banks, institutional investors or the bond market. According to the latest data from CPI, market rate debt at the project level made up USD 37.5 billion (59%) of average annual adaptation funding in 2021–2022, an increase from USD 24.2 billion (46%) in 2019–2020.

A key example of market-based debts for climate action is the green bonds. Green bonds and other bonds like the Eurobonds are similar in form. For instance, they are both fixed-income securities, are accessible to international investors, and provide periodic coupon payments based on the agreed interest rate. On the other hand, green bonds typically adhere to standards like the Green Bond Principles, which provide some guidelines on the framework for green bonds. The Green Bond principles work on four major components – (1) use of proceeds, (2) process for market evaluation and selection, (3) management of proceeds, and (4) reporting.

Table 1: Key Components of the Green Bond Principles

Component	Description
Use of Proceeds	Proceeds from green bonds must be exclusively applied to finance or refinance eligible green projects (e.g. renewable energy, energy efficiency, pollution prevention and control, clean transportation, etc.)
Process for Project Evaluation and Selection	o Green Bond issuers should communicate to investors the overall environmental objectives, project eligibility determination processes, and methods for identifying and managing social and environmental risks. o Issuers are encouraged to align project information with their broader sustainability goals, official market-based taxonomies, and green standards or certifications. o A risk mitigation process should address potential social and environmental impacts, including trade-off analysis and monitoring where significant risks are identified.
Management of Proceeds	o Net proceeds from a Green Bond must be allocated to a specific account or portfolio linked to eligible Green Projects, ensuring distinct management and proper use. o Issuers should regularly update proceeds allocation and disclose how unallocated funds are temporarily managed or invested. o To enhance trust, issuers should use external auditors or third parties to verify fund tracking and allocations, ensuring transparency and proper oversight.
Reporting	o Issuers must provide annual updates on using Green Bond proceeds until full allocation, including a project list, descriptions, allocated amounts, and expected impacts. o Issuers should use qualitative and, where feasible, quantitative performance indicators, disclosing methodologies and assumptions used in the determination

Source: International Capital Market Association (2022)

Debt-based instruments, such as bonds and loans, will remain vital in financing climate adaptation projects, providing essential capital to address the increasing impacts of climate change. However, leveraging debt-based instruments is a significant responsibility to ensure debt sustainability. For countries like Ghana, which recently underwent a debt exchange program to address severe fiscal challenges, the prudent and transparent utilisation of net proceeds from bonds and other debt instruments is critical. An ineffective management of these funds could exacerbate existing debt burdens, undermining economic stability and progress toward climate adaptation goals.

Conclusions and Policy Recommendations

Ghana's updated Nationally Determined Contributions outline 47 measures aimed at achieving both adaptation and mitigation goals, with a significant focus on the agriculture, forestry, and other land use (AFOLU) sector due to its vulnerability to climate change and importance to the economy. To bridge the funding gap, innovative financing instruments such as disaster risk tools, catalytic instruments, and outcome-based mechanisms could play a critical role by attracting private capital and ensuring financial sustainability in climate adaptation efforts.

This chapter highlights a range of innovative climate financing instruments available for Ghana's AFOLU sector, demonstrating that climate action can be financed through mechanisms beyond traditional grant funding. These instruments provide diverse options to mobilise resources while addressing specific climate-related challenges and opportunities in the sector.

For example, disaster risk instruments play a critical role by hedging the government against the financial impacts of climate-induced disasters, ensuring rapid response and recovery. Catalytic instruments, such as guarantees, attract private investors by mitigating risks and enhancing the viability of climate action projects. Outcome-based instruments, mainly through carbon markets, facilitate the transfer of verified mitigation outcomes, enabling Ghana to capitalise on its sustainable practices. Market-based mechanisms, such as green bonds, integrate debt financing to fund large-scale projects for mitigation and adaptation.

A notable aspect of climate financing is the flexibility to combine different instruments rather than relying on them individually. Blended finance schemes allow for integrating various mechanisms, such as grants, disaster risk instruments, catalytic guarantees, and market-based options like green bonds or carbon markets. This approach leverages each instrument's strengths to create comprehensive and effective solutions for addressing climate-induced challenges, ensuring broader participation and maximising impact.

To address the climate adaptation financing gap in Ghana's AFOLU sector, the government should prioritise the following:

1. **Mobilising Private Capital**: The Ministry of Finance, in collaboration with the Ministry of Environment, Science and Technology, as well as the Environmental Protection Agency should implement blended finance frameworks that attract private-sector investments by reducing risks and enhancing returns. This approach will make climate-related projects in the AFOLU sector more appealing to investors. Additionally, the government should establish mechanisms like green bonds and guarantees to mobilise private capital by offering secure and purpose-driven investment opportunities.
2. **Enhancing Project Development and Attractiveness**: The Ghana Investment Promotion Centre (GIPC) and the Ministry of Finance, working with sector-specific agencies like the Forestry Commission and Ministry of Food and Agriculture, should lead the development of bankable, investor-ready projects. These entities must work to ensure that these projects meet the criteria of international financiers and institutional investors. This approach will enhance funding opportunities and demonstrate commitment to advancing climate action and sustainability in the AFOLU sector.
3. **Building Local Capacity**: The Bank of Ghana and the Ghana Association of Banks, with support from the Ministry of Finance should lead targeted capacity-building initiatives for local financial institutions. These initiatives should focus on equipping financial institutions with the skills expertise to structure, finance, and manage climate adaptation projects, while encouraging collaboration with private sector actors to build long-term local competence.
4. **Foster an enabling regulatory environment:** The Ministry of Finance, working closely with MEST, EPA, and financial regulatory bodies such as the Securities and Exchange Commission (SEC), should establish clear, transparent regulations to streamline access to climate finance. Coordination with international finance providers should also be institutionalised to improve investment flows and build investor confidence in Ghana's AFOLU sector.

5. **Promote Sound Governance Principles:** The Ministry of Finance, in collaboration with the Parliament of Ghana and oversight bodies like the Auditor-General's Office, should ensure that governance frameworks for climate finance uphold debt sustainability and economic stability. Climate financing strategies should include safeguards to monitor borrowing, manage risks, and align funding with national development priorities.

References

Boston Consulting Group (2024). Climate adaptation and resilience needs more innovative funding - here's how to design financing to unlock it. Available at https://www.weforum.org/stories/2024/02/climate-adaptation-and-resilience-innovative-funding/

Burmeister, H., Cochu, A., Hausotter, T., & Stahr, C. (2019). Financing Adaptation to Climate Change: An Introduction. *Adelphi, Berlin*.

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., & Chawla, N. (2024). University of Notre Dame global adaptation index. *University of Notre Dame*.

CPI (2022b). Methodology for Landscape of Climate Finance in Africa. Climate Policy Initiative (CPI). Retrieved from: https://www.climatepolicyinitiative.org/wp-content/uploads/2022/09/Methodology-l-Landsc ape-of-Climate-Finance-in-Africa-1.pdf

CPI (2022c). Climate Finance Needs of African Countries. Climate Policy Initiative (CPI). Retrieved from: https://www.climatepolicyinitiative.org/wp-content/uploads/2022/06/Climate-Finance-Needs-of-African-Countries-1.pdf

CPI (2023) Climate Finance in Ghana. Retrieved from: https://www.climatepolicyinitiative.org/wp-content/uploads/2023/12/Climate-Finance-in-Ghana.pdf

CPI. (2022a). The State of Climate Finance in Africa: Climate Finance Needs of African Countries. Available at:

https://www.climatepolicyinitiative.org/wp-content/ uploads/2022/06/Climate-Finance-Needs-of-African-Countries-1.pdf

Ghana Statistical Service (2021). Ghana 2021 Population and Housing Census. Volume 3E: Economic Activity.

Hoegh-Guldberg, O. et al. (2018) 'Chapter 3: Impacts of 1.5°C global warming on natural and human systems. In: Global Warming of 1.5 °C. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways [...]', Special Report, Intergovernmental Panel on Climate Change, (ISBN 978-92-9169-151-7), pp. 175–311.

International Capital Market Association (2021). *Green Bond Principles: Voluntary Process Guidelines for Issuing Green Bonds*. ICMA Group. Paris.

IPCC (2019b) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick,. doi:10.4337/9781784710644.00020.

Jia, G. et al. (2019) Chapter 2: Land–climate interactions, Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmot.

Juste, M. (2023). Climate Smart Adaptation: From Theory to Practice. Scale for Resilience Nature Based Solutions. Available at https://www.scaleforresilience.global/climate-smart-adaptation-finance-from-theory-to-practice/

MESTI. (2021). Ghana: Updated Nationally Determined Contribution under the Paris Agreement (2020 – 2030) Environmental Protection Agency, Ministry of Environment, Science, Technology and Innovation, Accra.

PPIAF (2023). GI Hub Explainer: Climate Finance. Available at https://www.gihub.org/articles/gihubexplainerclimatefinance/#:~:text=Climate%20finance%20is%20a%20subset,support%20pollution%20reduction%20or%20biodiversity.

Pringle, P., & Thomas, A. (2019). Climate adaptation and theory of change: making it work for you. *Clim Analytics Retrieved*, *26*.

UNEP (2023). Theory of Change for Climate Mitigation. Available at https://www.unepfi.org/wordpress/wp-content/uploads/2022/09/14-Theory-of-Change-for-Climate-Mitigation-D1_JD.pdf

UNEP (2024). Green Financing. Available at https://www.unep.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-financing

UNFCCC (2016) 'Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015', in Environmental Policy and Law. Bonn, Germany: United Nations Framework Convention on Climate Change (UNFCCC)., pp. 71–75. Available at https://unfccc.int/sites/default/files/resource/docs/2015/cop21/eng/10a01.pdf.

UNFCCC (n.d). Introduction to Climate Finance. Available at https://unfccc.int/topics/introduction-to-climate-finance

World Bank (2021). Climate Risk Country Profile: Ghana. World Bank Group. Retrieved from: https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15857-WB_Ghana%20Country%20Profile-WEB.pdf

9

How much is enough? Understanding the Sustainable Financing Model of Green Businesses in Developing Countries – Focusing on Green Enterprises in Ghana

Dennis Asare, Mohammed Abubakari and Mudasiru Mahama

Abstract

Despite the enormous green growth opportunities in developing countries, significant challenges exist in mobilizing the necessary financing to scale up local green solutions and mitigate the impact of climate change. This issue has attracted scholarly and policy interest in green financing. However, to date, green financing studies have paid little attention to understanding the form and structure of financing suitable for scaling up green ventures and solutions, especially in emerging economies like Ghana. The overarching aim of the chapter is to understand the structure of a sustainable financing model for green businesses in developing economies like Ghana. Through a desk literature review, this chapter adopts the business model framing by Richardson (2008) and Bocken et al. (2014) and green business archetypes by Boon and Ludeke-Freund (2013) and Bocken et al. (2014) to explain the sustainable financing model for green business ventures in emerging economies like Ghana. The analysis reveals that grants and debt financing instruments are more suitable for green businesses in their early development stages. Additionally, a combination of capital market and results-based financing instruments becomes valuable to green firms as they build sustainable financial positions and demonstrate supportive cash flow through an improved customer base. As green businesses mature, they are exposed to diverse financing instruments available. Thus, how much is enough largely rests on the business's development stage and the risk it can accommodate. This chapter recommends that government policies be designed to provide incentives that minimize their cost of operations, create demand for green products and services, and de-risk green business investments in emerging countries like Ghana.

Keywords: SMEs, Sustainable Financing, Climate Change

Introduction

Climate change presents far-reaching global consequences (e.g. high temperatures, erratic rainfall, natural catastrophes, etc.), with developing countries being the most vulnerable. Consequently, these concerns have sparked widespread interest across multiple sectors, including business and finance, which have traditionally prioritized profit maximization (Bocken et al., 2014; Schaper, 2002). Addressing climate change requires a comprehensive approach that includes adaptation, mitigation, and resilience. Achieving the climate action goal requires a deliberate and strategic investment in sustainability to ensure harmony between economic activities and environmental stewardship (United Nations Environment Program (UNEP, 2015).

Businesses have increasingly become more interested in Environmental, Social, and Governance (ESG) concerns (Nedopil et al., 2021). This interest has resulted in the widespread mainstreaming of ESG practices into corporate strategies and investor portfolios via investments in green assets and interventions (Florea and Morales, 2021). Additionally, many countries worldwide, particularly in developed economies, have made substantial commitments to sustainability by introducing policies to reduce emissions, achieving carbon neutrality, and allocating substantial funds for a green economic transition (Yu, Liu, and Chen, 2023). These efforts have contributed to the rapid growth of green enterprises worldwide.

Green enterprises, whether established firms or startups, prioritise environmental protection by implementing sustainability-focused projects or initiatives (Yuan et al., 2020) such as clean energy, climate-smart agriculture, circular waste management and so forth. While these enterprises are crucial in advancing sustainable development, their operations often demand significant financial resources (Yu, Liu, and Chen, 2023). However, many developing countries have constrained fiscal space for broader economic growth, let alone for investments in green projects and enterprises (Bhattacharyya, 2022; Pindiriri and Kwaramba, 2024). Consequently, green businesses whose viability depends on access to financing face significant financial barriers, especially in developing countries in Africa where funding options for such businesses remain limited (He and Liu, 2018).

Evidence from the literature shows green businesses and startups in Africa encounter significant financial barriers in sustainability interventions (Fonta, Ayuk, and van Huysen, 2018). While various business financing models have emerged in developed and emerging economies across Europe, North America, Asia, and South America to fund green actions, this trend is not mirrored in most African countries. Addressing this issue is crucial for green businesses and startups to secure the necessary funding to operate, innovate, and expand their sustainability solutions.

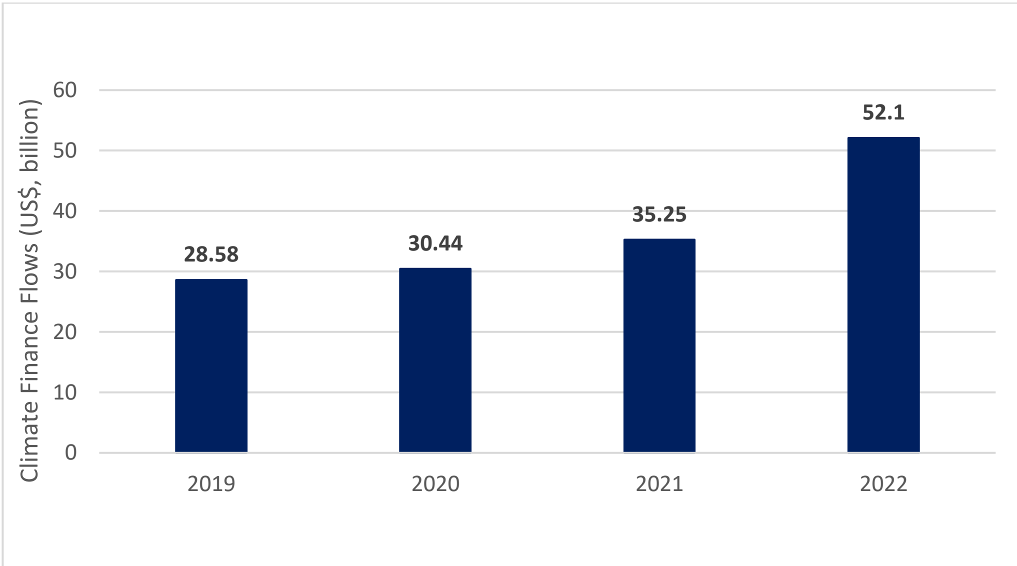
Although the importance of green finance is widely acknowledged, academic and policy discourse on financing models for green enterprises in Africa remains relatively limited. This chapter, therefore, seeks to synthesize available literature on green business financing in Africa with a specific contextual focus on Ghana. It aims to (i) examine the business models of green enterprises and solutions, (ii) identify the range of financing mechanisms employed across different points in the business value chains, (iii) develop a theoretically grounded framework to guide the selection of suitable financing models for scaling local green solutions, and (iv) assess the implications for climate change and just transition policymaking.

The subsequent sections of the chapter focus on a review of literature on the state of green financing in Africa (Section 2), the methodology showcasing how the literature findings were gathered (Section 3), the results and discussions which involve understanding business model and types of green businesses, and the sustainable financing model for green business in developing countries, taking into account the policy implications (Section 4); and conclusion and policy recommendations (Section 5).

Literature Review

Countries in Africa have been making efforts towards green financing, although it is still in its early stages. Between 2019 and 2022, climate finance flows in Africa averaged about $36.5 billion. Between 2020 and 2030, the continent must raise about $2.3 trillion to fund various commitments to implement its Nationally Determined Contributions (NDCs) initiatives. Of this amount, 10 per cent is expected to be financed through public resources (i.e. from governments). In contrast, domestic and foreign private sectors are expected to cover the remaining 90% (about $2 trillion) (Guzmán et al., 2022).

Figure 1: Climate Finance Flows in Africa



Source: Climate Policy Initiative (2024)

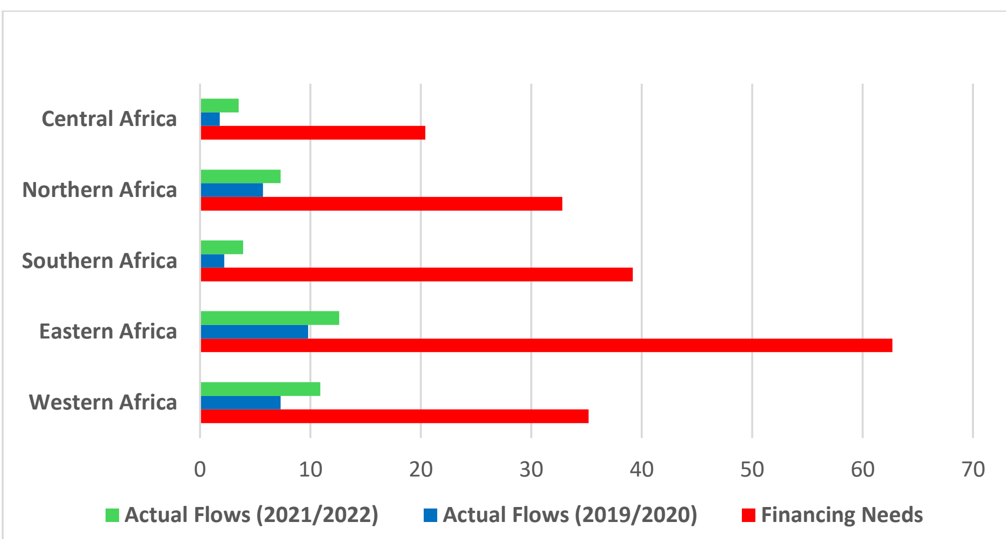
Innovative finance is being experimented throughout Africa; examples include Nigeria's financing of green bonds and Uganda's crowdsourcing of renewable energy (Dia, 2019). Furthermore, some nations have obtained funds from international multilateral institutions, such as the Green Climate Fund (GCF). For example, Zambia secured a $2.2 million grant from the GCF to support the development of its National Adaptation Plan. Morocco also received a $40 million package to build agricultural resilience.

Despite the widespread efforts of African countries to combat climate change, the lack of access to climate finance at a large scale continues to be one of the most significant obstacles (Dia, 2019). A survey conducted by Africa Climate Week revealed that over half of the countries in Africa have encountered challenges in mobilising international and national climate finance. Additionally, less than one-quarter of the countries have implemented a financing strategy, and only one-third have implemented financial instruments. Nevertheless, two-thirds of the countries have initiated the implementation of their NDCs, and approximately 80% have begun the implementation of mitigation and adaptation measures to attain the NDCs.

Countries like Nigeria, South Africa, and Kenya have seen significant expansion in their green bond markets (Turner, 2014). South Africa established the Green Fund to support its transition to a green economy by providing catalytic finance for project initiation, policy development, and capacity-building initiatives (Mohamed et al., 2014). Similar funds were established in Africa, such as the Environmental Investment Fund of Namibia and Maurice Ile Durable in Mauritius (Mohamed et al., 2014). In 2016, the Nigerian government established a Green Bonds Framework that issued the country's first green bonds in 2017, attracting over 10.6 billion Naira ($34.67 million), which was used to finance the Energising Education Project, Rural Electrification Project, and the Afforestation Project (Fonta et al., 2018; The New Practice, 2019).

Generally, policymakers and stakeholders in Sub Saharan Africa are investigating funding sources for climate action that their countries may not have heavily utilised in the past. Four main schemes have drawn immediate interest as potential government funding sources. In certain situations, these funding streams may also be utilised for private sector adaptation and mitigation initiatives: (1) Concessional finance, especially through climate funds; (2) partially climate-related debt instruments; (3) global carbon credit programs; and (4) insurance policies relating to climate change (International Monetary Fund, 2022).

Figure 2: Estimated climate finance needs in Africa by region USD



Source: Climate Policy Initiative (2024)

Nigeria and Morocco are the two African countries that have created national programs for green finance (Kitakogelu, 2022). The Johannesburg Stock Exchange in South Africa established a specific green market niche. Kenya's capital market authorities and the Nairobi Securities Exchange have also collaborated to establish green bond guidelines. Blue and green bonds have been announced for issuance by Seychelles and Namibia, respectively. Mauritius and Gabon have also developed national roadmaps for financing green bonds.

In other parts of Africa, the green capital market is taking shape (Kitakogelu, 2022). In 2020, the Egyptian government and Standard Bank of South Africa issued two African green bonds up to $800 million and $200 million, respectively. These two issues together account for 53% of all African issuances as of 2020 (Lemma et al., 2021). Between 2014 and 2020, Sub-Saharan African countries issued bonds targeted at green projects. The funds issued were primarily used for financing projects in water, energy, transportation, energy buildings, conservations, etc. South Africa and Nigeria are the major issuers, with total values of $625.6 million and $136.6 million respectively (Tyson, 2021). Kenya raised about $40.9 million for building projects (Tyson, 2021).

Despite these developments, African countries have encountered difficulties accessing the Green Climate Fund (GCF). This fund was established to assist developing countries in mitigating the effects of climate change, planning for them, and financing the shift to a green economy. The minimal readiness support provided to African countries and their heavy reliance on International Accredited Entities (IAEs) presents an enormous barrier. African countries are less able to develop institutions and obtain direct access to the Fund (Fonta et al., 2018). Fonta et al. (2018) claim that because Africa has lower acceptance rates for ready support requests than other regions, there is a considerable disparity between the finance needs of African countries and their access to GCF resources.

Coordinated efforts are required to address both supply and demand-side constraints to financing. On the supply side, strengthening domestic capital markets, improving regulatory clarity around what constitutes “green” investments, and enhancing disclosure standards are critical. On the demand side, building institutional capacity, improving access to direct climate finance channels, and regional collaboration can enable African countries to better mobilise resources. Ultimately, the expansion of green finance in Africa will depend on the availability of capital and the enabling ecosystem that supports it. Robust policy frameworks, technical capacity, and alignment with international climate finance standards are essential to ensuring that Africa's green transition is inclusive, well-financed, and responsive to national development priorities.

Methodology

This analysis is a desk study of key literature related to the concept of green business models contextualised from the perspective of green financing in developing countries like Ghana, where the investment risk is considered high, and access to finance is challenging. The catalogue of literature on green business models was sourced from mainstream academic databases, including Elsevier, Scopus, Web of Science, Google Scholar, and Emerald. The academic databases were complemented by development partners' reports, such as the Africa Green Business and Finance Report by the United Nations Development Programme. The review was carried out in four steps, as Moher et al. (2009) proposed: literature identification, screening, inclusion and exclusion eligibility, and use of eligible literature. Keywords such as green enterprises, green financing, sustainability financing, green ventures and solutions, and so on were utilised to identify literature by combining them in a phrasal form and, in some instances, contextualising them to meet the Ghana, Africa, and developing country setting.

Over 100 publications were initially identified, including scholarly and policy-related materials. These publications were evaluated mostly by reading the abstracts and introductions to determine their relevance to the chapter. Based on this, approximately 80 papers were deemed suitable, offering a mix of empirical, practical, conceptual, and theoretical insights into green financing, green enterprises, and sustainability. The decision to use literature materials was based on relevance and synergy with the chapter's objectives. This integration allowed for the mobilisation of thoughts that are not only theoretically relevant but also policy workable.

The green business model by Richardson (2008) and Bocken et al. (2014) was adopted to explain the concept of the green business model. Additionally, the green business archetype models by Boon and Ludeke-Freund (2013) and Bocken et al. (2014) were adopted to explain the different types of green businesses. Richardson (2008) and Bocken et al. (2014) provide the key tenets of explaining the business model – *the value proposition, value creation and delivery system, and value capture*.

These building blocks help to distinguish between a green business model and a traditional brown business model. Similarly, Boon and Ludeke-Freund (2013) and Bocken et al. (2014) framework provide the basis for understanding the different types of businesses that can emerge from the business models explained using Richardson's (2008) framing of the business model. The key distinguishing factors depend on how the business uses technology, organisational systems, and strategy to achieve green business objectives. Finally, the business stages of development by Churchill and Lewis (1983) and the Climate Policy Initiative (2022) innovative green financing models in Africa were used to explain the sustainable financing for green businesses in Ghana.

Results and Discussions

Understanding the Business Model and Types of Green Businesses

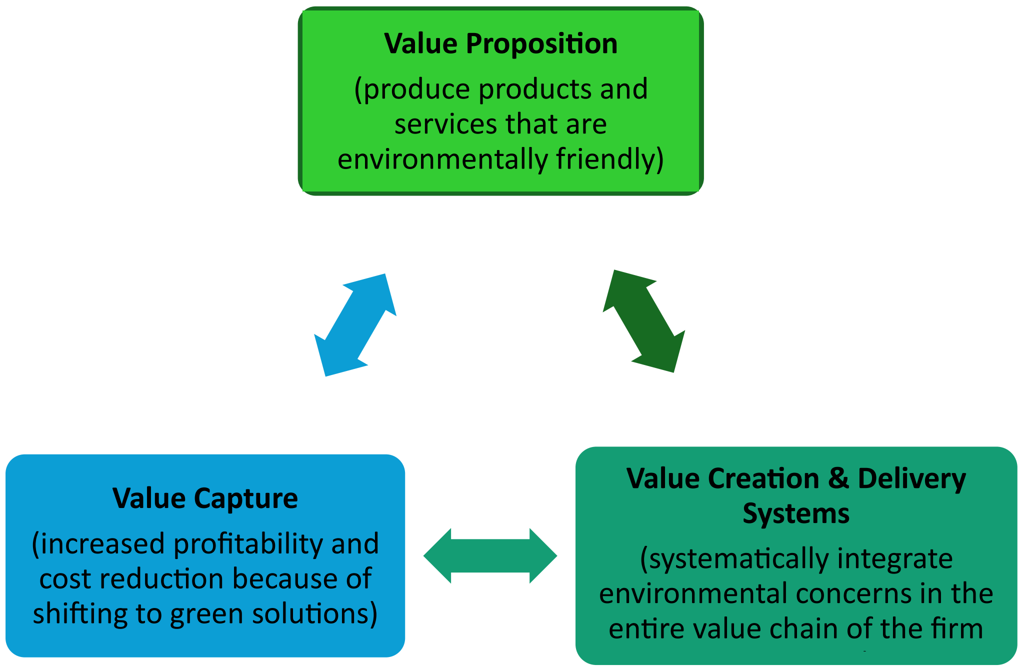
Responding to the climate crisis requires a shift towards sustainable production and consumption systems that maximise resource efficiency and increase the utilisation of renewable energy resources (Bocken et al., 2014; Jackson, 2009; Agrawal et al., 2024; Stern, 2007). Thus, how businesses meet consumers' needs must reflect the environmental transformations. Business innovations require the rethinking of the concept or purpose of the firm beyond profit maximisation to include social and environmental impact, which is at the heart of green businesses (Bocken et al., 2014). Porter and Kramer (2011) and Stubbs and Cocklin (2008) argue that matured enterprises can integrate sustainable practices into their business models by rethinking them. New businesses can pursue green or sustainable business model practices from the onset. The iterations to business models to respond to environmental and social concerns are the surest pathway to achieve the transformations in production and consumption that respond effectively to the climate crisis.

Even though the concept of a green or sustainable business model is not new, it has received much attention in the literature across several disciplines. This attention has contributed to several definitions of the concept and its application. Nosratabadi et al. (2019), examining the concept of a sustainable business model, identified that the number of documents published annually on the concept of a sustainable business model has significantly increased from two in 2017 to about 74 by 2022 across a wide range of journals presenting diverse perspectives to understanding sustainable business model. Also, the terms green and sustainable business have been used interchangeably in most literature. Other studies have argued that green business covers every aspect of sustainable development. Hence, the two terms can be used interchangeably (Sarkis et al., 2013; Molenaar and Kessler, 2017). In this analysis, the terms green and sustainable business will be used interchangeably but will have the same meaning.

Richardson (2008), examining the extant literature on business models, concludes that the business model consists of three main components – the value proposition, value creation and delivery system, and value capture, as briefly explained. **Value proposition** refers to the products or services the firm offers, the segment of customers it targets and the relationships between the firm and customers. **Value creation** and delivery systems encompass the key resources used by the firm, activities, technology, and channels used to reach its customers. The **Value capture** relates to the cost and revenue structure of the firm. For this analysis, the business model refers to the perfect blend of a firm's value proposition, value creation and delivery system, and value capture. Zott and Amit (2010) simplify the business model as what (activities undertaken), how (the structure within which the activity takes place) and who (the actors performing the activity) of a firm's operations. The value proposition, value creation and delivery system, and value capture distinguish a green or sustainable business from a traditional business.

With this understanding of a business model, a green business model can be explained as one that goes beyond profit maximisation to include environmental and social goals in the production and service delivery to customers. Fora (2010) explains that a business can be considered green if its products and services have environmental benefits, reduce or reuse waste, and are economically viable. Thus, achieving environmental and social benefits is at the heart of green or sustainable businesses. Moreover, green business models can refer to brown businesses introducing environmentally friendly solutions into their business practices (Nordic Innovation, 2012). Integrating green solutions and practices in the business process demonstrates a firm's commitment to minimising the environmental impact of its operations. The business transformations that minimise the environmental impact of a firm's operations on the environment can be explained as green business innovations (Bocken et al., 2014). Garetti and Taisch (2012) simplify green or sustainable business models as models that preserve the environment and maintain the quality of human life.

Figure 3: The Concept of Green Business Model



Source: Bocken et al. (2014) and Richardson (2008)

Using Richardson’s (2008) business model definition, a green business's value proposition is to produce ecologically friendly products and services and minimise the use of non-renewable resources. A green business's value creation and delivery systems will focus on an operational system that relies on renewable resources, reduces waste, and other business innovations that ensure efficient resource maximisation across the entire value chain. The value capture of a green business will focus on increased revenues and cost reduction through adopting environmentally sustainable processes. Boons and Ludeke-Freund (2013) add that environmental and social impacts are considered when designing the financial model of sustainable businesses. Simply put, green business models are business practices that are environmentally friendly across every aspect of the value chain. A summary of the three concepts is presented in Table 1 below:

Table 1: Value proposition, creation and capture in green businesses

Component	Definition	Green business context	Examples
Value Proposition	The core offering of the business that delivers value to a defined customer segment by solving a specific problem or meeting a need.	Articulates a green enterprise's unique environmental and socio-economic benefits to its target customers, investors, or stakeholders. It highlights the problem addressed, the target beneficiaries, and why it is worth investing in.	**Nature of problem**: unreliable electricity access **Sustainable solution offered**: decentralised renewable energy. **Intended beneficiaries**: Targeting low-income communities. **What makes it worth investing:** Contributing to climate action and energy access
Value Creation	The processes, resources, and activities used to develop and deliver the value proposition to customers.	Involves internal capabilities and external collaborations that ensure the green solution is impactful, scalable, and aligned with sustainability goals.	- Leveraging partnerships (e.g., with NGOs, donors) - Deploying clean technology - Building local capacity for sustainable implementation
Value Capture	Mechanisms through which a business converts created value into financial returns or measurable benefits.	For green businesses, value capture is more complex than in traditional enterprises due to the inclusion of non-market benefits. These businesses rely on a combination of traditional revenue models, policy instruments, and innovative financing options	- Revenue from selling clean energy products - Accessing carbon credits or green bonds - Receiving subsidies or results-based finance

As the literature on green businesses grows, it becomes difficult to distinguish green businesses because all sustainable businesses prioritise environmental sustainability. Boon and Ludeke-Freund (2013), from the work of Wirth (2011), provide three main streams of distinguishing between green businesses. Wirth (2011) recognised that the type of technology, organisational structure, and firm strategy are key factors for distinguishing between business models**.**

Applying the three factors to green businesses, Boon and Ludeke-Freund (2013) developed different types of green businesses across several disciplines and business operations. They explained that a firm's technology can maximise its eco-friendliness and enhance its ability to meet the social needs of its stakeholders. Additionally, the firm can be structured to reduce waste, cut costs, and improve overall firm efficiency to achieve its environmental goals, and the firm's broader strategy can be used to repurpose its business model to achieve environmental sustainability.

Using these three factors, Boon and Ludeke-Freund (2013) produced eight (8) key archetypes of green businesses. **Technology-oriented** green businesses typically seek to maximise material and energy efficiency, create value from waste, and substitute with renewable resources and natural processes. The **organisational-oriented** green enterprises seek to deliver functionality rather than ownership. It allows customers to explore the vast functional benefits of a product, adopt a stewardship role in the sense of being conscious of its stakeholders' social and environmental concerns, and encourage eco-efficiency. These businesses undertake solutions that encourage customers to pursue sustainable consumption. **Strategy-oriented** green businesses seek to repurpose the firm's focus towards social and environmental benefits and develop solutions that maximise their operations' social and environmental benefits to stakeholders (See Table 2).

This analysis focuses on understanding the sustainable financing model of clean energy and climate-smart agriculture businesses. These businesses fall under the technology-oriented archetypes of green businesses, mainly creating value from waste and substituting it with renewable energy and natural processes. Clean energy businesses utilise renewable energy resources such as solar, wind, and hydrogen fuel technologies as the main energy source for producing and delivering value to consumers. Similarly, climate-smart agricultural businesses utilise technologies to harness natural processes to support agrarian practices. They focus mainly on restorative and regenerative processes in their agricultural processes.

Table 2: Types of Green or Sustainable Businesses

Type of Green Business	Focus

A. Technology	
1. Maximise material and Resource Efficiency.	- Increase resource efficiency by minimising the use of fossil fuels and reducing resource consumption. **E.g.,** Hydrogen-fuelled industrial processes and solar-powered manufacturing.
2. Create value from waste	- Increase the circularity of products and keep materials in the closed loop. - Prioritise the principles of circular economy in their operations. **E.g.,** waste recycling companies.
3. Use renewable and natural processes.	- Substitute fossil fuels for renewable energy resources. - Use natural processes rather than non-renewable resources. **E.g.,** e-mobility companies.
B. Organisational	
4. Deliver functionality rather than ownership	- Offer customers the opportunity to use products instead of owning them. - Customers pay to use the products but do not have to own them **E.g.,** pay-per-use companies like Amazon web services and car-sharing firms.
5. Adopt a stewardship role	- Engage companies to ensure their business activities amplify their stakeholders' environmental and social needs. **E.g.,** consumer care and bio-diversity advocates.
6. Encourage Efficiency	- Encourage sustainable consumption practices. - Reduce resource consumption through reduced consumption. **E.g.,** slow fashion businesses and reuse companies.
C. Strategy	
7. Repurpose business for society and the environment	- Use firm strategies to shift focus towards their stakeholders' environmental and social concerns. E.g., non-profit organisations that advocate eco-friendly practices
8. Develop scale-up solutions	- Facilitating and supporting the scaling up of green solutions. **E.g.,** incubators and green innovation hubs.

Source: Boon and Ludeke-Freund (2013) and Bocken et al. (2014)

Determining the Sustainable Financing Model for Green Businesses in Developing Countries

The green business ecosystem is nascent and less understood, increasing the perceived risk associated with green businesses in countries like Ghana. Consequently, most green businesses in developing countries remain small (Boston Consulting Group, 2022). Addressing the financing constraint for green businesses requires an understanding of the business model of green companies and the suitable financing strategies that can support their scalability. This section focuses on identifying the key issues that influence the suitability of a financing model for green businesses. It focuses on clean energy technologies and climate-smart agriculture.

These focus areas have been selected because they are Africa's main drivers of greenhouse gas emissions. For instance, the energy sector, including transportation, accounts for about 73% of greenhouse gas emissions, whereas agriculture, forestry and land use (AFOLU) and waste management account for 18% and 3% respectively (African Development Bank, 2020). Transforming innovations in these sectors towards green business models remains the surest pathway to addressing the climate crisis in Africa.

While the climate finance landscape provides a picture of the scarcity of financial flows to support green innovations, it does not provide a complete picture of the extent of green finance demand in developing countries (UNDP, 2024). This phenomenon exists because some of the estimates of climate finance are only based on the government's estimates of the finances needed to implement their programmed mitigation and adaptation solutions. Secondly, although the climate finance landscape consists of many instruments, it is difficult to understand the financing instruments suitable for green businesses, considering the different sizes and scales of operation. Additionally, it is possible to lose sight of the firm-level financing needs and assume that the available financing instruments are supportive and sustainable for green businesses in developing countries like Africa. This section of the analysis explores the common financing instruments for green businesses in Africa and critically reviews the literature to identify the key factors determining the type of financing instrument suitable for green businesses.

Common Financing Instruments for Green Businesses in Africa

There is a wide range of financial instruments to support green businesses in Africa in scaling up innovation and overcoming barriers to accessing finance. Broadly, the financing instruments can be grouped into public and private resources. Given the constraints with domestic and international public finance resources, a greater share of financing for green businesses would have to come from the private sector. Nonetheless, some public financial resources can be used to de-risk green businesses and crowd in private sector finance (Climate Policy Initiative, 2022). Additionally, the range of financing instruments can be categorised into unlisted instruments, capital market instruments, risk mitigation guarantees, results-based financing instruments, structured finance instruments, and non-financial instruments (UNDP, 2024).

The **unlisted financial** instruments are financing sources not traded through public exchange markets. They can take the form of debt, equity, venture and other forms of loans. Typically, these instruments are used by development finance institutions. Common unlisted financial instruments include grants, equity and debt instruments. Unlisted debt and equity instruments are payable, which means the firms that receive them are expected to pay them through a loan or equity arrangement. However, grants are provided for businesses to undertake specific functions that may benefit the public.

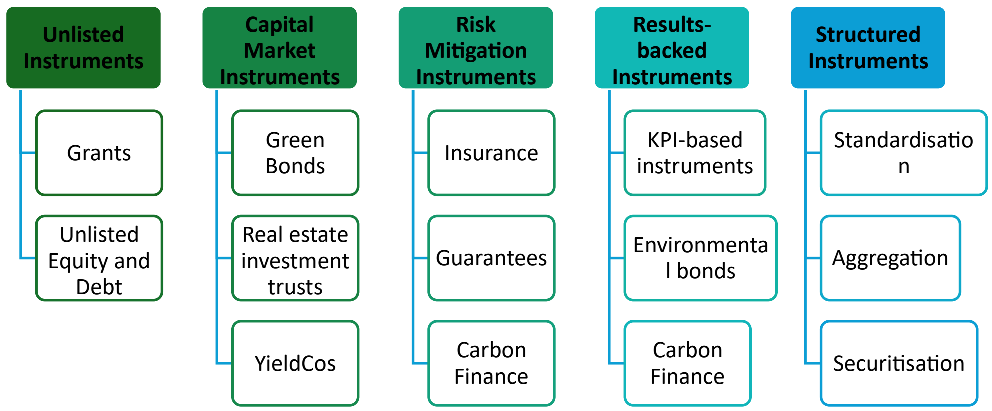
Capital market instruments are traded in public exchange markets to raise financing from various investor groups. In most cases, capital market-oriented instruments expand the scope of reach of businesses because they can source finance from different categories of investors, like institutional investors. Key examples include thematic bonds and loans, real estate investment trusts, and *yieldcos* (Climate Policy Initiative, 2022). Thematic bonds and loans are fixed-income instruments whose proceeds are used to finance specific projects that have social and environmental benefits (UNDP, 2024). Typical examples include green bonds, social bonds, and orange and blue bonds. Real estate investment trusts are companies that own, finance, and operate income-producing real estate assets whose incomes are mainly shared with shareholders. They operate like mutual funds, allowing people to invest in high-paying real estate assets. Given that they hold and own high assets, they have become one of the target sources of financing, especially for businesses engaged in green building solutions (Climate Policy Initiative, 2022). *YieldCos* are local currency instruments used to mobilise finance to invest in renewable energy projects. Even though they are new in Africa, they represent almost half of the financing in green infrastructure (OECD, 2020).

Results-based financing instruments are green finance solutions that link access to finance to key performance indicators (KPIs). Typical examples include environmental bonds, KPI conditional financing instruments, and, to some extent, carbon finance (Climate Policy Initiative, 2022). These solutions require the businesses to reach some performance standards before they can access financing. Additionally, they can be unlocked after satisfying a set of conditionalities. Unlike the KPI conditional financing and environmental bonds linked to specific outcomes, the carbon finance instruments allow businesses to trade avoided emissions for financial resources to invest in the business (Climate Policy Initiative, 2022).

Risk mitigation financial instruments are typically designed to address real or perceived investment risks in a specific sector or country (Climate Policy Initiative, 2022). They are primarily designed to de-risk and prevent a wide range of barriers to accessing finance. Examples include currency hedging instruments, insurance, and guarantees. Currency hedging instruments address the local currency risk that can affect investment returns when local currency financing is unavailable. Insurance and guarantees are designed to respond to risks such as political risk, war and conflict, and natural disasters. These instruments help to de-risk a project or the country, making it more attractive to investors.

Structured financial instruments are designed to remove certain types of risk that may discourage high-risk-averse investors. Instruments like standardisation, securitisation, and aggregation help to reduce any potential risk associated with a project or an entire sector. For instance, standardisation instruments like power purchase agreements assure the purchase of power from the project, and aggregation can help bring together small-scale projects with similar terms and make them commercially viable compared to selling them as individual projects.

Figure 4: Existing Green Business Financing Sources in Africa



Source: Climate Policy Initiative (2022), UNDP (2024)

How Much is Enough? – Linkages between Green Business Growth and Financing Sources

Green Business Development Stages and Common Challenges Associated with Clean Energy and Climate-Smart Agriculture Enterprises

The relevance of a financing instrument to a business depends on several factors, including the size and scale of green business operations and peculiar financial barriers encountered by the business (Green-WIN, 2016; Climate Policy Initiative, 2022). Essentially, the type of financing utilised by a green business must adequately support its ability to meet its economic viability, as well as social and environmental concerns, which are at the heart of the business model of green businesses (Bocken, 2015).

Most green businesses in developing countries like Ghana tend to be small and medium-scale enterprises (SMEs) (Boston Consulting Group, 2022). SMEs are at the centre of production and consumption in developing countries and are key targets for sustainable business innovations (Bocken, 2015). This analysis adopts Churchill and Lewis's (1983) model of small business stages of development to explain the stages of green business development, the potential financing barriers they may face, and the most suitable financing instruments for overcoming finance barriers. Churchill and Lewis (1983) explain that small businesses go through six main stages of development. The stages are existence, survival, success-disengagement, success-growth, take-off, and resource maturity. Each stage presents different management and financing needs, which must inform the type of financing sources green businesses should pursue. These stages are explained in Table 3.

The analysis further explores common challenges that clean energy and climate-smart agricultural businesses face. It maps them to the development stages and the most relevant financial instrument that can address the challenges. Clean energy investments like renewable energy tend to have high upfront costs, several regulatory certifications, and long-term revenue horizons and require secured local infrastructure and a ready market to purchase power outputs to be economically viable (International Energy Agency, 2022; Climate Policy Initiative, 2022). However, due to the weak energy sector planning in countries like Ghana, clean energy investments face multiple risks. Some of the common challenges identified in the literature concerning clean energy investments in developing countries like Ghana include regulatory barriers, market risks (ready market, currency risk and high interest rate), technology risks, financing constraints, and local infrastructure challenges (access to land and grid) (International Energy Agency, 2022; Climate Policy Initiative, 2022; AfDB, 2018; McKinsey, 2020; McKenzie, 2018). These challenges are corroborated by the Energy Commission's review of Ghana’s renewable energy policy as constraints renewable energy businesses are likely to face (Energy Commission, 2015).

Most farmers in Ghana operate small-scale agriculture, and thus, green businesses in climate-smart agriculture are likely to face challenges with high upfront capital due to low farm output and the high cost of aggregating smallholder farmers (Climate Policy Initiative, 2022; Chatham, 2019). Other common challenges identified in the literature include land tenure security, currency risk, supply chain risk, low revenue, extreme weather effects, and local infrastructure constraints such as roads, electricity, data and information service, and low-capacity workforce (Chiriac, 2020; ISF, 2019; Mazza, 2021; Skendzic et al., 2021).

Table 3: Key stages of SME business growth and implications for green businesses

Stage	Description / Focus	Challenges	Implications for Green Businesses
Existence	- Acquiring customers - Delivering contracted products/services.	- Low consumer awareness - Limited seed funding - Unproven business models - Poor cash flows - High cost of inputs	- Need to prove the viability of green solutions - Awareness-creation and venture capital funding are critical.
Survival	- Business model becomes clearer - **Goal:** break even or generate cash flow to support growth. - Financial position is improved but still fragile.	- Difficulty scaling due to limited market penetration - High operating costs - Difficulty accessing working capital - Uncertain policy support.	- Opportunity to showcase the financial, environmental and social benefits of products and services **E.g.** A solar energy startup might now be able to track and report on electricity access and carbon offsets. -
Success	- Focuses on consolidating gains to either maintain the business or scale. - Decision point for introducing joint ventures and other shareholders.	- Need for impact verification - Difficulty in securing permits and agreements as proof of ready market - High cost of financing - Challenges with local infrastructure	- Opportunity to scale proven green models or deepen impact in existing markets.
Success – Disengagement	- Business is stable and profitable. - Owner steps back, and professional teams are engaged to manage operations.	- Risk of mission drift; - Difficulties in institutionalising sustainability values - Difficulty in building professional capacity in green finance and operations.	- Transition from founder-led to institution-led business allows for more strategic partnerships in green businesses. - Enables green businesses to evolve from passion-driven initiatives into influential actors within larger climate action and sustainable development ecosystems.
Success – Growth	- Owner consolidates and strategically invests in growth. - Stable cash flow and profitability.	-	- Capacity to invest in advanced sustainability technologies and expand impact.
	-	-	-

Table 3: Key stages of SME business growth and implications for green businesses (Cont'd)

Stage	Description / Focus	Challenges	Implications for Green Businesses
	-	- Difficulty in maintaining profitability while scaling - Difficulty in attracting suitable growth-stage financing - Difficulty aligning growth with climate and social impact outcomes.	-
Take-off	- Rapid growth phase. - Focus on strengthening systems and sourcing finance for expansion	- Managing operational complexity - Accessing large-scale finance - Sustaining ESG performance amid rapid expansion.	- Strong potential to tap into global climate finance, green bonds, and blended finance models.
Maturity	Consolidation and control of financial gains achieved through growth.	- Risk of complacency; - Staying competitive as new green entrants emerge - Continual impact reporting and compliance updates.	- Opportunity to lead in the green sector; influence policy, markets, and value chains.

Reflections on the Green Business Development Stages and the Relevant Financing Instruments

The enterprise has limited customers at the existence and survival stages of green business development; hence, cash flow and profits are not strong. At this stage, they are concerned about the upfront cost of technology and the regulatory barriers, market risk, exchange rates, and local infrastructure constraints that increase the cost of operations. **Financial instruments that are easily accessible, with low interest rates and opportunities for long-term financing and refinancing options, will be relevant for green businesses.** For example, grants, unlisted debt, and equity offered by development partners, and non-financial instruments like capacity building will be helpful for these businesses. For instance, grants and low-interest rate loans can help address the short-term financing need for renewable and climate-smart agriculture businesses to deal with the upfront cost (Climate Policy Initiative, 2022). Also, unlisted equity would provide long-term financing and refinancing opportunities to avoid over-reliance on initial capital and cushion them as they seek to expand.

At the success stage, the business has built sufficient financial health and demonstrated economic viability. They have many customers and expanded operational capacity, including the necessary management systems. The main concern of the business at this stage is to find opportunities to grow by accessing new markets and growing its customer base. In the case of renewable energy businesses, this would be the stage where they have enough household customers and may want to build large projects and supply direct grid electricity while increasing the number of households they can reach. For a climate-smart agriculture business, this is the stage where they have aggregated enough smallholder farmers, reached a wider network of consumers, and invested in their supply chains.

As highlighted in Table 3, key challenges include securing competitive financing, regulatory permits and power purchase agreements. At this stage, the business has demonstrated viability and thus can go to the capital market. **Hence, instruments that provide long-term financing and refinancing options, results-based instruments, and risk mitigation would be relevant.** For example, renewable energy companies could use *yieldcos*, real estate investment trusts, bonds, KPIs, and carbon finance to undertake their long-term expansions while limiting the cost of borrowing. For a climate-smart agricultural business, financing instruments linked to risk mitigation against climate change and results-based instruments would be beneficial.

The take-off and maturity stages are quite like the success stages; however, they focus more on consolidating the growth strategies and deepening their market reach. At these final stages, the business is more concerned with growing and taking up more projects on its portfolio. The key concerns include expansion, growing their financial health, and minimising the exposure to risk in the market. **The main financing need will be instruments to finance their long-term growth strategies**. Capital market and risk mitigation financial instruments will be more useful at these stages because they offer long-term financing and refinancing opportunities for the business to consolidate its growth. By this time, the green business would gather enough evidence and results to benefit from results-based instruments like carbon finance, environmental impact bonds, and KPIs.

While this section attempts to map the business stage of development against relevant financial instruments, the instruments are not exclusive to one stage of business development. The analysis recognises that a business may be in the maturity stage. However, grants may be relevant for dealing with fundamental challenges unrelated to its growth and profitability. For example, grants can be leveraged to enhance the skills and capacity of its workers. The analysis concludes that *how much is enough* largely depends on a company's development stage, which also influences how much financing it can take up to scale its operations. The sustainable financing model a green business may adopt largely depends on its stage of development.

Table 4: Green Business Development Stages and Relevant Financial Instruments

Category of Financing Instrument	Type of Financing Instrument	Stages of Green Business Development Stage		
		Existence and Survival Stage	Success Stage (Disengagement & Growth Stage)	Take-Off and Maturity Stage
Unlisted Financial Instruments	Grants			
	Debt			
	Equity			
Capital Market Instruments	Green Bonds			
	Real Estate Investment Trusts			
	YieldCo's			
Results-based Financing Instruments	Key Performance Indicator Lending			
	Environmental Bonds			
	Carbon Finance			
Risk Mitigation Instruments	Currency-hedging Instruments			
	Guarantees			
	Insurance			
Structured Finance	Standardisation			
	Aggregation			
	Securitisation			

Source: Author's Construct adapted from Climate Policy Initiative (2022) and Churchill and Lewis (1983)

Conclusion

This chapter sought to understand the sustainable financing models for green businesses in developing countries like Ghana. Enormous green business opportunities exist, but access to finance remains a challenge. It attempts to understand how the green business model and stages of green business development, which are typically overlooked in the literature, can influence the financing sources accessible to green businesses. The study concludes that unlisted financial instruments like grants, low-interest rate debt, and equity are sustainable financing approaches for green businesses in their existence and survival stages, which are the foundational stages of green business.

Furthermore, the range of financial instruments available to green businesses increases as the business builds substantial cashflows and demonstrates profitability. Green businesses in their intermediate stages (success stages) can access more innovative financing, including capital market instruments, result-based mechanisms, and risk mitigation instruments. Such financial solutions are more long-term and support the refinancing of activities. As green businesses mature, they can access and combine innovative financing to support their growth. Thus, *how much is enough* largely depends on the business's development stage.

Green businesses are at the heart of Ghana's climate resilience and transition towards a low-carbon economy. Their business models do not only deliver economic viability but enormously support social and environmental sustainability. However, they face significant barriers from policy to financing, which increases the risk associated with their business models. Policy tools are critical starting points for minimising their risk and improving their access to finance. The following policy reflections are recommended.

1. **At the existence and survival stages of green business development, government policies must attempt to simplify regulatory procedures and reduce administrative barriers that cause delays and increase business costs.** Green business models are expensive because they require high upfront capital and take relatively longer periods to build a substantial customer base. As a result, they take relatively longer to build stable cash flow and profitability. The role of policy is to reduce barriers to establishment and increase their access to incentives.
2. **Government policy must provide incentives to reduce their upfront capital.** For example, the government can leverage its share of the Green Climate Fund and Global Environmental Facility to provide grants to viable green solutions to reduce their upfront cost. For instance, sovereign funds like the Minerals Income Investment Fund and other state-owned enterprises can take equity in viable green businesses to build the credibility of their innovations, which can serve as a key lever for attracting private investments. Also, more national SME support schemes must be directed towards green businesses in their foundational stages.
3. **Government policies must be designed to create demand for green products and services to incentivise the sector.** For instance, policies related to carbon taxes must be properly designed and implemented in such a way that they make the use of renewable energy products

profitable. Additionally, the government can implement purchase guarantee programmes with green businesses like climate-smart agriculture for products purchased by the National Buffer Stock Company and second-cycle institutions to stimulate demand from green businesses to enhance their profitability. Such programmes can serve as guarantees for green businesses to access financing. When green businesses can demonstrate positive cash flow and profitability, it opens them to a wide range of financing solutions.

4. **Government policies must lead to building the necessary infrastructure that facilitates** measuring and certification of emissions reductions. This approach allows green businesses to secure results-based financing like carbon finance.
5. **Ghana's Nationally Determined Contributions must be accompanied by clear policy guidelines** that help green businesses understand how their innovations fit the national climate ambitions and the level of incentives the government is willing to provide to support their scalability. Clear policy guidelines communicate to investors the readiness and supportiveness of the business environment for green solutions. This is important for minimizing perceived investment risk. Green policymaking in Ghana should aim to remove barriers that increase investment risk in green innovations and create more incentives to support their scalability.

References

AfDB. (2018). African Economic Outlook 2018. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/African_Economic_Outlook_2018_-_EN.pdf

African Development Bank. (2020). Drivers of Greenhouse Gas Emissions in Africa – Focus on Agriculture, Forestry and Other Land Use. https://blogs.afdb.org/climate-change-africa/drivers-greenhouse-gas-emissions-africa-focus-agriculture-forestry-and-other

Agrawal R., Agrawal S., Samadhiya A., Kumar A., Luthra S., and Jain V. (2024). Adoption of Green Finance and Green Innovation for Achieving Circularity: An Exploratory Review and Future Directions. Geoscience Frontiers, Vol. 15(4). https://doi.org/10.1016/j.gsf.2023.101669

Aller, C., Herrerias, M. J., & Ordóñez, J. (2018). The effect of financial development on energy intensity in China. *The Energy Journal*, *39*(1_suppl), 25-38. https://journals.sagepub.com/doi/abs/10.5547/01956574.39.SI1.call

Batrancea, I., Batrancea, L., Maran Rathnaswamy, M., Tulai, H., Fatacean, G., & Rus, M. I. (2020). Greening the financial system in USA, Canada and Brazil: A panel data analysis. *Mathematics*, *8*(12), 2217. https://www.mdpi.com/2227-7390/8/12/2217

Beattie, V., Smith, S. (2013). Value creation and business models: refocusing the intellectual capital debate. Br. Acc. Rev. http://dx.doi.org/10.1016/j.bar.2013.06.001

Bhattacharyya, R. (2022). Green finance for energy transition, climate action and sustainable development: overview of concepts, applications, implementation and challenges. *Green Finance*, *4*(1), 1-35. https://www.aimspress.com/article/id/61b72862ba35de53d6ee0d3d

Bocken N.M.P. (2015). Sustainable Venture Capital – Catalyst for Sustainable Start-up Success?, Journal of Cleaner Production (2015), doi: 10.1016/j.jclepro.2015.05.079

Bocken, N. M., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. Journal of Cleaner Production, 65, 42-56. https://www.sciencedirect.com/science/article/pii/S0959652613008032

Bocken, N., Short, S., Rana, P., Evans, S. (2013). A Value Mapping Tool for Sustainable Business Modelling. Corp. Gov. 13 (5), 482e497.

Bocken, N.M.P., Short, S.W., Rana, P & Evans S. (2014). A Literature and Practice Review to Develop Sustainable Business Model Archetypes. Journal of Cleaner Production 65, pp. 42-56.

Boons, F. and Lüdeke-Freund, F. (2013). Business Models for Sustainable Innovation: State of the Art and Steps Towards a Research Agenda, Journal of Cleaner Production, Vol. 45, 9-19.

Boons, F. and Lüdeke-Freund, F. (2013). Business Models for Sustainable Innovation: State-Of-The-Art and Steps Towards a Research Agenda. Journal of Clean. Prod. 45, 9e19.

Boston Consulting Group. (2022). Strategies for Scaling Africa's Green Ventures. Strategies for Scaling Africa's Green Ventures (bcg.com)

Čekanavičius, L., Bazytė, R., and Dičmonaitė, A. (2014). Green Business: Challenges And Practices. Ekonomika 2014 Vol. 93(1). https://doi.org/10.15388/EKON.2014.0.3021

Chiriac, D. and Naran, B. (2020). Examining the Climate Finance Gap for Small-Scale Agriculture. Retrieved from: https://www.climatepolicyinitiative.org/wp-content/uploads/2020/11/Examining-the-Climate-Finance-Gap-in-Small-Scale-Agriculture.pdf

Climate Policy Initiative. (2022). Climate Finance Innovation in Africa. Climate_Innovation_Finance_for_Africa.pdf (climatepolicyinitiative.org)

Dia, A. M. (2019). How Africa can improve the mobilization of climate finance for sustainable development? UNDP. https://www.undp.org/africa/blog/how-africa-can-improve-mobilization-climate-finance-sustainable-development

Energy Commission. (2015). Renewable Energy Policy – Gaps and Opportunities. Renewable-Energy-Policy-Review-Identification-of-Gaps-and-Solutions-in-Ghana.pdf (energycom.gov.gh)

Falcone, P. M., & Sica, E. (2019). Policy pathways for green finance in biomass production: The case of Italy. *Economics and Policy of Energy and the Environment*, (2018/2). https://www.francoangeli.it/riviste/Scheda_rivista.aspx?IDArticolo=64071

Florea, A., & Morales, N. (2021). Green financing: A look at the history and the options available for developers. Bechtel. https://www.bechtel.com/newsroom/blog/green-financing-a-look-at-the-history-and-the-options-available-for-developers/

Fonta, W. M., Ayuk, E. T., & van Huysen, T. (2018). Africa and the Green Climate Fund: Current challenges and future opportunities. *Climate policy*, *18*(9), 1210-1225. https://www.tandfonline.com/doi/abs/10.1080/14693062.2018.1459447

Fonta, W. M., Ayuk, E. T., & van Huysen, T. (2018). Africa and the Green Climate Fund: current challenges and future opportunities. Climate Policy, 18(9), 1210–1225. https://doi.org/10.1080/14693062.2018.1459447

FORA. (2010). Green Paper - Green business models in the Nordic Region - A key to promote sustainable growth.

Garetti, M., Taisch, M. (2012). Sustainable manufacturing: trends and research challenges. Prod. Plann. Control 23 (2e3), 83e104.

Global Centre on Adaptation, (2023). New Research Shows Africa Needs Ten-Fold Increase in Funding for Climate Adaptation. Available here: https://gca.org/news/new-research-shows-africa-needs-ten-fold-increase-in-funding-for-climate-adaptation/#:~:text=Africa%20only%20received%20%2411.4%20billion,new%20research%20estimates%20it%20needs.

Green-WIN. (2016). Green growth and win-win solutions for sustainable climate action. https://green-win-project.eu/sites/default/files/D4.1-green_investment_landscape-V2.pdf

Guzmán, S., Dobrovich, G., Balm, A., & Meattle, C. (2022). The State of Climate Finance in Africa: Climate Finance Needs of African Countries (Issue June). https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS?locations=ZG

He, L.Y., & Liu, L. (2018). Stand by or follow? Responsibility diffusion effects and green credit. *Emerging Markets Finance and Trade, 54*(8), 1740–1760. https://www.tandfonline.com/doi/abs/10.1080/1540496X.2018.1430566

International Energy Agency. (2022). Financing Clean Energy Transition in Emerging and Developing Economies. Financing Clean Energy Transitions in Emerging and Developing Economies (iea.blob.core.windows.net)

International Monetary Fund. (2022). Internat.

Jackson, T. (2009). Prosperity without Growth: Economics for a Finite Planet. Earthscan, London.

Jones, R., Baker, T., Huet, K., Murphy, L., & Lewis, N. (2020). Treating ecological deficit with debt: The practical and political concerns with green bonds. *Geoforum*, *114*, 49-58. https://www.sciencedirect.com/science/article/pii/S0016718520301329

Lee, J. W. (2020). Green finance and sustainable development goals: The case of China. *Lee, Jung Wan (2020). Green Finance and Sustainable Development Goals: The Case of China. Journal of Asian Finance Economics and Business*, *7*(7), 577-586. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4035104

Lemma, A., Tyson, J., & Tizzani, A. (2021). Greening Africa's financial sector during crisis recovery. In Finance in Africa: for green, smart and inclusive private sector development. www.eib.org/economics

Linh, D. H., & Anh, T. V. (2017). Impact of stakeholders on the performance of green banking products and services: The case of Vietnamese banks. *Economic annals-XXI*, (165), 143-151. https://www.ceeol.com/search/article-detail?id=577959

Mazza, F. (2021). Smallholder Resilience Fund: Lab Instrument Analysis. Retrieved from: Smallholder-Resiliense-Fund_Instrument-Analysis.pdf (climatefinancelab.org)

McKinsey. (2020). Solving Africa's Infrastructure Paradox. Retrieved from: https://www.mckinsey.com/capabilities/operations/our-insights/solving-africas-infrastructure-paradox

Mohamed, N., Maitho, E., Masvikeni, E., Fourie, R., Tilly, M., & Zondi, N. (2014). The Green Fund of South Africa: Origins, establishment and first lessons. Development Southern Africa, 31(5), 658–674. https://doi.org/10.1080/0376835X.2014.935295

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Altman, D., Antes, G., ... & Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement (Chinese edition). Journal of Chinese Integrative Medicine, 7 (9), 889–896. https://doi.org/10.7326/0003-4819151-4-200908180-00135

Mustaffa, A. H., Ahmad, N., & Bahrudin, N. Z. (2021). A systematic literature review on barriers to green financing participation worldwide. *Global Business & Management Research*, *13*(4).

Nedopil, C., Dordi, T., & Weber, O. (2021). The nature of global green finance standards—evolution, differences, and three models. *Sustainability*, *13*(7), 3723. https://www.mdpi.com/2071-1050/13/7/3723

Nosratabadi S., Mosavi A., Shamshirband S., Zavadskas E.K., Rakotonirainy A., and Chau K.W. (2020). Sustainable Business Models: A Review. Sustainability. http://dx.doi.org/10.2139/ssrn.3706127

OECD (Organisation for Economic Co-operation and Development). (2020). Green Infrastructure in the decade for Delivery: Assessing Institutional Investment. Retrieved from: https://www.oecd-ilibrary.org/sites/aaa8a6c2-en/index.html?itemId=/content/%20component/aaa8a6c2-en

Osterwalder A. and Pigneur Y. (2005). Clarifying Business Models: Origins, Present, and Future of the Concept. Commun. v15 (May).

Ouyang, H., Guan, C., & Yu, B. (2023). Green finance, natural resources, and economic growth: Theory analysis and empirical research. *Resources Policy, 83*, Article 103604.

https://doi.org/10.1016/j.resourpol.2023.103604

Peterson Kitakogelu, O. (2022). Green finance research around the world: a review of literature Green finance research around the world: a review of literature. International Journal of Green Economics, 114899, 56–75. https://doi.org/10.1504/IJGE.2022.125554

Pindiriri, C., & Kwaramba, M. (2024). Climate finance in developing countries: green budget tagging and resource mobilization. *Climate Policy*, 1-15. https://www.tandfonline.com/doi/abs/10.1080/14693062.2024.2302325

Porter M. and Kramer M. (2011). Creating Shared Value. Harvard Bus. Rev. (February).

Rajala R. and Westerlund M. (2007): Business models – A New Perspective on Firms' Assets and Capabilities. Entrepreneurship and Innovation, Vol.8, no.2, pp.115-125

Rashid A., Asif F.M.A., Krajnik P., and Nicolescu C. M. (2013). Resource Conservative Manufacturing: An Essential Change in Business and Technology Paradigm for Sustainable Manufacturing. Journal of Cleaner Production, Vol. 57, pp. 166-177. https://doi.org/10.1016/j.jclepro.2013.06.012.

Rasmussen, B. (2007). Business Models and the Theory of the Firm. https://vuir.vu.edu.au/15947/1/15947.pdf

Richardson, J. (2008). The business model: an integrative framework for strategy execution. Strategy. Change.133-144.

Schaper, M. (2002). The essence of ecopreneurship. *Greener Management International*, (38). https://www.jstor.org/stable/pdf/greemanainte.38.26.pdf

Skendžić S., Zovko M., Živković I.P., Lešić V., and Lemić D. (2021). The Impact of Climate Change on Agricultural Insect Pests. Insects. doi: 10.3390/insects12050440. PMID: 34066138; PMCID: PMC8150874.

Sommer A. (2012). Managing Green Business Model Transformations. Springer Science & Business Media.

Stern N. (2007). The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge, UK.

Stubbs, W., Cocklin, C., 2008. Conceptualizing a "Sustainability business model." Organ. Environ. 21 (2), 103e127.

Taghizadeh-Hesary, F., & Yoshino, N. (2020). Sustainable solutions for green financing and investment in renewable energy projects. *Energies*, *13*(4), 788. https://www.mdpi.com/1996-1073/13/4/788

Taghizadeh-Hesary, F., Zakari, A., Alvarado, R., & Tawiah, V. (2022). The green bond market and its use for energy efficiency finance in Africa. China Finance Review International, 12(2), 241–260. https://doi.org/10.1108/CFRI-12-2021-0225

Teece D. (2010). Business Models, Business Strategy and Innovation. Long Range Planning 43.

Turner, B. (2014). Asian Development Bank Institute (Issue 1212, pp. 75–75). https://doi.org/10.1007/978-1-349-67278-3_116

Tyson, J. E. (2021). Developing green bond markets for Africa.

United Nations Development Programme. (2024). Africa Green Business and Finance Report. https://www.undp.org/africa/publications/africa-green-business-and-financing-report

United Nations Environment Program (UNEP). Building Inclusive Green Economic in Africa, experience and lessons learned (2010–2015). 2015. https://wedocs.unep.org/bitstream/handle/20.500.11822/9265/-Building_Inclusive_Green_Economies_in_Africa_-_Experience_and_Lessons_Learned_2010-2015-2.pdf?sequence=3&amp%3BisAllowed

Wang, Y., Lei, X., Long, R., & Zhao, J. (2020). Green credit, financial constraint, and capital investment: evidence from China's energy-intensive enterprises. *Environmental Management*, *66*, 1059-1071. https://link.springer.com/article/10.1007/s00267-020-01346-w

Yu, B., Liu, L., & Chen, H. (2023). Can green finance improve the financial performance of green enterprises in China?. *International Review of Economics & Finance*, *88*, 1287-1300. https://www.sciencedirect.com/science/article/pii/S105905602300271X

Yuan, Q., Yang, D., Yang, F., Luken, R., Saieed, A., & Wang, K. (2020). Green industry development in China: An index based assessment from perspectives of both current performance and historical effort. *Journal of Cleaner Production, 250*, Article 119457. https://doi.org/10.1016/j.jclepro.2019.119457

Zhang, M., Lian, Y., Zhao, H., & Xia-Bauer, C. (2020). Unlocking green financing for building energy retrofit: A survey in the western China. *Energy Strategy Reviews*, *30*, 100520. https://www.sciencedirect.com/science/article/pii/S2211467X20300730

Zott, C., Amit, R. (2010). Business model design: an activity system perspective. Long Range Plan. 43 (2/3), 216e226.

Technological Innovations and Data-Driven Solutions

10

Data-Driven Solution for Coastal Flood Adaptation and Climate Resilience

Steven Yirenkyi and Cyril D. Boateng

Abstract

Coastal floods pose serious threats to the environmental and socioeconomic well-being of coastal communities. Usually attributed to high-energy waves and rising sea levels, these events are becoming increasingly frequent and severe, primarily due to human-induced climate change. Effective climate mitigation and adaptation strategies are critical to protect lives, livelihoods, and infrastructure in areas vulnerable to coastal floods. A key adaptation strategy for addressing coastal flooding is the use of an Early Warning System (EWS). However, Ghana lacks such a system and must prioritise its development to protect citizens and strengthen flood resilience. To create an effective coastal flood EWS, it is essential to have the infrastructure to collect and monitor critical meteorological and oceanographic parameters, such as wind speed, wave heights, and tidal levels. In Ghana, the necessary infrastructure for gathering this data is either inadequate or non-existent, leading to a significant data gap. As a result, the development of reliable forecasting models and the timely implementation of mitigation measures are severely hindered. Therefore, addressing the fundamental issue of climate data collection is the first step toward the successful development of an EWS in Ghana. This chapter highlights the role of governments in climate data collection and proposes policy strategies to improve the collection and accessibility of meteorological and ocean data. Policy proposals include establishing a national climate data hub, fostering public-private partnerships, funding local research to develop affordable ocean-state data collection technologies, collaborating with other African nations, partnering with leading climate agencies, and implementing community-based monitoring programmes. When implemented, these policy strategies will not only increase the availability of climate data to support the development of a coastal flood EWS but also foster local technical capacity, encourage innovation, and promote decent work opportunities.

Keywords: Coastal Floods, Early Warning System, Climate Adaptation

Introduction

Coastal inundation poses a persistent and escalating threat to Ghana's coastline, with communities like Dansoman projected to lose approximately 0.80 km^2 of land to the sea by 2100 (Appeaning Addo et al., 2011). Recent events in Agavedzi, a coastal community in the Ketu South Municipality, starkly illustrate this threat. In early February 2025, tidal waves displaced 129 residents and destroyed fifteen buildings.[1] The situation worsened in March, with more powerful waves demolishing 51 houses and leaving over 300 individuals homeless.[2]

Driven by factors such as geomorphology, low coastal elevations, and human development (Appeaning Addo et al., 2011; Babanawo et al., 2022; Boateng et al., 2017; Yankson et al., 2017), this phenomenon has devastating consequences for residents, destroying homes, erasing livelihoods, and submerging towns while exacerbating socioeconomic disparities. As climate change intensifies, the frequency and severity of coastal flooding are expected to rise, underscoring the urgent need for effective mitigation strategies. Central to these efforts is the development of an Early Warning System (EWS), which relies heavily on accurate and accessible climate data. However, Ghana faces significant challenges in this regard, hindering the effective implementation of a robust EWS.

This chapter stems from observations made during a broader systematic review of the applications of Artificial Intelligence (AI) in forecasting the drivers of extreme coastal water levels. A key finding from that review was that an overwhelming proportion of climate data collection is publicly funded and managed by government agencies. To further explore this trend, a targeted search for supporting evidence was conducted, involving the review of academic papers, policy documents, institutional reports, and relevant websites. Searches were carried out using keywords like "early warning systems", "climate data sources", and "coastal flood".

[1] https://www.graphic.com.gh/news/general-news/agavedzi-tidal-waves-displace-129-residents.html

[2] https://www.myjoyonline.com/the-sinking-agavedzi-community/

Building on these findings, this chapter examines the role of governments in climate data collection and management, with a focus on Ghana. It highlights key challenges, such as the lack of prioritization of data collection, and explores opportunities for improvement through strategic investments and policy interventions. The chapter offers actionable recommendations to strengthen climate resilience through enhanced data collection and EWS development. The insights presented aim to achieve three primary objectives:

1. To highlight the role of climate data in EWS development
2. To underscore the government's responsibility in data collection
3. To provide practical recommendations for overcoming existing challenges

The chapter is organized into four parts. It begins by providing context on coastal flooding, including its causes, impacts, and the role of data in forecasting. The following section discusses the challenges of climate data collection in Ghana, while the next section argues for the leading role of governments in data collection. Finally, the chapter concludes with actionable policy recommendations to improve data collection and accessibility, drawing on global best practices and local realities.

The Context and Background of Coastal Flooding in Ghana

Understanding the causes and impacts of coastal flooding is essential for developing effective strategies to mitigate its effects. This section presents some drivers of coastal flooding and their socioeconomic and environmental impacts. Furthermore, it provides an overview of the various mitigation efforts, highlighting the importance of proactive strategies like EWS. Finally, the role of data in forecasting coastal floods is presented.

Coastal Flooding: Causes and Impacts

Coastal flooding is primarily caused by extreme water levels resulting from a combination of oceanic and atmospheric factors, such as changes in average sea levels, storm surges, rainfall, and river discharge (Brempong et al., 2023). The eastern coastline of Ghana, especially Keta and its environs, is extremely vulnerable to coastal inundation caused by the concurrent occurrence of high tides and high-energy waves, commonly referred to as tidal waves (Brempong et al., 2023). Inundation in these areas is also triggered by lagoon overflows and rainfall. However, according to local accounts, tidal waves are considered the most destructive[3]. Over the past decade, tidal waves have wreaked havoc on the coastal communities of Kporkporgbor and Fuveme in the Keta Municipality, permanently inundating the entire town of Kporkporgbor and large parts of Fuveme (Ghanaian Times, 2022; GhanaWeb, 2018; Kasapa, 2015; Mattah et al., 2024). These waves had devastating impacts on local communities, destroying buildings and displacing residents.

The effects of these events go beyond the destruction of properties. Coastal floods destroy farmlands and crops, leaving farmers, their dependents, and entire communities in poverty (Ile & Garr, 2011). The fishing sector is disrupted during coastal flooding, making harvesting and selling fish difficult due to turbulent seas and blocked roads (Babanawo et al., 2023). Major investments in beach resorts, public infrastructure, and historical sites, such as forts, are also at risk from these coastal floods (Brempong et al., 2023). Additionally, the debris deposited or displaced by floods may pose significant health risks to humans (Babanawo et al., 2023; Ile & Garr, 2011). Living in areas prone to coastal floods further impacts self-actualisation and well-being (Ile & Garr, 2011), as it creates barriers to economic stability, health, education, equal opportunity, and a sense of security (Sene, 2008). While high-income countries experience greater absolute economic losses from flooding, these losses may have negligible impacts on their GDP (Perera et al., 2019). In contrast, developing countries face smaller absolute losses, but these account for a much larger percentage of their GDP, highlighting their greater vulnerability (Perera et al., 2019).

The frequency and intensity of coastal inundation in Ghana have increased significantly in recent years due to climate change, and they are expected to continue worsening (Appeaning Addo et al., 2011; Brempong et al., 2023; Ministry of Environment, Science, Technology, and Innovation [MESTI], 2013). Concomitant with the increased frequency and intensity of coastal floods is the profound negative impact on the physical and mental well-being, as well as the socioeconomic status of coastal residents, none more so than those on the eastern coastline of Ghana (Boateng, 2012; Brempong et al., 2023). Given the

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[3] Information based on discussions with locals and representatives of the National Disaster Management Organization in Keta, conducted in November 2024.

severe and far-reaching damage caused by coastal flooding, Ghana must take proactive measures to address this threat.

Coastal Flood Mitigation Strategies

Measures to address coastal floods can be categorised into three strategies: defence, retreat, and adaptation (Dedekorkut-Howes et al., 2020; Gbedemah, 2023).

Defence strategies directly combat flooding by using physical barriers and are widely used by the Government of Ghana (GoG). Notably, in Keta, the GoG has implemented numerous structures over the years, from steel sheet pile walls in the 1960s (Nairn et al., 2015) to the Keta Sea Defence Project (KSDP) in the 2000s (Nairn & Dibajnia, 2004). Locals also construct defensive structures by sealing sand in sacks and depositing them along the shore to build a wall (Owusu & Andriesse, 2023). While these defence projects reduce the immediate impacts of flooding, they are not permanent solutions. Their effectiveness can diminish over time due to factors like sea-level rise, coastal erosion, and inadequate maintenance. Therefore, integrating these strategies with improved coastal planning is essential for long-term resilience.

Retreat strategies involve relocating residents and infrastructure to higher ground further inland. While this strategy provides a more pragmatic long-term solution, its sustainability depends on the ability to provide adequate housing units. In practice, relocation activities often face affordability, land availability, and community acceptance issues. For example, while the KSDP primarily focused on physical defence structures, it included elements of retreat strategies. However, its implementation has been hindered by financial constraints, resulting in inadequate shelter for many households (Ile & Garr, 2011). The one-bedroom units provided by the KSDP proved inadequate for larger families accustomed to living in more spacious homes (Ile & Garr, 2011).

Additionally, these structures, built with substandard materials, are prone to early deterioration (Ile & Garr, 2011). On the western coastline, fishermen temporarily relocate to higher grounds inland to avoid coastal flood damage and return to their original homes when the floods recede (Owusu & Andriesse, 2023). While the temporary relocation helps mitigate immediate risk, it is not a sustainable long-term solution to coastal vulnerability.

Adaptation strategies focus on enhancing the resilience of coastal residents and their environments to flooding by adjusting to mitigate its impact (Dedekorkut-Howes et al., 2020). It is a flexible approach to addressing climate change, which can be integrated with defence and retreat strategies (Bray et al., 1997; Rogers & Tsirkunov, 2011). Residents on the eastern coast of Ghana employ adaptation measures such as drainage channels and flood insurance (Babanawo et al., 2023) to mitigate the impact of flooding. However, these approaches face limitations, including maintenance challenges for drainage infrastructure and limited access to affordable insurance options. Traditional methods like sand filling, building further inland, and elevating structures were once effective but are now less practical due to climate change (Gbedemah, 2023).

This book chapter advocates for improving Ghana's adaptation strategies, particularly in Early Warning Systems (EWS), to mitigate the impacts of coastal flooding. An EWS is a widely proposed adaptation measure that alerts communities to impending disasters, enabling proactive responses and minimising potential damages (Perera et al., 2019; Rogers & Tsirkunov, 2011; United Nations, 2006). The Ghanaian government recognises the importance of such a system, as reflected in its National Climate Change Policy (NCCP), which prioritises adaptation under its disaster preparedness and response theme (MESTI, 2013). However, despite this recognition, little progress has been made toward implementing an EWS.

Early Warning Systems

Several studies have recommended implementing an EWS (Adams et al., 2022; Babanawo et al., 2022; Owusu & Andriesse, 2023; Pienaah et al., 2023). These systems enable communities to take preventive actions to protect lives and property. Through timely alerts, these systems help safeguard homes, businesses, and livelihoods, thereby reducing economic losses (Mohanty et al., 2022; United Nations Office for Disaster Risk Reduction, 2009). The decline in disaster-related deaths in countries like Bangladesh and China is primarily due to advancements in EWS (Sene, 2008). Rather than serving as a replacement, EWS provides a strategic approach to anticipating threats, enabling timely action (such as activating flood defences like floodgates) to minimize risks and reduce potential losses. In addition, EWSs are cost-effective and can reduce the need for expensive post-disaster relief (Rogers & Tsirkunov, 2011). The adaptability and ability of EWSs to incorporate new data makes them valuable

(Rogers & Tsirkunov, 2011), especially in the era of human-induced climate change.

It is essential to highlight that an EWS has been previously implemented in Ghana, with collaboration from the United Nations Development Program (UNDP), the Norwegian Embassy, and the Government of Ghana under the Community Resilience Through Early Warning (CREW) project. The project aimed to reduce disaster risks by developing a drought and flood EWS and disseminating information via the web. However, the project is inactive. A quick review of the project website shows that the last update was in January 2016,[4] and the website hosting the EWS dashboard is currently unreachable.[5] Moreover, empirical assessments found that coastal communities do not receive any form of early warning (Owusu & Andriesse, 2023).

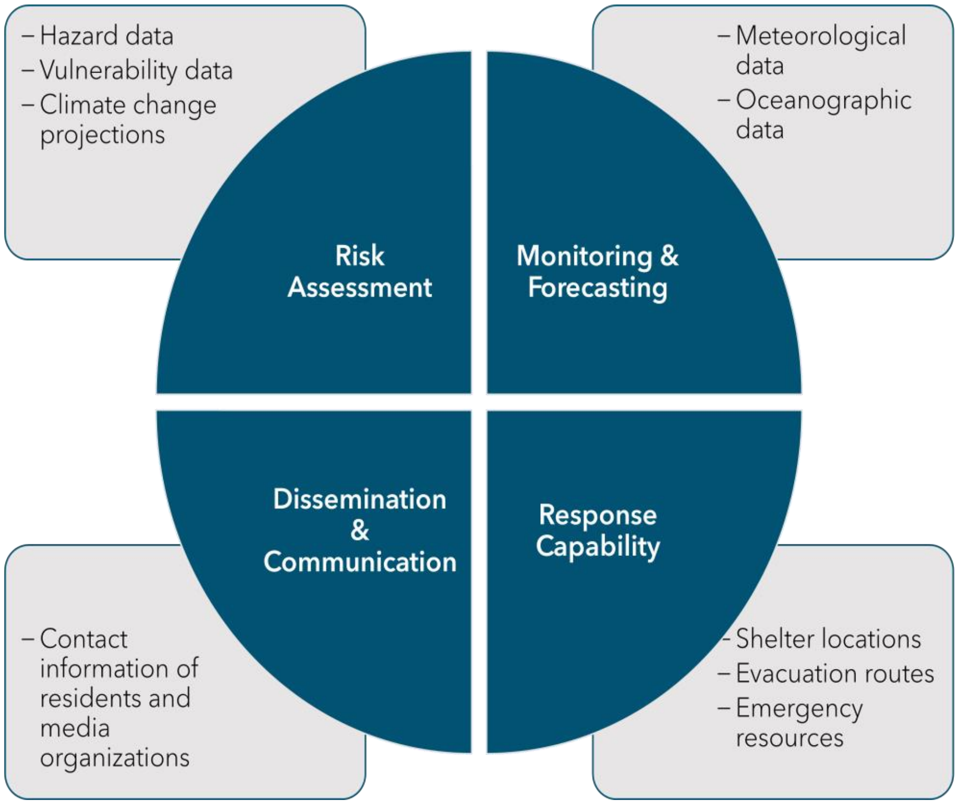
EWSs consist of four components: (1) *risk assessment*, which identifies hazards and vulnerable areas; (2) *monitoring and forecasting*, which involves collecting and analysing data to predict when and where an event is likely to occur; (3) *communication*, which delivers timely warnings to those at risk; and (4) *response capability*, which ensures emergency actions are taken to reduce damage and protect lives (United Nations, 2006).

A key requirement for each component of an EWS is adequate and accurate data (see Figure 1). Forecasting, the heart of an EWS, requires extensive, long-term datasets to produce reliable predictions of flood likelihood (Tucci, 2003), timing, and severity. The timing here is in terms of lead time, which is the time gap between a forecast and the expected occurrence of the predicted event. It varies from a few seconds to several months, depending on the forecasted hazard type (Tucci, 2003; United Nations, 2006). Given the essential role of forecasting in an EWS, this chapter will focus on acquiring and using data for its effective operationalisation.

[4] https://crewghana.wordpress.com/

[5] https://crew.nadmo.gov.gh/ewsghana/#dashboard/1

Figure 1: Data required for each Early Warning System component.



In developed countries, flood forecasting is done using a formalised data-driven approach. However, in Ghana, no formal systems for flood forecasting exist. Instead, forecasting is primarily based on indigenous knowledge. This knowledge, rooted in cultural practices, is commonly used by local communities to forecast and adapt to environmental changes. For instance, farmers use indigenous knowledge to predict rainfall patterns (Adanu et al., 2022; Baffour-Ata et al., 2021), while fishermen rely on indigenous knowledge to assess the likelihood of storms (Owusu & Andriesse, 2023). Similarly, coastal residents intuitively understand when to expect flooding and the type of flooding likely to occur (Babanawo et al., 2023).

While indigenous knowledge is valuable, it has several limitations, including challenges in data collection, its ephemeral nature, and the difficulty of measuring its accuracy (Adanu et al., 2022; Baffour-Ata et al., 2021). As a result, there is a growing movement to adopt scientific forecasting or, at the very least, integrate scientific forecasts with indigenous knowledge (Adanu et al., 2022; Gbangou et al., 2021; Nyadzi et al., 2022). Scientific forecasting refers to using systematic, data-driven methods to predict future weather and climate conditions, relying on various data sources such as satellites, in situ devices, and numerical models. The main challenge in Ghana is the lack of sufficient and reliable data sources to support such data-backed forecasts. Therefore, before Ghana can achieve the level of forecasting seen in advanced countries, it must first tackle the fundamental issue of climate data availability.

Role of Data in Forecasting

Data is crucial for accurate and reliable forecasting (Wu et al., 2020). Every proposed forecasting framework begins with acquiring relevant data (Fernández-Nóvoa et al., 2024; Jain et al., 2018; Sene, 2008). The crux of data-backed forecasts is predicting outcomes based on historical observations, with historical observations allowing forecasting models to identify patterns and trends that inform predictions.

A series of regional workshops involving hydrologists and meteorologists from 85 countries identified and ranked the status of flood forecasting in participating countries into three levels (Sene, 2008).

- **Level 1,** the lowest level, indicates a lack of basic data collection and warehousing.
- **Level 2** signifies that basic data collection and warehousing exist but require improvement in data management.
- **Level 3** includes countries that have addressed all data-related issues and use the latest data observations for flood forecasting.

The workshops concluded that insufficient data observations are the primary obstacle to implementing national flood forecasting, making it impossible to answer questions critical for emergency response.

Emergency Management Australia (1999), as cited in Sene (2008), summarised flood forecasting by posing five key questions: "(1) How high will the flood reach and when? (2) Where will the water go at the predicted height? (3) Who will be affected by the flooding? (4) What information and advice do the people affected by the flooding need to respond effectively? and (5) How can flood-affected people be best informed?". To answer these five questions, there must be historical and real-time data from which forecasting models, relevant authorities, and policymakers learn to make decisions.

Accurate flood forecasting requires diverse climate data (see Table 1) that spans an extended period. The diversity of data is essential for capturing the complex interactions between the various environmental factors. Additionally, the data must cover a sufficiently lengthy period—especially when using Artificial Intelligence (AI)—to ensure forecasts can identify and account for long-term trends, seasonal variations, and rare extreme events.

Table 1: Examples of types of data needed to forecast coastal floods.

Type of data	Examples of variables to monitor
Meteorological	Rainfall, wind speed, wind direction, air temperature, and atmospheric pressure
Ocean	Wave heights, tide levels, sea surface temperature, sea levels, sea elevations, currents, and storm surges.
Hydrological	River discharge, streamflow, soil moisture levels, and groundwater levels
Topographical	Elevation, slope, coastal geomorphology, land use, and land cover

Coastal floods are influenced by various climate factors, particularly meteorological and oceanographic conditions, making accurate flood forecasting and impact assessment dependent on extensive climate data. For example, meteorological factors such as intense storms or hurricanes generate high-energy winds, and heavy rainfall influences oceanic conditions such as storm surges, wave heights, and sea levels (Sene, 2008). Notably, while this chapter frequently references climate data, its focus is specifically on a subset of climate data known as *metocean data*. Metocean data (a combination of meteorological and oceanographic data) is essential for forecasting and managing coastal floods. Important metocean variables influencing coastal flooding include wind speed, wind direction, sea surface temperature, wave height, wave period, wave direction, tidal levels and sea levels. These variables characterise the state of the ocean and are essential for modelling ocean behaviour. Modelling ocean behaviour helps predict its future state, allowing forecasters to estimate potential risks and damage to residents. Additionally, it enables relevant authorities to initiate appropriate responses.

Climate data agencies in the US, India, China, Iran, and the EU face challenges not in data scarcity but in managing the overwhelming volume of climate data and ensuring it is accessible to researchers (Overpeck et al., 2011). Ghana, however, faces the opposite problem. As a developing nation, it is in no less need of metocean data than its wealthier counterparts. Given the vulnerability of developing countries to the impacts of climate change, the demand for climate data becomes even more pressing (Donatti et al., 2024; MESTI, 2013). To address this, local efforts must aim to collect, process, and disseminate the same types of climate data being gathered by developed nations, as climate variables remain universal across the globe.

Challenges in Climate Data Collection and Accessibility

Reliable climate data is essential for understanding environmental changes and developing effective mitigation and adaptation strategies. This section examines the barriers impeding climate data collection and accessibility in Ghana.

The lack of sufficient and reliable climate data is a pervasive problem across Africa. This challenge is worsened by sparse and declining observation networks, uneven weather station distribution and inadequate investment in climate infrastructure. Additionally, issues such as poor data quality and restricted access to existing data compound the situation. Barriers to accessing data include legal restrictions, low funding, limited tools to disseminate data, high costs to access data, and a lack of digitised records. Together, these challenges hinder the collection, management and dissemination of climate data (Dinku, 2019; Dinku et al., 2022; Kaspar et al., 2022; Lamptey et al., 2024; Oluwagbemi et al., 2022).

Ghana exemplifies this broader issue of climate data scarcity faced across Africa. However, as Manteaw et al. (2022) highlight, two issues complicate climate data collection in Ghana: institutional incapacity, which has also been highlighted in the NCCP, and a pervasive poor attitude toward data collection.

Institutional Incapacity: The Case of Ghana Meteorological Agency

The Ghana Meteorological Agency (GMet) is responsible for collecting, managing, and disseminating reliable climate information to the residents of Ghana. However, it faces numerous challenges that hinder its ability to provide accurate and reliable climate information (Manteaw et al., 2022). These challenges are multifaceted, spanning technological, infrastructural, and methodological issues. GMet struggles with limited data collection tools, insufficient funding, and scarce resources, compromising its mandate (Ghann, 2020; Yamba et al., 2023). Its climate data are inadequate, so researchers often resort to global climate datasets to supplement the information obtained from GMet, as done by Arfasa et al. (2024). Another example of its limitations is its failure to provide seasonal climate forecasts, which are crucial for strategic planning and risk management (Baffour-Ata et al., 2022).

While historically, GMet lacked the comprehensive infrastructure for monitoring metocean variables. Recent developments mark a significant improvement in their data collection systems. The agency launched its first coastline and maritime weather forecast on 16 August 2024, with its inaugural sea state forecast following on 23 September 2024.[6] These weekly forecasts represent a crucial advancement in climate monitoring capabilities. However, whether these forecasts are generated using local infrastructure and data or sourced from external databases remains unclear.

Poor Attitude Toward Data Collection: Coastal Flood Documentation

The culture of poor data collection is evident in the documentation of disasters like coastal floods. Basic information, such as the dates of flood occurrences, is not systematically recorded, resulting in the absence of a comprehensive coastal flood database. This problem persists despite the establishment of the National Disaster Management Organization (NADMO). While such a database may exist, the institutional incapacity renders it inaccessible.

To illustrate the importance of such a simple dataset in flood forecasting studies, consider one method for training and evaluating AI forecasting models.

[6] https://www.meteo.gov.gh/Services/marine/

Researchers train AI models using metocean data and then validate the performance of the models through a process called *hindcasting*. This process involves going back to a time before a known disaster occurred, feeding the historical data into the AI model, and checking if the model can successfully predict this known event. This straightforward workflow becomes significantly more challenging when forecasting coastal floods in Ghana due to the absence of historical flood records.

While Ghanaian metocean data from global datasets can be obtained, the lack of historical flood data prevents researchers from using the outlined workflow. Global data like ERA5 and satellite data do not include specific flood events, which is why historical flood records are essential for validation. Furthermore, knowing when floods occurred in Ghana would allow researchers to use these global datasets to go back in time and study the metocean conditions before, during, and after the floods. It must also be noted that such global climate datasets may not be entirely exact; thus, they are typically validated against in situ data, like wave buoy measurements, to assess their accuracy. Sadly, Ghana's lack of comprehensive in situ data hinders the validation of global climate data.

Despite recognising the importance of EWS as a climate adaptation strategy, Ghana is struggling to implement the necessary measures due to persistent data collection and management practices. The resulting data poverty, characterised by the lack of relevant, timely, accessible, and usable climate information, hampers effective decision-making (Manteaw et al., 2022) and has led to a governance framework focused on disaster response and relief rather than prevention and mitigation (Amponsah, 2022). This data scarcity leads to reactive and speculative adaptation strategies, often based on flawed assumptions and misunderstanding of local conditions.

Role of Government in Climate Data Acquisition

This section examines why governments play a central role in collecting metocean data and their distinct capability to fulfil this essential function. It explores the primary reasons governments worldwide serve as the principal funders of climate data projects, details various categories of metocean data, and highlights specific government-led programs dedicated to metocean data acquisition.

Government and intergovernmental agencies often lead and implement climate data projects (Hersbach et al., 2020; Saha et al., 2010) and are the primary sources of ocean and climate data necessary for accurate coastal flood forecasting. Their involvement ensures the availability, accuracy, and accessibility of data that underpin forecasting models. Institutions such as the National Oceanic and Atmospheric Administration (NOAA), European Centre for Medium-Range Weather Forecasts (ECMWF), Copernicus, national meteorological agencies, hydrological agencies, and ports contribute significantly to the collection, maintenance, and dissemination of these data. These agencies manage infrastructures such as tide gauges, wave buoys, weather stations, and satellites, which are indispensable for monitoring coastal dynamics.

Why Governments Lead Climate Data Collection

Climate data collection is essential for understanding and managing the risks associated with coastal flooding. However, its acquisition is expensive and requires long-term sustained investments in monitoring stations, satellites, computing, and research initiatives. Given their responsibility for public welfare and long-term planning, governments are best positioned to undertake this critical task.

Climate data is also considered a public good (Verhulst, 2024) because it is non-excludable and non-rivalrous. The non-excludability of climate data implies that once it becomes publicly available, no one can be prevented from using it. Additionally, its non-rivalrous attribute means that use by one person does not reduce the amount available for others. Stakeholders from disaster management agencies, urban planners, coastal engineers, and local communities can use the information to make informed decisions on coastal management. For example, timely access to weather forecasts and tide levels allows disaster management agencies to issue early warnings and coordinate evacuations, while infrastructure planners can use long-term climate projections to design resilient sea defence systems.

The North Atlantic Treaty Organisation (NATO) describes climate change as a threat multiplier that exacerbates geopolitical tensions, increases state fragility, fuels conflicts, and disproportionately impacts vulnerable populations by intensifying competition for scarce resources (NATO, 2021). Additionally, climate change is intensifying the frequency and severity of coastal flooding, particularly affecting vulnerable coastal communities. In response to these complex threats, collecting and analysing climate data is essential not only for understanding the environment but also for safeguarding national security, a responsibility that rests solely with the government. Without reliable data, governments may struggle to identify at-risk zones or to allocate resources effectively for flood defence projects. Climate data allows policymakers to focus equally on the indirect impacts of climate change, such as migration, economic instability, and political unrest (Malone, 2013).

Government Support for Climate Data

The metocean data managed by these institutions can be classified into five categories: in situ data, laboratory experiments, remote sensing data, reanalysis data, and numerical model simulations. Further details on these data categories and some institutions responsible for them are provided in this section.

In Situ Data

In situ data refers to measurements collected directly from the natural environment using various instruments and sensors. This category includes wave buoys, tide gauges, and weather stations. Government agencies are instrumental in operating and maintaining these instruments. For example, NOAA manages a large network of wave buoys and tide gauges across the globe through its National Data Buoy Centre.[7] Similarly, the United Kingdom (UK) Met Office has a weather station network that spans the length and breadth of the country.[8] The European Global Ocean Observing System also has a tide gauge network across the shores of EU countries.[9] These agencies ensure that the instruments are properly maintained and are responsible for the dissemination of the data.

Laboratory Experiments

Controlled lab experiments, such as those conducted by Liu et al. (2022), provide high-resolution data for modelling metocean variables. These experiments are typically conducted in research labs and institutions funded by the government, which are equipped with advanced facilities such as wave

[7] https://www.ndbc.noaa.gov/

[8] https://www.metoffice.gov.uk/weather/guides/observations/uk-observations-network

[9] https://eutgn.marine.ie/

tanks, wave flumes, and current flumes that enable precise simulation and measurement of relevant variables. For instance, the Coastal, Ocean, and Sediment Transport Laboratory at the University of Plymouth, a public university in the UK, offers facilities for physically simulating waves, currents, wind effects, and a wide range of data acquisition equipment.[10] Similarly, the Kelvin Hydrodynamics Laboratory at the University of Strathclyde, another UK public university, offers facilities for the simulation and acquisition of wave observations.[11] Zhan et al. (2023) used wave height data obtained from a deep-water towing tank at the Shanghai Ship and Shipping Research Institute to train an AI model to forecast wave heights. The Pacific Northwest National Laboratory and the National Science Foundation (NSF) fund research facilities, such as the O.H. Hinsdale Wave Research Laboratory,[12] that conduct experiments on oceanic and atmospheric processes.

Remote Sensing Data

Remote sensing data is obtained through satellite and aerial platforms, offering a bird's-eye view of atmospheric and oceanic conditions. They play a critical role in early warning systems for coastal floods by providing real-time data on atmospheric and oceanic conditions. These measurements include sea surface temperatures, wave heights, wind patterns, and other variables (Hauser et al., 2023). This data is vital for detecting potential flood threats, predicting storm surges, and issuing timely alerts to at-risk coastal communities.

Government agencies are dominant in developing and managing satellite missions and remote sensing technologies, as well as processing and distributing remote sensing data. The Indian Space Research Organization (ISRO) is an example of such an agency; its Oceansat missions provide metocean data for sea state forecasting, monitoring extreme events such as cyclones, and monsoon forecasting (Parmar et al., 2006). Additionally, the Indian Regional Navigation Satellite System (IRNSS) provides disaster management services, including flood forecasting,[13] using satellite data. Another example is the Japan Aerospace Exploration Agency Earth observation missions, which focus on

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[10] https://www.plymouth.ac.uk/facilities/coast-laboratory

[11] https://www.strath.ac.uk/engineering/navalarchitectureoceanmarineengineering/workingwithbusinessorganisations/ourfacilities/kelvinhydrodynamicslaboratory/

[12] https://engineering.oregonstate.edu/wave-lab

[13] https://www.isro.gov.in/SpaceApplications.html

studying the water cycle and climate change while supporting operational activities like weather forecasting. (Hirabayashi, 2020).

Numerical Model Simulation

Numerical models are essential sources of metocean data that underpin EWS for coastal floods. The volume of data from this category is expected to outpace all other data sources (Overpeck et al., 2011). These models simulate atmospheric and oceanic processes computationally rather than through physical experiments as done in a laboratory. They require substantial computational resources and expertise, often provided through government-supported research programs. Numerical models use data from a wide range of observations, including satellite data, weather balloons, and ground stations, to initialise and predict the state of the atmosphere over time.

In climate research, numerical models are diverse, with two important categories being Numerical Weather Prediction (NWP) models and Numerical Wave Models (NWM).

NWP models are sophisticated simulations replicating atmospheric dynamics to provide accurate forecasts (Dodla, 2022). These forecasts are crucial for predicting extreme weather events that can trigger coastal flooding. Establishing an independent and sophisticated NWP model requires financial, technical, and computational resources, which are often beyond the capacity of a national meteorological agency.[14] As a result, some countries adopt a collaborative approach to developing NWPs. For instance, the German Weather Service developed the Icosahedral Nonhydrostatic (ICON) Modelling Framework, a unified system for numerical weather prediction, in partnership with the Max-Planck-Institute for Meteorology (Zängl, 2013). Other countries use an ensemble of NWP models developed by other agencies. For example, the Australian Community Climate and Earth System Simulator (ACCESS) integrates multiple NWP models, including the Unified Model of the Met Office.

NWM models, on the other hand, are computational tools that simulate ocean wave behaviour by translating wave processes into mathematical equations

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https://www.dwd.de/EN/research/weatherforecasting/num_modelling/01_num_weather_prediction_m
odells/num_weather_prediction_models_node.html

(Thomas & Dwarakish, 2015). Ocean behaviour is critical for predicting storm surges and high wave conditions that could threaten coastal zones. Their accuracy depends on how effectively they capture real-world processes by using energy-balance equations to estimate wave parameters (Thomas & Dwarakish, 2015). WAve Model (WAM), WaveWatch 3 (WW3), Simulating WAves Nearshore (SWAN), TELEMAC-based Operational Model Addressing Wave Action Computation (TOMAWAC), and MIKE 21 SW are among the most widely used NWMs (Lavidas & Venugopal, 2018). MIKE 21 SW, developed and maintained by DHI Water and Environment, is the only NWM of the five created by a private company (DHI Water & Environment, 2007). Table 2 provides an overview of various NWP and NWM models, summarising their key features, functionalities, developers, and funding sources.

Table 2: Overview of Numerical Weather Prediction Models and Numerical Wave Models

Model Type	Model Name	Description	Developer(s)	Funding Source
Numerical Weather Prediction Models	Global Spectral Model[15]	Global weather forecasts up to 11 days in advance.	Japan Meteorological Agency	Public Funds
	Icosahedral Nonhydrostatic (ICON) Modelling Framework (Zängl, 2013)	Numerical weather prediction and climate modelling	German Weather Service & Max-Planck Institute for Meteorology	Public Funds
	Australian Community Climate and Earth System Simulator[16]	Weather forecasting, climate prediction, and earth system research.	Australian climate research agencies	Public Funds
	Climate Forecast System[17]	Models the interactions between oceans, land, and atmosphere on a global scale.	National Centers for Environmental Prediction	Public Funds
	Unified Model[18]	Foundation for weather prediction in the UK; delivers accurate global and local forecasts.	UK Met Office	Public Funds
Numerical Wave Models	Wave Model (WAM) (The Wamdi Group, 1988)	Developed for wave forecasting using energy-balance equations.	WAMDI Group (various researchers)	Public Funds
	WaveWatch 3 (WW3) (Tolman, 2009)	Developed for global wave predictions.	National Centers for Environmental Prediction	Public Funds

[15] https://www.jma.go.jp/jma/en/Activities/nwp.html
[16] https://research.csiro.au/access/about/
[17] https://www.ncei.noaa.gov/products/weather-climate-models/climate-forecast-system
[18] https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/weather-forecasting

Model Type	Model Name	Description	Developer(s)	Funding Source
	Simulating WAves Nearshore (SWAN)[19]	Models nearshore wave dynamics.	Delft University of Technology	Public Funds
	TOMAWAC[20]	Used for wave action computation in coastal and marine environments.	Électricité de France - Laboratoire National d'Hydraulique et Environnement	Public utility company
	MIKE 21 SW	A commercial NWM developed for a variety of applications.	DHI Water and Environment	Private funds

Reanalysis Data

Reanalysis data, such as the Climate Forecast System Reanalysis (CFSR), combines two types of data: observational data from the environment, such as in situ and satellite data, and numerical model simulation data (Overpeck et al., 2011). This combination can enhance the accuracy of EWS for coastal floods. The data are combined through a data assimilation process where observations are integrated into numerical models to improve the predictions of these models.

Reanalysis is valuable because it provides long-term and comprehensive insights into how the climate system has evolved (Overpeck et al., 2011). For example, CFSR is a comprehensive reanalysis project conducted by the NCEP. Covering 31 years, it took over two years to complete and amounts to more than 250 TB in size (Saha et al., 2010). Similarly, the ECMWF maintains an extensive list of reanalysis datasets, including ERA-15, ERA-20C, and ERA-40 (Hersbach et al., 2020). ERA5 is the latest and most advanced of these datasets, covering the period from January 1940 to the present.[21] This level of detail is critical for identifying flood-prone zones, understanding historical flood trends, and enhancing predictive models for coastal flood EWS.

The production of ERA5 reflects significant government and institutional collaboration. At least three public institutions were directly involved in funding or supporting the creation of ERA5. Through the Copernicus Climate Change Service, the EU also directly funded the ERA reanalysis data production. Additionally, the European Organization for the Exploitation of Meteorological

[19] https://www.tudelft.nl/en/ceg/about-faculty/departments/hydraulic-engineering/sections/environmental-fluid-mechanics/research/swan/
[20] http://www.opentelemac.org/index.php/modules-list/20-tomawac
[21] https://confluence.ecmwf.int/display/CKB/ERA5%3A+data+documentation

Satellites funded two ECMWF staff whilst the National Centre for Atmospheric Science and Japan Meteorological Agency seconded staff during the preparation of ERA5 (Hersbach et al., 2020).

Conclusions and Policy Recommendations

As highlighted throughout this chapter, forecasting coastal flooding is contingent on the availability of metocean data. This data forms the foundation for developing Early Warning Systems (EWS), which are essential preventive measures for mitigating the impacts of coastal floods. EWS enables communities to better prepare for and respond to imminent flood threats, reducing the risk of loss of life, property damage, and livelihood disruptions.

Without urgent action to address gaps in metocean data collection, Ghana will remain vulnerable to the devastating impacts of coastal flooding. The technologies discussed, such as remote sensing platforms, numerical models, and reanalysis data systems, offer valuable solutions that can be adapted to the Ghanaian coastal context. For example, numerical models such as NWP and NWM can be customised to reflect local coastal dynamics, enabling more precise predictions.

Importantly, these advanced techniques are not intended to replace traditional or indigenous estimation methods or existing defensive infrastructure. Instead, they provide complementary and alternative approaches to improve the accuracy of predictions and strengthen overall flood management strategies. The following recommendations aim to guide policymakers on acquiring and enhancing access to metocean data.

1. **Increase Investment in Ghana Meteorological Agency:** The Ghana Meteorological Agency (GMet) is mandated to collect, manage, and share climate data. However, its efforts are hampered by insufficient resources and limited capacity. Increased funding could significantly enhance its operations by improving the density and maintenance of weather station networks, supporting staff training and capacity building, and acquiring advanced technologies and infrastructure, such as wave buoys. Additionally, such funding could support climate research and ensure wider data dissemination to end-users, making it more accessible and impactful.
2. **Establish an Ocean Data Central Repository:** The government should establish a national ocean data repository to centralise, store, and

disseminate oceanographic information, fostering broader accessibility and collaboration. Models like China's Ocean Professional Knowledge Service System and the U.S. National Centres for Environmental Information demonstrate how such repositories can support research, policymaking, and resource management.

3. **Leverage Global Data Sources*:*** Ghana's historical climate data is either non-existent or severely inadequate, posing a significant challenge to effective climate forecasting and adaptation. This gap can be bridged by integrating data from global sources such as the National Oceanic and Atmospheric Administration (NOAA), the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA5 reanalysis data, and public satellite systems. Leveraging these data sources can help the country to quickly establish a comprehensive dataset that meets specific needs. The approach adopted by the First Institute of Oceanography in China is a notable example. The institution combined satellite data from multiple sources to successfully develop its first ocean climate data record, showcasing the potential for efficient data acquisition and integration (Zhao et al., 2021).
4. **Partner Researchers and Private Sector:** The government must invest in local research and innovation as they are essential for developing low-cost, context-specific solutions for coastal flood forecasting. The partnerships can include the following:
    a. **Fund the Development of Low-cost IoT-Enabled Sensors***:* The GoG should fund the development and deployment of low-cost Internet of Things (IoT)-enabled sensors along the coastline to measure sea conditions and transmit data in real-time.
    b. **Fund Access High-Resolution Commercial Data***:* While agencies like NOAA and NASA provide free metocean data, high-resolution data, especially satellite data, might be necessary for more precise analysis. The government should fund researchers to acquire this data.
    c. **Partner with Local Research Institutions***:* The government should form partnerships with Ghanaian universities and research institutes with atmospheric science and meteorology expertise. These institutions can contribute technical knowledge, support data processing, and develop localised modelling frameworks. A relevant example is the collaboration between the local government and the

Georgia Institute of Technology to deploy sea level sensors to monitor coastal flooding.[22]

d. **Partner the Private Sector***:* Partner with fishing, telecommunication, and oil industries to install metocean sensors on communication towers, oil rigs, and fishing boats. This approach leverages existing infrastructure, thus minimising costs whilst maximising data collection.

5. **Promote International and Regional Collaboration:** International and regional cooperation aids in accessing data and sharing knowledge and skills while pooling resources for ocean and climate monitoring. Such collaborations can be fostered through the following approaches.
   a. **Initiate Regional Frameworks**: The government should engage regional bodies like the Africa Union to spearhead the establishment of a regional ocean monitoring network in West Africa, such as the Indian Ocean Tsunami Warning System. This structure could be modelled after the ECMWF or smaller regional climate agencies, collaborating with neighbouring countries in a framework like the Consortium for Small-scale Modelling (COSMO)[23].
   b. **Engage International Organizations**: Ghana should engage in partnerships with organisations such as NOAA, ECMWF, the African Centre of Meteorological Applications for Development (ACMAD), and The First Institute of Oceanography in China to gain access to ultramodern technology, advanced techniques, and state-of-the-art forecasting models.
6. **Encourage Citizen Science Initiatives:** Involving communities in data collection can provide valuable real-time information and increase public awareness of coastal flood risks. The GoG must initiate a citizen science program where coastal residents, fishers, and community members collect climate data using low-cost devices and mobile apps (Herrada Mederer et al., 2024). Ghana could fund a CoastSnap-like program (Harley & Kinsela, 2022), a citizen-science initiative using photos to monitor shoreline changes. This would provide a cost-effective tool for tracking coastal erosion and flood risks while engaging the public in disaster preparedness.

[22] https://sealevelsensors.org/

[23] https://www.cosmo-model.org/content/default.htm

References

Adams, I., Ghosh, S., & Runeson, G. (2022). Access to Early Warning for Climate Change-Related Hazards in Informal Settlements of Accra, Ghana. *Climate*, *10*(5), Article 5. https://doi.org/10.3390/cli10050062

Adanu, S. K., Abole, T., & Gbedemah, S. F. (2022). Use of indigenous knowledge to predict rainfall in the Yendi Municipality, Ghana. *GeoJournal*, *87*(4), 2805–2816. https://doi.org/10.1007/s10708-021-10403-8

Amponsah, P. (2022). Natural Hazards Governance in Ghana. In *Oxford Research Encyclopedia of Natural Hazard Science*.

https://oxfordre.com/naturalhazardscience/display/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-444

Appeaning Addo, K., Larbi, L., Amisigo, B., & Ofori-Danson, P. K. (2011). Impacts of Coastal Inundation Due to Climate Change in a Cluster of Urban Coastal Communities in Ghana, West Africa. *Remote Sensing*, *3*(9), Article 9. https://doi.org/10.3390/rs3092029

Arfasa, G. F., Sekyere, E. O., & Doke, D. A. (2024). Temperature and precipitation trend analysis using the CMIP6 model in the Upper East region of Ghana. *All Earth*, *36*(1), 1–14. https://doi.org/10.1080/27669645.2023.2290966

Babanawo, D., Mattah, P. A. D., Agblorti, S. K. M., & Aheto, D. W. (2023). Perspectives on factors that influence local communities' vulnerability to coastal floods in Ketu South Municipality of Ghana. *International Journal of Disaster Risk Reduction*, *90*, 103646. https://doi.org/10.1016/j.ijdrr.2023.103646

Babanawo, D., Mattah, P. A. D., Agblorti, S. K. M., Brempong, E. K., Mattah, M. M., & Aheto, D. W. (2022). Local Indicator-Based Flood Vulnerability Indices and Predictors of Relocation in the Ketu South Municipal Area of Ghana. *Sustainability*, *14*(9), Article 9. https://doi.org/10.3390/su14095698

Baffour-Ata, F., Antwi-Agyei, P., Apawu, G. O., Nkiaka, E., Amoah, E. A., Akorli, R., & Antwi, K. (2021). Using traditional agroecological knowledge to adapt to climate change and variability in the Upper East Region of Ghana. *Environmental Challenges*, *4*, 100205. https://doi.org/10.1016/j.envc.2021.100205

Baffour-Ata, F., Antwi-Agyei, P., Nkiaka, E., Dougill, A. J., Anning, A. K., & Kwakye, S. O. (2022). *Climate Information Services Available to Farming Households in Northern Region, Ghana*. https://doi.org/10.1175/WCAS-D-21-0075.1

Boateng, I. (2012). An assessment of the physical impacts of sea-level rise and coastal adaptation: A case study of the eastern coast of Ghana. *Climatic Change*, *114*(2), 273–293. https://doi.org/10.1007/s10584-011-0394-0

Boateng, I., Wiafe, G., & Jayson-Quashigah, P.-N. (2017). Mapping Vulnerability and Risk of Ghana's Coastline to Sea Level Rise. *Marine Geodesy*, *40*(1), 23–39. https://doi.org/10.1080/01490419.2016.1261745

Bray, M., Hooke, J., & Carter, D. (1997). Planning for Sea-Level Rise on the South Coast of England: Advising the Decision-Makers. *Transactions of the Institute of British Geographers*, *22*(1), 13–30.

Brempong, E. K., Almar, R., Angnuureng, D. B., Mattah, P. A. D., Jayson-Quashigah, P.-N., Antwi-Agyakwa, K. T., & Charuka, B. (2023). Coastal Flooding Caused by Extreme Coastal Water Level at the World Heritage Historic Keta City (Ghana, West Africa). *Journal of Marine Science and Engineering*, *11*(6), Article 6. https://doi.org/10.3390/jmse11061144

Dedekorkut-Howes, A., Torabi, E., & Howes, M. (2020). When the tide gets high: A review of adaptive responses to sea level rise and coastal flooding. *Journal of Environmental Planning and Management*, *63*(12), 2102–2143.

https://doi.org/10.1080/09640568.2019.1708709

DHI Water & Environment. (2007, November 19). *MIKE 21 Wave Modelling - MIKE 21 SW - Spectral Waves FM*.

https://www.dhigroup.com/upload/dhisoftwarearchive/shortdescriptions/marine/SpectralWaveModuleMIKE21SW.pdf

Dinku, T. (2019). Chapter 7—Challenges with availability and quality of climate data in Africa. In A. M. Melesse, W. Abtew, & G. Senay (Eds.), *Extreme Hydrology and Climate Variability* (pp. 71–80). Elsevier. https://doi.org/10.1016/B978-0-12-815998-9.00007-5

Dinku, T., Faniriantsoa, R., Islam, S., Nsengiyumva, G., & Grossi, A. (2022). The Climate Data Tool: Enhancing Climate Services Across Africa. *Frontiers in Climate*, *3*. https://doi.org/10.3389/fclim.2021.787519

Dodla, V. B. R. (2022). *Numerical Weather Prediction*. CRC Press. https://doi.org/10.1201/9781003354017

Donatti, C. I., Nicholas, K., Fedele, G., Delforge, D., Speybroeck, N., Moraga, P., Blatter, J., Below, R., & Zvoleff, A. (2024). Global hotspots of climate-related disasters. *International Journal of Disaster Risk Reduction*, *108*, 104488. https://doi.org/10.1016/j.ijdrr.2024.104488

Fernández-Nóvoa, D., González-Cao, J., & García-Feal, O. (2024). Enhancing Flood Risk Management: A Comprehensive Review on Flood Early Warning Systems with Emphasis on Numerical Modeling. *Water*, *16*(10), Article 10. https://doi.org/10.3390/w16101408

Gbangou, T., Slobbe, E. V., Ludwig, F., Kranjac-Berisavljevic, G., & Paparrizos, S. (2021). *Harnessing Local Forecasting Knowledge on Weather and Climate in Ghana: Documentation, Skills, and Integration with Scientific Forecasting Knowledge*. https://doi.org/10.1175/WCAS-D-20-0012.1

Gbedemah, S. F. (2023). Eruditing from indigenous adaptation strategies for resilient and sustainable coastal erosion management in southeastern Ghana. *Discover Sustainability*, *4*(1), 12. https://doi.org/10.1007/s43621-023-00123-z

Ghanaian Times. (2022, January 27). *Puveme in Anlo District rendered ghost town after tidal waves destruction*. Ghanaian Times. https://ghanaiantimes.com.gh/puveme-in-anlo-district-rendered-ghost-town-after-tidal-waves-destruction/

GhanaWeb. (2018, September 26). *Tidal waves swallow Fuveme*. GhanaWeb. https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Tidal-waves-swallow-Fuveme-687963

Ghann, P. (2020). Overhauling the Activities of Ghana Meteorological Agency through ICT. *All Nations University Journal of Applied Thought*, 213–227.

https://doi.org/10.47987/WUJJ3470

Harley, M. D., & Kinsela, M. A. (2022). CoastSnap: A global citizen science program to monitor changing coastlines. *Continental Shelf Research*, *245*, 104796. https://doi.org/10.1016/j.csr.2022.104796

Hauser, D., Abdalla, S., Ardhuin, F., Bidlot, J.-R., Bourassa, M., Cotton, D., Gommenginger, C., Evers-King, H., Johnsen, H., Knaff, J., Lavender, S., Mouche, A., Reul, N., Sampson, C., Steele, E. C. C., & Stoffelen, A. (2023). Satellite Remote Sensing of Surface Winds, Waves, and Currents: Where are we Now? *Surveys in Geophysics*, *44*(5), 1357–1446. https://doi.org/10.1007/s10712-023-09771-2

Herrada Mederer, E. A., Puigdefàbregas Sagristà, J., Villalonga Llauger, J., Gomis Bosch, D., & Jordà Sánchez, G. (2024). Empowering citizen science in coastal oceanography through low-cost open source devices: The SECOSTA project at the intersection of technology and education. *Instrumentation Viewpoint*, *23*, 38–39.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., … Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, *146*(730), 1999–2049. https://doi.org/10.1002/qj.3803

Hirabayashi, T. (2020). *Contribution of JAXA's Earth Observation Missions to Water Cycle and Climate Studies, Disaster Mitigation, and Operational Applications* (Nos. EGU2020-19165). EGU2020. Copernicus Meetings. https://doi.org/10.5194/egusphere-egu2020-19165

Ile, I. U., & Garr, E. Q. (2011). Infrastructure policy reforms and rural poverty reduction in Ghana: Perspectives from the Keta Sea Defence Project. *African Journal of Governance and Development*, *1*(1), 39–57. https://doi.org/10.10520/EJC195207

Jain, S. K., Mani, P., Jain, S. K., Prakash, P., Singh, V. P., Tullos, D., Kumar, S., Agarwal, S. P., & Dimri, A. P. (2018). A Brief review of flood forecasting techniques and their applications. *International Journal of River Basin Management*, *16*(3), 329–344. https://doi.org/10.1080/15715124.2017.1411920

Kasapa. (2015, December 10). *Tidal waves destroy Fuveme, Kporkporgbor communities*. https://kasapafmonline.com/?p=30527

Kaspar, F., Andersson, A., Ziese, M., & Hollmann, R. (2022). Contributions to the Improvement of Climate Data Availability and Quality for Sub-Saharan Africa. *Frontiers in Climate*, *3*. https://doi.org/10.3389/fclim.2021.815043

Lamptey, B., Sahabi Abed, S., Gudoshava, M., Mutemi, J., Bopape, M.-J., Adefisan, E. A., Igri, M. P., Seidou Sanda, I., Ndiaye, O., Parker, D. J., Dougill, A. J., Fink, A. H., Knippertz, P., Woolnough, S., & Kolstad, E. W. (2024). Challenges and ways forward for sustainable weather and climate services in Africa. *Nature Communications*, *15*(1), 2664. https://doi.org/10.1038/s41467-024-46742-6

Lavidas, G., & Venugopal, V. (2018). Application of numerical wave models at European coastlines: A review. *Renewable and Sustainable Energy Reviews*, *92*, 489–500. https://doi.org/10.1016/j.rser.2018.04.112

Liu, Q., Feng, X., & Tang, T. (2022). A Machine Learning Model for Wave Prediction Based on Support Vector Machine. *International Journal of Offshore and Polar Engineering*, *32*(4), 394–401. Scopus. https://doi.org/10.17736/ijope.2022.jc879

Malone, E. (2013). Climate Change and National Security. *Weather, Climate, and Society*, *5*. https://doi.org/10.1175/WCAS-D-12-00016.1

Manteaw, B. O., Amoah, A.-B., Ayittah, B., & Enu, K. B. (2022). Climate-Informed Decision-Making in Data-Poor Environments: Managing Climate Risk Through Citizen Science Networks. *Frontiers in Climate*, *4*. https://doi.org/10.3389/fclim.2022.835768

Mattah, M. M., Mattah, P. A. D., Mensah, A. M., Adarkwah, F., Mensah, J., & Addo, K. A. (2024). Community perceptions, knowledge, and coping mechanisms concerning perennial climate change-related disasters along the Volta estuary of Ghana, West Africa. *Scientific African*, *25*, e02333. https://doi.org/10.1016/j.sciaf.2024.e02333

MESTI. (2013). *National Climate Change Policy*.

https://www.epa.gov.gh/epa/sites/default/files/downloads/publications/National%20Climate%20Change%20Policy.pdf

Mohanty, A., Dubey, A., & Singh, R. B. (2022). The Application of Early Warning System in India. In A. Mohanty, A. Dubey, & R. B. Singh (Eds.), *Cyclonic Disasters and Resilience: An Empirical Study on South Asian Coastal Regions* (pp. 65–102). Springer Nature. https://doi.org/10.1007/978-981-19-1215-3_3

Nairn, R. B., & Dibajnia, M. (2004). Design and Construction of a Large Headland System, Keta Sea Defence Project, West Africa. *Journal of Coastal Research*, 294–314.

Nairn, R. B., MacIntosh, K. J., Hayes, M. O., Nai, G., Anthonio, S. L., & Valley, W. S. (2015). *Coastal Erosion at Keta Lagoon, Ghana – Large Scale Solution to a Large Scale Problem*. 3192–3205. https://doi.org/10.1061/9780784404119.242

NATO. (2021, June 14). *NATO Climate Change and Security Action Plan*. NATO - NATO Climate Change and Security Action Plan, 14-Jun.-2021.

https://www.nato.int/cps/en/natohq/official_texts_185174.htm

Nyadzi, E., Werners, S. E., Biesbroek, R., & Ludwig, F. (2022). Towards weather and climate services that integrate indigenous and scientific forecasts to improve forecast reliability and acceptability in Ghana. *Environmental Development*, *42*, 100698. https://doi.org/10.1016/j.envdev.2021.100698

Oluwagbemi, O. O., Hamutoko, J. T., Fotso-Nguemo, T. C., Lokonon, B. O. K., Emebo, O., & Kirsten, K. L. (2022). Towards Resolving Challenges Associated with Climate Change Modelling in Africa. *Applied Sciences*, *12*(14), Article 14. https://doi.org/10.3390/app12147107

Overpeck, J. T., Meehl, G. A., Bony, S., & Easterling, D. R. (2011). Climate Data Challenges in the 21st Century. *Science*, *331*(6018), 700–702. https://doi.org/10.1126/science.1197869

Owusu, V., & Andriesse, E. (2023). Local Differentiation and Adaptation to Climate Change in Coastal Ghana. *Geographical Review*, *113*(3), 337–358.

https://doi.org/10.1080/00167428.2021.2023530

Parmar, R. M., Arora, R. K., Rao, M. V., & Thyagarajan, K. (2006). Oceansat 2: Mission and its applications. *GEOSS and Next-Generation Sensors and Missions*, *6407*, 62–73. https://doi.org/10.1117/12.697883

Perera, D., Seidou, O., Agnihotri, J., Mohamed Rasmy, A. W., Smakhtin, V., Coulibaly, P., & Mehmood, H. (2019). *Flood Early Warning Systems: A Review Of Benefits, Challenges And Prospects*. https://doi.org/10.13140/RG.2.2.28339.78880

Pienaah, C. K. A., Batung, E., Saaka, S. A., Mohammed, K., & Luginaah, I. (2023). Early Warnings and Perceived Climate Change Preparedness among Smallholder Farmers in the Upper West Region of Ghana. *Land*, *12*(10), Article 10. https://doi.org/10.3390/land12101944

Rogers, D., & Tsirkunov, V. (2011). Costs and benefits of early warning systems. *Global Assessment Rep*.

Saha, S., Moorthi, S., Pan, H.-L., Wu, X., Wang, J., Nadiga, S., Tripp, P., Kistler, R., Woollen, J., Behringer, D., Liu, H., Stokes, D., Grumbine, R., Gayno, G., Wang, J., Hou, Y.-T., Chuang, H., Juang, H.-M. H., Sela, J., … Goldberg, M. (2010). *The NCEP Climate Forecast System Reanalysis*. https://doi.org/10.1175/2010BAMS3001.1

Sene, K. (2008). *Flood Warning, Forecasting and Emergency Response*. Springer. https://doi.org/10.1007/978-3-540-77853-0

The Wamdi Group. (1988). *The WAM Model—A Third Generation Ocean Wave Prediction Model*. https://journals.ametsoc.org/view/journals/phoc/18/12/1520-0485_1988_018_1775_twmtgo_2_0_co_2.xml

Thomas, T. J., & Dwarakish, G. S. (2015). Numerical Wave Modelling – A Review. *Aquatic Procedia*, *4*, 443–448. https://doi.org/10.1016/j.aqpro.2015.02.059

Tolman, H. L. (2009, May). *User manual and system documentation of WAVEWATCH III TM version 3.14*. https://polar.ncep.noaa.gov/mmab/papers/tn276/MMAB_276.pdf

Tucci, C. E. (2003). Flood flow forecasting. *Bulletin of the World Meteorological Organization*, *52*(1), 46–52.

United Nations. (2006). *Global Survey of Early Warning Systems* (p. 46). United Nations. https://www.unisdr.org/2006/ppew/info-resources/ewc3/Global-Survey-of-Early-Warning-Systems.pdf

United Nations Office for Disaster Risk Reduction. (2009). *2009 UNISDR terminology on disaster risk reduction*. https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction

Verhulst, S. (2024). *The Need for Climate Data Stewardship: 10 Tensions and Reflections regarding Climate Data Governance* (No. arXiv:2403.18107). arXiv. https://doi.org/10.48550/arXiv.2403.18107

Wu, W., Emerton, R., Duan, Q., Wood, A. W., Wetterhall, F., & Robertson, D. E. (2020). Ensemble flood forecasting: Current status and future opportunities. *WIREs Water*, *7*(3), e1432. https://doi.org/10.1002/wat2.1432

Yamba, E. I., Aryee, J. N. A., Quansah, E., Davies, P., Wemegah, C. S., Osei, M. A., Ahiataku, M. A., & Amekudzi, L. K. (2023). Revisiting the agro-climatic zones of Ghana: A re-classification in conformity with climate change and variability. *PLOS Climate*, *2*(1), e0000023. https://doi.org/10.1371/journal.pclm.0000023

Yankson, P. W. K., Owusu, A. B., Owusu, G., Boakye-Danquah, J., & Tetteh, J. D. (2017). Assessment of coastal communities' vulnerability to floods using indicator-based approach: A case study of Greater Accra Metropolitan Area, Ghana. *Natural Hazards*, *89*(2), 661–689. https://doi.org/10.1007/s11069-017-2985-1

Zängl, G. (2013, September). *ICON: The Icosahedral Nonhydrostatic Modelling Framework of DWD and MPI-M*. ECMWF Seminar on Numerical Methods for Atmosphere and Ocean Modelling. https://www.ecmwf.int/sites/default/files/elibrary/2014/76999-icon-icosahedral-nonhydrostatic-modelling-framework-dwd-and-mpi-m_0.pdf

Zhan, K., Li, C., & Zhu, R. (2023). A frequency domain-based machine learning architecture for short-term wave height forecasting. *Ocean Engineering*, *287*, 115844. https://doi.org/10.1016/j.oceaneng.2023.115844

Zhao, J., Cai, R., & Sun, W. (2021). Regional sea level changes prediction integrated with singular spectrum analysis and long-short-term memory network. *Advances in Space Research*, *68*(11), 4534–4543. https://doi.org/10.1016/j.asr.2021.08.017

11

Leveraging Solar Photovoltaics: A Triple-Win Strategy to Address Ghana's Energy Trilemma of Security, Affordability, and Sustainability

Griselda Asamoah-Gyadu and Phil Faanu

Abstract

Ghana struggles with the interconnected challenges of energy security, affordability, and sustainability - globally referred to as the energy trilemma. High electricity costs, mainly due to emergency procurement measures and unfavourable currency exchange rates, create affordability issues. Furthermore, reliance on traditional energy sources hampers sustainability efforts and hinders commitments to decarbonisation, meeting climate goals, and ensuring the sustainability of its energy provision. As Ghana grapples with rising energy demands, environmental commitments, and affordability concerns, solar PV presents an increasingly viable option to diversify its energy mix. This research examines the use of Solar PV technologies and addresses the energy trilemma, specifically in rural areas. It does this by presenting these technologies as a triple-win approach facilitated through the concept of Climate Compatible Development (CCD). The CCD framework employs a triple-win strategy designed to lower emissions (mitigation), build resilience (adaptation), and promote other socio-economic development objectives (employment, investments). Applying this framework to the energy sector (specifically power generation), a CCD 'triple win' ensures low carbon climate resilient development. This approach can be realised through clean, efficient, and reliable energy sources, which promote livelihood diversification, provide critical infrastructure, and strengthen local institutions. We draw data from energy reports, policy analyses, and pilot projects highlighting how solar PV can alleviate grid dependency, reduce fuel imports, and support climate targets to achieve these research goals.

Keywords: Tripple Win, Energy Trilemma, Solar PV, Sustainability

Introduction

Ghana faces a pressing energy trilemma characterised by the need to ensure energy security, maintain affordability, and achieve sustainability. As the country's economy and population grow, energy demand surges, placing pressure on an already strained energy infrastructure. Some scholars have argued that the country's energy landscape is vulnerable to various external and internal challenges due to reliance on a mix of hydroelectric power, fossil fuel imports, and a small share of renewables. These challenges include climate variability, global fuel price fluctuations, unstable foreign exchange rates and technical inefficiencies (Amanfo & Puthenkalam, 2024; Shalman, 2024). These issues jeopardise reliable access to power and increase costs, making Ghana's industrial and residential energy consumers susceptible to high prices (Sefa-Nyarko, 2024).

Furthermore, as evident in the National Energy Transition Framework, Ghana is committed to climate goals that necessitate transitioning from fossil fuels to reduce greenhouse gas emissions. These targets further heighten the urgency for sustainable energy solutions. Addressing this trilemma requires a strategic approach that simultaneously strengthens energy security, maintains economic feasibility, and advances environmental objectives.

Solar photovoltaic (PV) technology has been noted to be a key driver for reduced greenhouse gas emissions from the energy sector. Solar PV is particularly well-suited for Ghana due to its high solar irradiation potential, making it a viable option for reducing reliance on hydropower and imported fossil fuels. Earlier research found that large-scale deployment of solar PV could mitigate the risks associated with climate-induced hydropower instability, minimise exposure to volatile oil markets, and support Ghana's sustainability goals by lowering carbon emissions (Atuahene & Sheng, 2023; Ingo et al., 2024). However, despite these benefits, challenges such as intermittency and poor macroeconomic conditions that offset the reducing cost of solar PVs continue to undermine their ability to become a major power generation source in Ghana. Thus, a key question arises as to whether solar PV could solve Ghana's energy trilemma.

This chapter explores the use of solar PV technologies to solve energy trilemma, specifically in Ghana's rural areas. It does this by presenting these technologies as a triple-win approach facilitated through the concept of Climate Compatible Development (CCD hereafter) designed to lower emissions (mitigation), build resilience (adaptation), and promote other socio-economic development objectives (employment, investments). Through a comprehensive analysis of Ghana's energy landscape and the role of solar PV under this framework, this study presents a pathway toward a more secure, affordable, and sustainable energy future for the country.

Literature Review

Global Energy Trilemma in a Ghanaian Context

The global energy trilemma stems from three major elements (Energy Security, Energy Equity and Environmental Sustainability) stipulated by the World Energy Council in 2018 (Afful-Dadzie *et al*., 2020; Fleming, 2021). The issue of **energy security** is recognised to originate from the 1987 Brundtland report, where a chapter of the report concluded that "a safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative" (Brundtland et al., 1987, p. 21). Energy security simply implies a reliable and adequate supply of energy. It also concerns the availability of natural resources for energy consumption (Flaherty & Filho, 2013). On the other hand, **energy equity** refers to the affordability and equitable distribution of energy among people (Roberts, 2008; Tarekegne *et al.*, 2021). **Environmental sustainability** deals with energy sources' climate and environmental impact, ensuring they have a minimal carbon footprint and contribute to global emission targets (Dincer & Rosen, 1998). In other words, environmental sustainability is the practice of interacting with the planet responsibly.

The energy trilemma is a global challenge, but its impact is more pronounced in the Global South. According to reports from the International Energy Agency (IEA), approximately 600 million people in Sub-Saharan Africa lack access to electricity, with rural areas experiencing even more severe deficits (IEA, 2023). The IEA's Africa Energy Outlook 2022 highlights that rural electrification rates remain disproportionately low, exacerbating economic and social inequalities.

This underscores the urgent need for strategic interventions to expand energy access, particularly in underserved communities.

Ghana's energy mix comprises thermal, hydro, and a modest share of non-hydro renewable sources. However, the country's energy sector faces significant challenges beyond frequent power outages. These include infrastructure limitations, financial constraints, regulatory inefficiencies, and the need for diversified energy sources. Addressing these challenges necessitates a strategic reorientation in Ghana’s energy planning to ensure a sustainable, cost-effective, and reliable power supply that supports economic growth. This section provides a comprehensive review of Ghana’s power sector, examining its structure, challenges, and prospects through the lens of the energy trilemma.

Energy Security

Ghana’s energy mix has undergone a significant transformation, shifting from a predominant reliance on hydroelectric power to include a substantial share of thermal generation. This transition was driven by recurring power crises, particularly in the late 1990s and early 2000s, when severe drops in water levels at the Akosombo Dam, Ghana’s largest hydroelectric facility, led to widespread electricity shortages. At the turn of the millennium, hydro accounted for approximately 92% of Ghana’s total installed capacity (Energy Commission, 2023). However, the country has since expanded its thermal generation capacity, relying mainly on natural gas, to surpass hydro as the dominant source of electricity generation. As of 2024, Ghana’s total installed capacity is approximately 5,500 MW, with thermal power contributing about 69%, while hydro accounts for around 29% (Energy Commission, 2025). Renewable energy contributes only a marginal share to Ghana’s energy mix, making up approximately **2.1%** of the total installed capacity as of **2024.**

Although there are clearly outlined plans to improve the energy situation in its energy policy documents, Ghana still struggles with reliable access to electricity (Energy Commission, 2023). The Energy Commission reports that a number of areas in rural Ghana lack access to electricity altogether, and areas that have access frequently experience erratic supply of electricity. Many factors contribute to these erratic shortages, including lower hydro dam levels, fuel shortages, and other operational challenges in transmission and distribution systems (see Gyamfi *et al*., 2015; Owusu *et al*., 2022).

The issues characterising the country's power supply affect Ghanaian businesses, leading to unemployment and livelihood crises, especially among rural people. In the past, these energy-related issues have caused public protests against the government's lack of strategy and commitment to address the crises, which was christened "*Dumsor*" (Destrée, 2019). The energy crisis played a role in the defeat of the ruling **National Democratic Congress** in the **2016 general elections**. The opposition party at the time, the **New Patriotic Party (NPP)**, capitalised on the situation by branding then-President **John Dramani Mahama** as the *"Dumsor President,"* a reference to the persistent power outages. This label became a popular campaign slogan and contributed to the NDC's loss (Agomor et al., 2023). It is, therefore, plausible to posit that over the years, citizens' protestation and dissent against the energy sector have been informed by a perceived lack of government initiative in dealing with these issues (Nyabor, 2021).

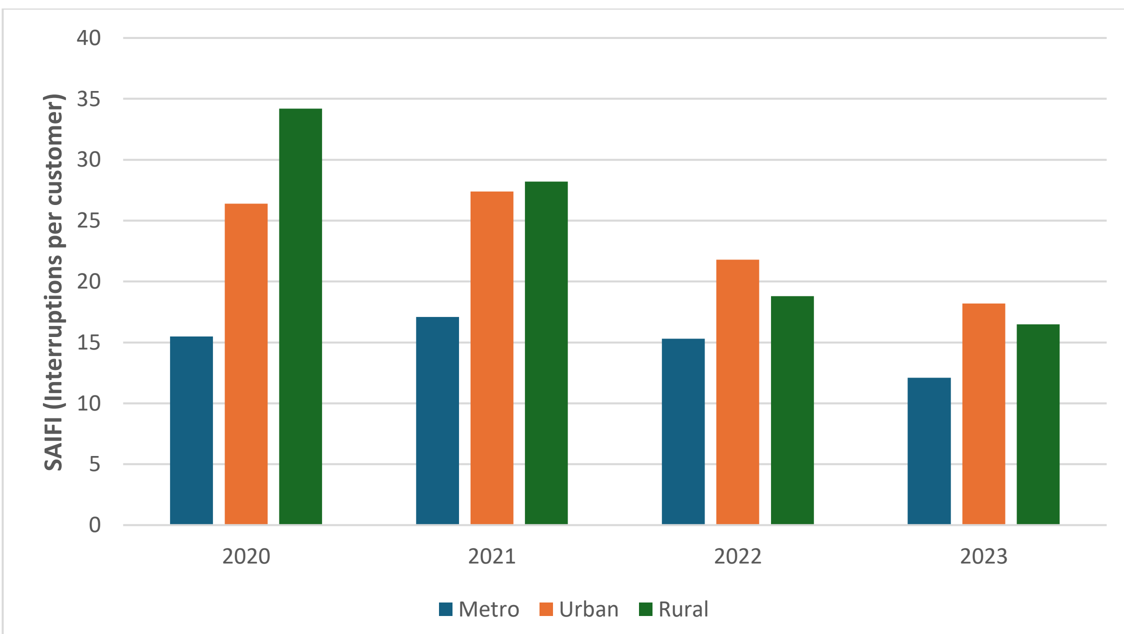
In the run-up to the 2016 experiences, some had argued that Ghana's power outages were a result of over-reliance on hydro, yet, even with the addition of thermal energy into the local energy mix, the supply of energy for power generation remains a problem (Gyamfi et al., 2015). As such, energy security issues, as conceptually understood under the trilemma framework, remain an essential area for Ghana to address if the country aims to achieve sustainable and equitable energy distribution and access. Within this context, we assert that Ghana's rural electrification and energy access, as well as the potential to address the energy challenges, can be facilitated by large-scale investment in Solar PV sources of energy generation. This investment will cause large-scale deployment of these energy technologies to help provide triple-win solutions in the country's energy sector and contribute to its net-zero efforts.

Energy Equity

In addition to the unreliable energy supply in Ghana, the country's energy sector is also characterised by issues of affordability and equity in distribution. Energy equity is critical in Ghana, as access to affordable and reliable energy remains uneven across different regions and socio-economic groups. Despite considerable efforts to expand electricity access through initiatives like the National Electrification Scheme, a significant disparity exists between urban and rural areas. While urban centres and wealthier households often benefit from more stable power supplies, rural communities—particularly those in remote or underdeveloped areas—frequently experience limited or no access to electricity (Nduhuura et al., 2021).

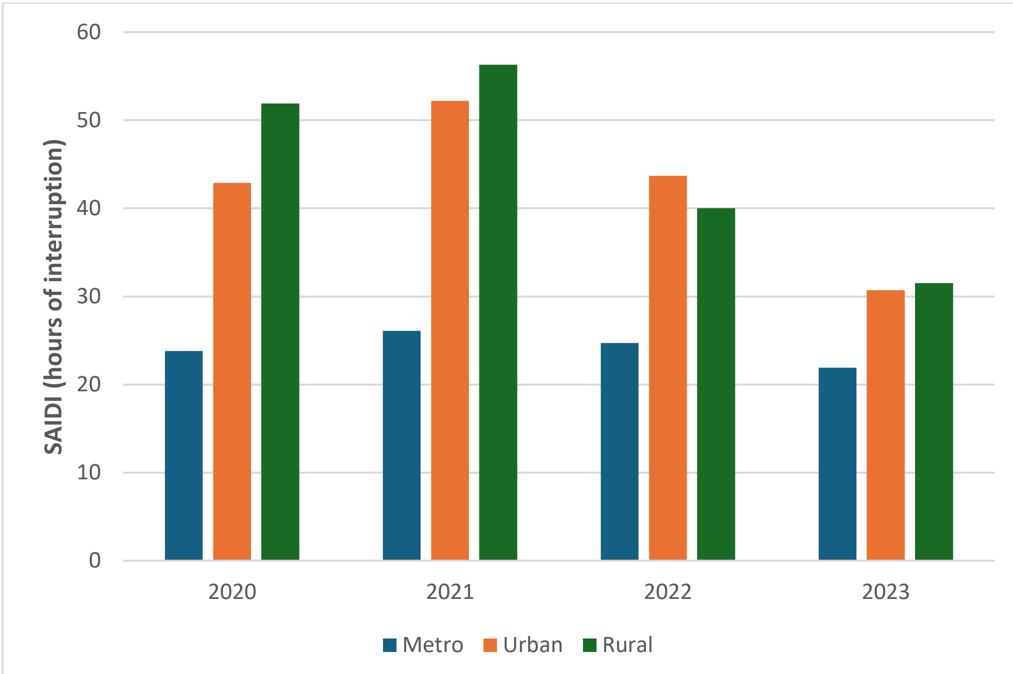
The frequency and duration of power interruptions, measured by the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI), are significantly higher in rural areas than in urban centres. In 2023, rural areas experienced an average SAIFI of 16.5 and a SAIDI of 31.5 hours, while urban areas recorded lower averages of 12.1 interruptions and 22 hours of outage duration. These disparities highlight the growing inequities in energy distribution, with rural communities facing greater challenges in accessing reliable electricity compared to urban populations in Ghana. Elsewhere, Riva et al. (2018) established that energy disparity restricts rural economic opportunities, exacerbates poverty, and limits access to essential services such as healthcare and education, which increasingly rely on electricity for effective operation.

Figure 1: SAIFI values for Electricity Company of Ghana (2020-2023)



Source: Energy Commission (2024)

Figure 2: SAIDI values for Electricity Company of Ghana (2020-2023)



Source: Energy Commission (2024)

The lack of access to energy worsens social inequality; as Jain et al. (2015) observed, rural households and lowest-income individuals pay more for electricity. Affordability, therefore, becomes an essential element of energy equity. Many low-income households in Ghana struggle to afford rising electricity tariffs, often consuming a disproportionate share of household income. According to Debrah et al. (2020) and Diawuo et al. (2020), the reliance on imported fossil fuels and the costs associated with infrastructure maintenance and expansion have contributed to higher energy prices. This situation is further complicated by subsidies that do not always reach the most vulnerable, leading to inequities within the subsidy system. For instance, Lindebjerg et al. (2015) asserted that Ghana's energy subsidies result in consumer price reductions.

Table 1 provides an illustration of energy distribution across the country. It reveals that some regions have a higher percentage of universal and household access to electricity than others (Energy Commission Ghana, 2023). As illustrated in Table 1 below, Greater Accra, Ashanti and Western regions, predominantly urban, have over 90% access to electricity. The bottom three regions, with an access rate of less than 75%, are located in northern Ghana and have dominant rural populations.

Table 1: Regional Population and Household access to electricity in Ghana

Region	% of Household Access
Greater Region	99.3
Bono Region	95.8
Ashanti Region	95.5
Western Region	94.5
Central Region	93.7
Volta Region	92.8
Eastern Region	90.7
Ahafo Region	84.2
Northern Region	82.2
Upper West Region	81.1
Western North Region	81.1
Bono East Region	79.8
Oti Region	75.1
Northeast Region	74.3
Upper East Region	65.5
Savannah Region	61.3

Source: Compiled from Energy Commission Ghana Energy Statistical Bulletin (2023)

Additionally, despite Ghana's commitment to renewable energy and reducing greenhouse gas emissions, it is safe to argue that the high cost of solar PV promotes accessibility among wealthier households and businesses, leaving low-income and rural communities reliant on less sustainable energy sources. Addressing these energy equity challenges will require policy interventions prioritising subsidies in Solar PV investment in rural electrification and efforts to make Solar PV technologies more accessible across all socio-economic levels.

Sustainability

Energy sustainability takes its conceptual meaning from the sustainable development framework of the 1987 Brundtland report, where sustainable development is defined as development that aims to meet the needs of the present without compromising the ability of future generations to meet their own needs. Similarly, sustainable energy involves using clean and renewable energy sources, such as wind, wave, and solar energy, instead of depletable sources like fossil fuels (Kaushika et al., 2016). Therefore, the definition of sustainable energy prioritises the effects of energy production on the environment, the economy, and society.

Energy sustainability is a key component of Ghana's energy trilemma, representing the challenge of balancing environmental stewardship with growing energy demands. As Ghana seeks to meet rising electricity needs, sustainability concerns have emerged due to the high environmental costs associated with current energy sources. Hydropower, one of the primary sources of power generation in Ghana, is increasingly susceptible to climate-related challenges like drought, which reduces water availability and, thus, energy production (Falchetta et al., 2019). Similarly, as alluded to earlier, reliance on imported fossil fuels not only incurs high costs but also contributes to greenhouse gas emissions, conflicting with the climate commitments under international frameworks like the Paris Agreement.

Even though Ghana is geographically located outside the Sahara Desert region of Africa, the country is predisposed to climate vulnerability. It is thus essential that technological innovation and investment in energy production prioritise environmental sustainability to mitigate climate crisis and ensure climate resilience among Ghanaians. To enhance sustainability, Ghana must explore Solar PV and wind energy options, which offer low-emission alternatives that can help diversify its energy mix (Shahsavari & Akbari, 2018). However, we recognise transitioning to these sources requires substantial investment, supportive policies, and infrastructure upgrades to ensure they are viable and accessible across rural areas.

Balancing sustainable energy solutions with energy security and affordability is important within Ghana's energy trilemma. A key approach to achieving this is integrating low-carbon energy sources supporting climate adaptation and socio-economic development. This is where the triple-win framework becomes crucial in addressing the climate-energy nexus. The strength of the triple-win approach lies in its ability to simultaneously address climate adaptation, mitigation, and socio-economic development (Stringer et al., 2014). Energy solutions must not only contribute to emissions reduction but also enhance resilience and provide tangible socio-economic benefits. A gain in one area should not come at the expense of another, as this would worsen existing climate, energy, or development challenges. Instead, solutions must work together to achieve a true "triple win" that fosters long-term sustainability.

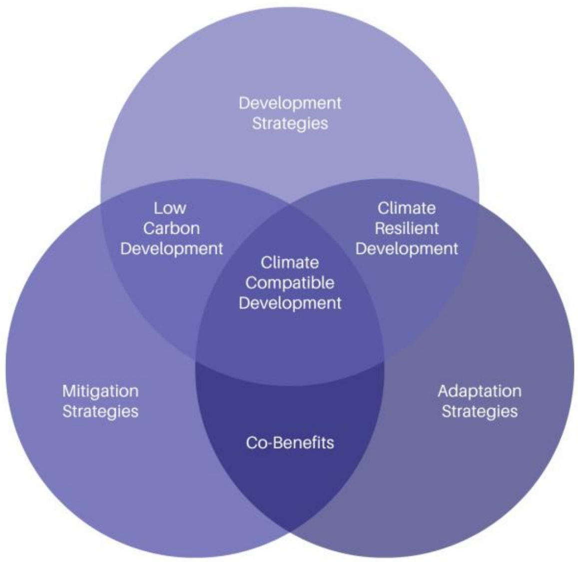
Conceptual Framework: Climate Compatible Development (CCD) and Triple-Win Approach

Mitchell and Maxwell (2010) presented Climate Compatible Development as a triple-win approach that simultaneously addresses issues of climate adaptation, mitigation and development. These authors defined CCD as "development that minimises the harm caused by climate impacts while maximising the many human development opportunities presented by a low emission, more resilient future" (Mitchell and Maxwell, 2010, p.1).

Climate Compatible Development (CCD) achieves multiple goals through integrated actions, as shown in Figure 3. It assesses how to link mitigation, adaptation, and development strategies cost-effectively, leading to low-carbon development, climate resilience, and broader co-benefits (Ficklin et al., 2018). CCD counters the argument that green transitions harm economic progress by demonstrating that they can simultaneously reduce emissions and generate socio-economic benefits like job creation and skills development. Furthermore, many adaptation efforts, such as gender mainstreaming capacity building, inherently support development by strengthening communities' ability to cope with climate change (Mitchell & Maxwell, 2010).

CCD is intended to be a deliberate framework where policymakers specifically design solutions to meet this triple win. However, Robinson et al. (2022) have also argued that it can come across as unintentional, in the sense that policy decisions made to address one component of CCD may end up positively affecting another. For instance, the **Honiara Urban Resilience and Climate Action Plan** in the **Solomon Islands** prioritised climate adaptation by constructing resilient infrastructure to mitigate flooding from heavy rainfall. Similarly, **Hawaii's Aloha Clean Energy Transformation Plan** aimed to reduce

Figure 3: Mitchell and Maxwell's (2010) CCD Framework



carbon emissions but also contributed to broader development goals, such as promoting climate action (SDG 13), reducing poverty (SDG 1), and ensuring access to clean and affordable energy (SDG 7). These examples demonstrate how policies can align with CCD principles, even if not explicitly framed as such.

This chapter argues that when CCD is **intentionally and systematically applied**, it has the potential to yield even greater results. This argument is plausible because a **deliberate** CCD approach allows for comprehensive planning, resource optimisation, and the anticipation of synergies across policy areas.

The Dominican Republic's policy efforts to reduce carbon emissions in its waste and cement sectors exemplify the climate-compatible development (CCD) framework, aiming for climate and socio-economic co-benefits (Suckall & Tompkins, 2020). However, achieving a "triple-win" through CCD often involves multi-sectoral and multi-level trade-offs, requiring difficult decisions about prioritising competing goals (Ficklin et al., 2018). For instance, national-level collaboration between traditionally separate sectors may necessitate negotiations about emission allowances to support development and adaptation in other areas (Stringer et al., 2014). This multi-sectoral approach has been applied in coastal regions of Belize, Ghana, Kenya, and Vietnam, linking tourism and fisheries development with adaptation by recognising their shared dependence on healthy coastal ecosystems (Tompkins et al., 2013). It is also important to note that CCD can be implemented in individual projects, not solely through multi-sectoral initiatives (Mitchell & Maxwell, 2010)

Generally, the literature on CCD recognises the difficulty in operationalising the framework, as some scholars conflate low-carbon, climate-resilient, and sustainable development (Ficklin et al., 2018). Suckall and Tompkins (2020) also argue that these concepts are difficult to measure as there is a lack of clarity on how these triple-wins and the distributional consequences of CCD can be properly evaluated. England et al. (2018) have created classification schemes to operationalise the various concepts under the CCD, assigning numeric values to projects that have achieved triple wins and double wins with and without regrets. Regrets here imply losses from trying to achieve climate adaptation, mitigation and development, which might include generating electricity from carbon-intensive sources.

While CCD presents conceptual and operational challenges, these can be tackled through **greater conceptual clarity, enhanced measurement tools, a balance between theory and practice, and increased empirical engagement**. CCD can move beyond an abstract framework to a **practical and impactful approach** to sustainable development by **refining definitions, improving evaluation methods, and showcasing real-world applications**. This chapter upholds CCD as an appropriate framework for analysing the triple-win effects of Ghana's quest for energy security, equity and sustainability as the country seeks to achieve its net-zero goals. It employs CCD to explore the viability of Solar PV to address the energy trilemma.

This triple-win helps address the energy trilemma as energy solutions that address climate adaptation and mitigation challenges eventually address the environmental sustainability facet of the trilemma. Also, the realisation of energy security and equity under the applied CCD invariably results in socio-economic development, creating more economic growth opportunities. In the energy sector, CCD can manifest in off-grid Solar PV initiatives that support clean cooking, low carbon emissions, low deforestation (mitigation), quality health and resource efficiency (adaptation), zero-emission jobs and improved energy access (adaptation).

A Triple-Win in Context: Off-grid Solar PV for Ghana's Energy Trilemma

The advantage of off-grid solar PV solutions is their use of renewable energy, particularly given Ghana's abundant sunlight. They also offer the benefit of decentralised energy production, making electricity more accessible to rural populations. This is especially important for communities not connected to the national grid or frequently experiencing power outages (Bannor et al., 2023). This lack of access to the central grid is contributed by insufficient financial resources, making power generation and supply across all populations expensive (Merem et al., 2018).

Furthermore, another challenge associated with Ghana's energy trilemma is the growing energy leakages or losses through transmission and distribution. Hence, our proposed standalone solar PV systems become a more attractive approach to energy security, equity, sustainability and mitigation of these losses (Bannor et al., 2023). It is also a scalable solution to providing universal electrification, especially to these underserved communities, increasing energy access and promoting a low-carbon energy source to address the growing climate threats (Korzhenevych & Owusu, 2021). Nunan et al. (2017) indicate that it has the potential to provide pro-poor climate-resilient access to electricity where more vulnerable populations have access to a low-carbon and dependable supply of electricity to facilitate economic activity and also build household resilience.

To meet the socio-economic objectives associated with electricity access and achieve a triple-win in Ghana's energy sector, policymakers and industrial players must aim to ensure the availability of affordable and universal energy access. The importance of triple-wins lies in that confronting one facet of the issue must address the other aspect of the energy trilemma but not aggravate the problem. As such, any clean energy technologies that come with additional costs to rural communities and their livelihoods while addressing the climate crisis will be unsustainable and negatively impact the vulnerable rural people.

Most of these rural people are already struggling to protect themselves and their livelihood sources from climate vulnerability, and such initiatives would be of great disservice. A case in point is the Kaleo Solar Plant in the Upper region of Ghana (Energy Commission, 2023).

The Kaleo 13 MW Solar PV plant, although providing solar energy to the community, has led to resource dispossessions. Land that served as a primary source of raw materials and traditional biomass (firewood) to facilitate household and economic activity was cleared for this solar plant (Stock et al., 2023). Considering that women are the principal users of these resources, this plant geared at climate mitigation has increased their vulnerability by threatening their livelihoods. The unique effects of this initiative on women and their livelihoods were not catered for, as priorities were on climate mitigation and providing clean energy to residents. However, the irony is that the government of Ghana's energy policy documents and other policy actions make provisions for gender mainstreaming in all sectors of the economy.

The **CCD framework does not inherently exclude social considerations** but emphasises **synergies among climate mitigation, adaptation, and development**. In cases like Kaleo, the issue lies not in deploying solar PV itself but in the **failure to incorporate just transition principles** and **gender-sensitive planning** in its implementation. In the following subsections, we briefly demonstrate some steps and actions Ghana can use to address energy trilemma, especially in rural communities.

A Low-Carbon Energy Source for Climate Mitigation.

Low-carbon energy is the starting point for a triple-win with power generation. This strategy has the potential to directly address the facet of the energy trilemma that deals with environmental sustainability. As of 2022, the Ghanaian energy sector contributed significantly to its total greenhouse gas (GHG) emissions, and a key constituent is due to thermal electricity generation through fossil fuels (Environmental Protection Agency, 2024). According to Ghana's EPA, increasing renewable energy penetration to 10% and fulfilling other plans outlined in the Renewable Energy Master Plan has the advantage of abating about 1514KtCO_2e of GHG emissions.

Improving access to electricity to mitigate climate change would be a sustainable and recommended way to net zero. Ghana is known to reflect strong climate ambition as it is touted to have a clear adaptation and mitigation outlook in its policy documents (Olajide et al., 2020). There is a clear sense and understanding of the rippling effects of decarbonised power generation, especially for vulnerable rural populations. Initiatives to produce clean energy through off-grid solar PV in rural communities can improve household resilience and promote poverty alleviation, which are major adaptation goals.

Ghana clearly shows its policy documents its intention to mitigate climate change by ensuring low-carbon electricity generation and increasing renewable energy integration. The country has taken pragmatic steps to replace fossil fuels with solar, wind, geothermal and nuclear power sources for its electrification as part of its decarbonisation strategies. These initiatives aim to result in 26% of the abatement of CO_2 by 2060 as opposed to “business-as-usual” (BAU) emissions (Ghana Energy Transition and Investment Plan - ETIP, 2023). This transition and investment plan recognises the instrumental role of decarbonised solar PV technologies in achieving a smooth transition, particularly in the country’s electrification project. As such, low-carbon technologies for electricity generation are central to Ghana’s decarbonisation framework, with solar PV a high priority among available technologies.

The ETIP electrification objectives involving Solar PV include: i) the deployment of solar PV starting in 2020 to reach 26 GW by 2040, and ii) the fast deployment of solar PV starting 2040 at 5GW/yr on average to reach 146 GW by 2060. The ETIP also anticipates a fifteen times per annum increase in power demand by 2060 due to projected population growth, higher incomes, and the need for electric transportation. These high demands for energy for socio-economic activities due to hikes in population can be met by the abundant production and deployment of Solar PV technologies, as solar energy is seen as a cost-effective and sustainable energy source. It is therefore unsurprising that Ghana has already started moving towards off-grid solar PVs, with some projects funded by foreign companies/partners, in line with its mitigation goal of “promotion of energy efficiency in homes, industry and commerce” as stated in its NDCs/Nationally Determined Contributions (MESTI, 2021).

However, despite the numerous targets outlined in various policy documents, Ghana’s energy sector continues to be characterised by an insufficient energy supply, which is informed by limited financial, material, and technical resources. As a result, policy initiatives toward energy transition suffer implementation challenges. Ghana has developed a comprehensive renewable energy transition plan that outlines its decarbonisation strategy to achieve net-zero emissions by 2070. The National Energy Transition Framework sets a target for renewable energy to contribute at least 10% of the country's total electricity generation capacity. This goal was initially introduced in the 2010 Energy Sector Strategy and Development Plan, with a target year of 2020. However, it was later revised to 2030 in Ghana's Intended Nationally Determined Contributions (INDCs). As of December 2024, renewable energy accounts for approximately 2% of the country's total installed capacity, with actual generation at just 0.70%.

However, bridging the gap between policy and implementation requires a coordinated strategy that tackles financial, technical, regulatory, and infrastructure barriers. Unlocking investment, strengthening institutions, and prioritising decentralised solutions are essential for Ghana to advance its transition to low-carbon energy systems and achieve long-term environmental sustainability.

Adaptation – Energy Sustainability and Energy Equity

Climate adaptation measures intersect with socio-economic development to produce climate-resilient development, a key objective CCD aims to achieve. As it has already been established that clean energy solutions such as solar PV have immense climate mitigation benefits, low-carbon energy generation sources have the potential for climate adaptation and resilience building. Climate adaptation strategies and resilience building are essential for Ghana's rural communities because of their high susceptibility to climate vulnerability. Research shows that African countries are more vulnerable to climate change, although they contribute little to carbon emissions (Nyiwul, 2021). The impact on rural communities is more pronounced and life-threatening. For instance, Leichenko and O'Brien (2002) found that climate change affects rural agricultural workers in southern Africa, exacerbating their vulnerable rural lifestyle.

Vulnerability is operationalised to mean the susceptibility of people and systems to the adverse impacts of climate change (Downing et al., 2005).

Besides the high poverty levels and lack of reliable energy access, residents in rural communities have a high degree of susceptibility to climate vulnerability (Antwi-Agyei et al., 2013). Antwi-Agyei et al. (2013, p. 923) assert that residents in Ghana rural communities are more prone to vulnerability because they lack access to various forms of capital - natural capital (farmlands), physical capital (such as irrigation facilities/communication devices to inform of variable weather patterns), human capital (i.e. low educational level and health status), financial (e.g., savings and remittances) and social capital assets (e.g., access to relevant social networks).

Solar PV deployment can play a crucial role in reducing vulnerabilities in Ghana's rural communities by improving energy access, supporting economic activities, and strengthening climate resilience. Reliable solar electricity reduces dependence on traditional biomass and kerosene, both expensive and harmful to health. Off-grid solar mini-grids and standalone systems can electrify remote areas where grid extension is impractical, ensuring energy equity. This access to electricity enables small-scale businesses, agro-processing, and irrigation systems, reducing reliance on rain-fed agriculture and improving financial stability. Solar-powered cold storage facilities also help farmers preserve produce, minimising post-harvest losses and increasing incomes. Thus, communities can better adapt to erratic rainfall patterns and climate-induced disruptions. Additionally, the potential of agro-photovoltaics, a system where crops are cultivated beneath solar panels to create more resilient agricultural systems, cannot be overemphasised. This approach not only optimises land use but also helps enhance food production by providing shade that reduces water evaporation and protects crops from extreme weather conditions (Weselek et al., 2019).

Beyond economic benefits, solar PV enhances gender equity and strengthens social resilience. Women traditionally bear the burden of collecting fuelwood and benefit from solar energy as it reduces their workload, allowing them to pursue education and income-generating activities. Solar-powered lighting also improves safety, particularly for women and children, by reducing risks associated with darkness. Furthermore, household savings from lower energy costs can be redirected toward health, education, and business investments, enhancing financial security. Electrified communities attract development projects and investment, boosting overall social capital. However, for solar PV deployment to address vulnerability effectively, it must be inclusive, community-driven, and designed with safeguards to prevent unintended consequences such as land dispossession. Integrating solar solutions with rural economic development strategies will ensure a just and sustainable energy transition.

Ghana's climate adaptation strategies must align with global initiatives like the UNEP/UNDP CC DARE programs, which support climate adaptation in Sub-Saharan Africa. These programs emphasise off-grid alternative energy resources as a key strategy for achieving net-zero emissions. The UNEP/UNDP framework for Ghana prioritises alternative livelihoods for vulnerable populations, agricultural diversification to minimise climate risks, and energy system adaptation to climate change. These strategies align with Ghana's community-based adaptation approach, which focuses on enhancing local livelihoods through low-carbon technologies like solar PV.

Development- Energy Security/ Affordability and Co-benefits

Under the triple-win approach, the CCD promises low-carbon energy, which translates into co-benefits to beneficiary communities. The global energy transition agenda has an inherent developmental goal driven by low-carbon industrial and economic activities. Hassan et al. (2024) posits that the transition to renewable energy represents a profound socio-economic transformation, extending far beyond the scope of an industrial revolution. This revolution intersects with quality of life and socio-economic development, as energy access is crucial in these areas. As such, it is unsurprising that Ghana's economic growth is aligned with its nascent renewable energy sources and broader access to reliable energy (Acheampong et al., 2021).

As energy security ensures reliable and sustainable electrification, it equally facilitates sufficient power for economic activities across the country. However, with the erratic power outages characterised by Ghana's energy, the prospects of economic activities are challenged, underscoring the need for rigorous diversification in energy supply for electrification. Against this backdrop, decarbonised energy technologies such as solar PV can achieve sustainable and reliable energy sources for socio-economic activities and ultimately mitigate climate crises.

There are already guiding principles outlined in the Ghana Energy Transition Plan that seek to provide opportunities for new economic and business development in renewable energy to stimulate employment and investments. However, we recognise that implementing the steps in the Ghana Energy Transition Plan requires enormous capital and financial assets, which may present a tremendous challenge to Ghana despite the potential to transform lives through job creation. For instance, the ETIP (2023) predicts over 400,000 jobs will be created in Ghana across the energy sector, with a 61% increase in the power sector when the Ghana Energy Transition Plan was implemented with necessary financial and technical support. Such off-grid solutions allow countries to leapfrog into more sustainable sources of electricity without high emissions (Afful-Dadzie et al., 2020).

For Ghana to be able to diversify its energy sector into renewable energy technologies and ensure sustainable electrification through solar PV solutions, we join Pueyo (2015) to outline some conditions that must be satisfied for off-grid solutions to propel socio-economic development. Solar PV must be (i) capable of providing a durable and sufficient level of access to electricity, (ii) situated in areas where there is high poverty and made affordable to individuals in the community, (iii) sufficient to power income-generating activities, and (iv) able to boost economic growth in areas which are directly beneficial to the populations in rural areas to reduce poverty.

To achieve the triple-win and fix the energy trilemma in Ghana's energy sector, policies around establishing off-grid solar PV solutions must meet these requirements. Off-grid solar PVs that do not provide sufficient electricity access or are too expensive for the rural populations may not achieve the triple-win objective and remain a breeding ground for energy trilemma in Ghana.

Conclusions and Policy Recommendations

Ghana's abundant solar irradiation potential calls into question why solar energy is a relatively untapped energy source and is not ubiquitous in the country's energy mix. The literature reflects that Ghana's issues can be attributed to high costs due to fluctuating exchange rates, low education and literacy rates affecting understanding and uptake of these technologies, and unpromising government policy (Awuku et al., 2022). These barriers must be addressed in efforts to achieve a triple win. Furthermore, African countries must position themselves within the solar PV value chain by engaging in design and manufacturing activities rather than limiting their role to raw material production. Awuku et al. (2022) recommend that equipping local solar PV technicians with the requisite skills and establishing local power plants within the country are viable policy options to address this.

Our analysis of Ghana's policy documents reflects that Solar PV technologies lie within the government's plans, especially as the technology can achieve a triple-win and address energy trilemma. However, achieving a triple-win and addressing the trilemma presents some policy implications in Ghana's policy environment. Our quest to leverage solar PV to address Ghana's energy trilemma—security, affordability, and sustainability—involves critical policy recommendations.

1. Policymakers must prioritise supportive policies to expand solar PV adoption and integrate it effectively into the national energy grid. This involves creating favourable regulatory frameworks encouraging foreign and domestic investment in solar infrastructure, potentially through tax incentives, subsidies, and streamlined permitting processes. Lowering barriers to entry for solar energy projects reinforces energy security through energy diversification, reducing dependence on fossil fuels, and decreasing vulnerability to global energy price fluctuations.
2. The government must introduce targeted subsidies and financing mechanisms, such as microloans or pay-as-you-go solar systems, which could help make solar technology accessible to low-income households and small businesses. This approach can mitigate upfront costs, enabling a broader population to benefit from solar energy and reducing overall energy poverty. Relatedly, the government of Ghana must show commitment to creating policies and funding opportunities that support research and development in solar technology. Civil societies and industrial players must be proactive in workforce training for solar installations, which could lower costs over time by fostering local expertise and innovation.
3. Government policies on sustainability must emphasise environmental impacts by setting standards for solar panel disposal and recycling to address potential waste issues as the technology scales. Policies could also promote hybrid solar systems combined with energy storage

solutions to enhance reliability and meet peak demand, especially in rural areas. Through these comprehensive policy actions, Ghana can ensure solar PV development not only meets immediate energy needs but also aligns with long-term goals of environmental sustainability, energy accessibility, and economic resilience.

4. Before developing solar projects, policymakers must implement comprehensive land assessments to identify and mitigate socio-economic impacts on local communities. Affected individuals, particularly women who rely on land for biomass and livelihoods, should receive adequate compensation, alternative land, or sustainable livelihood options. Strengthening stakeholder consultations will ensure that local voices are heard and integrated into project planning and decision-making.

References

Acheampong, T., Menyeh, B. O., & Agbevivi, D. E. (2021). Ghana's changing electricity supply mix and tariff pricing regime: implications for the energy trilemma. *Oil, gas and energy law*, *19*(3).

Adjei, E. A., Amoabeng, K. O., Ayetor, G. K. K., Obeng, G. Y., Quansah, D. A., & Adusei, J. S. (2022). Assessing the impact of hydro energy project on poverty alleviation: The case of Bui Dam in Ghana. *Energy Policy*, *170*, 113227. https://doi.org/10.1016/j.enpol.2022.113227.

Adombila, M. A. (2023, May 26). Ghana power producers reject government bid to restructure $1.58 billion debt. *Reuters*. https://www.reuters.com/business/energy/ghana-power-producers-reject-government-bid-restructure-158-bln-debt-2023-05-26/.

Agomor, K. S., Banini, D. K., & Langnel, Z. (2023). Legislative electoral incumbent defeats: Cues from Ghana. *The Journal of Legislative Studies*, 1–20.

Amanfo, S. E., & Puthenkalam, J. J. (2024). Perspective Chapter: The Regime Matters–A Multidisciplinary Perspective on Energy Security in the Era of Climate Change and Growing Uncertainties for Resilience in Sustainable Energy Development. In *Power Quality and Harmonics Management in Modern Power Systems*. IntechOpen.

Antwi-Agyei, P., Dougill, A. J., Fraser, E. D. G., & Stringer, L. C. (2013). Characterising the nature of household vulnerability to climate variability: Empirical evidence from two regions of Ghana. *Environment, Development and Sustainability*, *15*(4), 903–926. https://doi.org/10.1007/s10668-012-9418-9

Atuahene, S. A., & Sheng, Q. X. (2023). Powering Ghana's future: Unraveling the dynamics of electricity generation and the path to sustainable energy. *Environmental Sciences Europe*, *35*(1), 25.

Awuku, S. A., Bennadji, A., Muhammad-Sukki, F., & Sellami, N. (2022). Public-private partnership in Ghana's solar energy industry: The history, current state, challenges, prospects and theoretical perspective. *Energy Nexus*, *6*, 100058. https://doi.org/10.1016/j.nexus.2022.10005

Bannor, R. K., Amfo, B., Sarquah, K., Oppong-Kyeremeh, H., & Kyire, S. K. C. (2023). Unwrapping the nexus between the off-grid system and its impact on the islands and remote villages of Ghana. *International Journal of Energy Sector Management*, *17*(1), 82–105. https://doi.org/10.1108/IJESM-01-2022-0004

Brundtland, G., Khalid, M., Agnelli, S., Al-Athel, S., Chidzero, B., Fadika, L., Hauff, V., Lang, I., Shijun, M., & de Botero, M. M. (1987). Our common future (\' Brundtland report\'). *Journal Medicine and War*, *4*(1).

Crentsil, A., Fenny, A., Ackah, C., Asuman, D., & Otieku, E. (2020). Ensuring access to affordable, sustainable and clean household energy for all in Ghana. *Occasional Paper Series*, *62*.

Debrah, S. K., Nyasapoh, M. A., Ameyaw, F., Yamoah, S., Allotey, N. K., & Agyeman, F. (2020). Drivers for nuclear energy inclusion in Ghana's energy mix. *Journal of Energy*, *2020*(1), 8873058.

Destrée, P. (2019). Power flashes: The political and visual cultures of electricity in Accra, Ghana. *Doctoral dissertation, University College London.*

Diawuo, F. A., Scott, I. J., Baptista, P. C., & Silva, C. A. (2020). Assessing the costs of contributing to climate change targets in sub-Saharan Africa: The case of the Ghanaian electricity system. *Energy for Sustainable Development*, *57*, 32-47.

Dincer, I., & Rosen, M. A. (1998). A worldwide perspective on energy, environment and sustainable development. *International Journal of Energy Research*, *22*(15), 1305–1321.

Downing, T. E., Patwardhan, A., Klein, R. J., Mukhala, E., Stephen, L., Winograd, M., & Ziervogel, G. (2005). *Assessing vulnerability for climate adaptation*. CGIAR Research Centers.

Energy Commission of Ghana (2023). National Energy Statistical Bulletin: Energy statistics and balances. https://www.energycom.gov.gh/newsite/files/2023-energy-Statistics.pdf

Environmental Protection Agency (2024). Ghana's first biennial transparency report to the UNFCCC under Article 13 of the Paris Agreement.

Falchetta, G., Gernaat, D. E., Hunt, J., & Sterl, S. (2019). Hydropower dependency and climate change in sub-Saharan Africa: A nexus framework and evidence-based review. *Journal of Cleaner Production*, *231*, 1399–1417.

Ficklin, L., Stringer, L. C., Dougill, A. J., & Sallu, S. M. (2018). Climate compatible development reconsidered: Calling for a critical perspective. *Climate and Development*, *10*(3), 193–196. https://doi.org/10.1080/17565529.2017.1372260

Flaherty, C., & Filho, W. L. (2013). Energy security as a subset of national security. *Global Energy Policy and Security*, 11–25.

Fleming, R. (2021). The Energy Trilemma. In *Energy Law, Climate Change and the Environment* (pp. 31–40). Edward Elgar Publishing.

Gyamfi, S., Modjinou, M., & Djordjevic, S. (2015). Improving electricity supply security in Ghana—The potential of renewable energy. *Renewable and Sustainable Energy Reviews*, *43*, 1035–1045.

Hassan, Q., Viktor, P., Al-Musawi, T. J., Ali, B. M., Algburi, S., Alzoubi, H. M., Al-Jiboory, A. K., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. *Renewable Energy Focus*, *48*, 100545.

Ingo, T. I., Gyoh, L., Sheng, Y., Kaymak, M. K., Şahin, A. D., & Pouran, H. M. (2024). Accelerating the Low-Carbon Energy Transition in Sub-Saharan Africa through Floating Photovoltaic Solar Farms. *Atmosphere*, *15*(6), 653.

International Energy Agency (2023). Africa Energy Outlook 2022.

Jain, A., Ray, S., Ganesan, K., Aklin, M., Cheng, C.-Y., & Urpelainen, J. (2015). *Access to clean cooking energy and electricity: Survey of states*.

Kaushika, N., Reddy, K., & Kaushik, K. (2016). *Sustainable energy and the environment: A clean technology approach*. Springer.

Korzhenevych, A., & Owusu, C. K. (2021). Renewable Minigrid Electrification in Off-Grid Rural Ghana: Exploring Households Willingness to Pay. *Sustainability*, *13*(21), 11711. https://doi.org/10.3390/su132111711

Leichenko, R. M., & O'Brien, K. L. (2002). The dynamics of rural vulnerability to global change: The case of southern Africa. *Mitigation and Adaptation Strategies for Global Change*, *7*(1), 1–18.

Lindebjerg, E. S., Peng, W., & Yeboah, S. (2015). Do policies for phasing out fossil fuel subsidies deliver what they promise. *Social Gains and Repercussions in Iran Indonesia and Ghana*.

Merem, E. C., Twumasi, Y., Wesley, J., Isokpehi, P., Fageir, S., Crisler, M., Romorno, C., Hines, A., Ochai, G. S., Leggett, S., & Nwagboso, E. (2018). Assessing Renewable Energy Use in Ghana: The Case of the Electricity Sector. *Energy and Power*, *8*(1), 16–34. https://doi.org/10.5923/j.ep.20180801.03

MESTI (2018). National Adaptation Plan Framework. https://napglobalnetwork.org/wp-content/uploads/2020/04/napgn-en-2018-ghana-nap-framework.pdf

MESTI (2023) Ghana Energy Transition and Investment Plan (ETIP)
https://www.seforall.org/system/files/2023-09/report-ghana-etip_WEB.pdf

Ministry of Energy, (2022). Ghana National Energy Transition Framework 2022-2070.

Mitchell, T., & Maxwell, S. (2010). Defining climate compatible development. Climate and Development Knowledge Network (CDKN) https://cdkn.org › regions › ghana ODI Policy Brief, 1–6.

Nduhuura, P., Garschagen, M., & Zerga, A. (2021). Impacts of electricity outages in urban households in developing countries: A case of Accra, Ghana. *Energies*, *14*(12), 3676.

Nunan, F., Phillips, J., Newell, P., & Pueyo, A.(eds.). (2017). *Making climate-compatible development happen*. Routledge, Taylor & Francis Group.

Nyabor, J. (2021, May 16). *Six years ago, Ghanaians marched against 'dumsor.'* https://citinewsroom.com/2021/05/six-years-ago-ghanaians-marched-against-dumsor-photos/

Nyiwul, L. (2021). Climate change adaptation and inequality in Africa: Case of water, energy and food insecurity. *Journal of Cleaner Production*, *278*, 123393.

Olajide, B., Tshidzumba, A., & Ojakorotu, V. (2020). Climate change and the politics of

implementation of the Nationally Determined Contributions (NDCs) in Africa. *Journal of Nation-Building & Policy Studies*, *v1*(1), 47–65. https://doi.org/10.31920/2516-3132/2020/v1n1a3

Owusu, D., Agyemang, P. O., & Agyeman, D. O. (2022). Electricity energy access and profitability of micro and small enterprises in Ghana. *Journal of Entrepreneurship and Innovation in Emerging Economies*, *8*(1), 46–59.

Pueyo, A. (2015). *Pro-Poor Access to Green Electricity in Kenya* [Report]. the Institute of Development Studies and partner organisations. https://opendocs.ids.ac.uk/articles/report/Pro-Poor_Access_to_Green_Electricity_in_Kenya/26465578/1

Riva, F., Ahlborg, H., Hartvigsson, E., Pachauri, S., & Colombo, E. (2018). Electricity access and rural development: Review of complex socio-economic dynamics and causal diagrams for more appropriate energy modelling. *Energy for Sustainable Development*, *43*, 203–223.

Roberts, S. (2008). Energy, equity and the future of the fuel poor. *Energy Policy*, *36*(12), 4471–4474.

Robinson, S., Carlson, D., Messer, A., Maunus, L., Bouton, E., & Roberts, J. T. (2022). Climate compatible development in practice. *Development in Practice*, *32*(2), 234–244. https://doi.org/10.1080/09614524.2021.1907534

Sefa-Nyarko, C. (2024). Ghana's National Energy Transition Framework: Domestic aspirations and mistrust in international relations complicate 'justice and equity.' *Energy Research & Social Science*, *110*, 103465.

Shahsavari, A., & Akbari, M. (2018). Potential of solar energy in developing countries for reducing energy-related emissions. *Renewable and Sustainable Energy Reviews*, *90*, 275–291.

Shalman, E. M. (2024). Regulating Public Utilities Within a Crisis Situation in Africa. In *Energy Regulation in Africa: Dynamics, Challenges, and Opportunities* (pp. 219–234). Springer.

Stock, R., Nyantakyi-Frimpong, H., Antwi-Agyei, P., & Yeleliere, E. (2023). Volta photovoltaics: Ruptures in resource access as gendered injustices for solar energy in Ghana. *Energy Research & Social Science*, *103*, 103222. https://doi.org/10.1016/j.erss.2023.103222

Stringer, L. C., Dougill, A. J., Dyer, J. C., Vincent, K., Fritzsche, F., Leventon, J., ... & Kalaba, G. (2014). Advancing climate compatible development: lessons from southern Africa. *Regional Environmental Change*, *14*, 713-725.

Suckall, N., & Tompkins, E. L. (2020). Climate Compatible Development: Generating Co-Benefits from Climate Change Planning. *Sustainability*, *12*(2), 496.

https://doi.org/10.3390/su12020496

Takase, M., Aboah, M., & Kipkoech, R. (2022). A review on renewable energy potentials and energy usage statistics in Ghana. *Fuel Communications*, *11*, 100065.

Tarekegne, B., O'Neil, R., & Twitchell, J. (2021). Energy storage as an equity asset. *Current Sustainable/Renewable Energy Reports*, *8*(3), 149–155.

Tompkins, E. L., Mensah, A., King, L., Long, T. K., Lawson, E. T., Hutton, C. W., Hoang, V. A., Gordon, C., Fish, M., & Dyer, J. (2013). *An investigation of the evidence of benefits from climate compatible development*.

UNEP/UNDP (n.d). National Climate Change Adaptation Strategy.

https://www.adaptation-undp.org/sites/default/files/resources/ghana_national_climate_change_adaptation_strategy_nccas.pdf

USAID (2016). Greenhouse Gas Emissions in Ghana. *GHG Emissions Factsheet Ghana.* https://www.climatelinks.org/sites/default/files/asset/document/GHG%20Emissions%20Factsheet%20Ghana_6-17-16_edited_rev08-18-2016.pdf

Weselek, A., Ehmann, A., Zikeli, S., Lewandowski, I., Schindele, S., & Högy, P. (2019). Agrophotovoltaic systems: Applications, challenges, and opportunities. A review. *Agronomy for Sustainable Development*, *39*(4), 35. https://doi.org/10.1007/s13593-019-0581-3

Yadav, P., Heynen, A. P., & Palit, D. (2019). Pay-As-You-Go financing: A model for viable and widespread deployment of solar home systems in rural India. *Energy for Sustainable Development*, *48*, 139–153.

12

Low Carbon Pathways for Ghana's Transport Sector

Josephine Tweneboah Koduah, Precious Okechukwu Iregbu, Michael Nandi

Abstract

Transport is a key sector for all progressive economies, fostering the growth of other economic sectors such as industry, agriculture and services. In Ghana, the transport sector accounts for approximately 6.4% of the Gross Domestic Product (GDP) as of 2022, highlighting its significance to the national economy. However, it is also a major contributor to climate change, accounting for about 15.4% of greenhouse gas (GHG) emissions. Consequently, promoting the expansion of the transport sector while reducing emissions presents a significant challenge. Addressing this problem necessitates a comprehensive analysis of the emission reduction potential of diverse decarbonisation strategies. While these strategies are primarily categorised into behavioural, policy-oriented and technological approaches, Ghana's energy transition plan predominately focuses on technology-oriented solutions. The transition plan aims for 100% electrification of rail and road and the use of biofuels for sustainable aviation by 2070. Therefore, assessing the potential of a broader spectrum of scenarios across different categories is essential. Four scenarios were modelled and analysed using the Low Emissions Analysis Platform (LEAP) and the Avoid, Shift, Improve and Fuel (ASIF) framework to ascertain the emission reduction potential between 2019 and 2050. While the resulting emissions by 2050 for the Business as Usual (BAU) scenario was 49.8 $MtCO_2$, the Minimalist Approach (MA) and Green Technology (GT) scenarios showed a 41% emission reduction potential. On the other hand, the Strict

Implementation of Existing Policy (SIEP) reduced emissions by 32% in 2050. These scenarios offer clear and concise pathways to guide policy makers in making informed decisions towards transport decarbonisation in Ghana. However, despite the promising emission reduction potentials from these scenarios, policymakers need to consider specific challenges in drafting a comprehensive strategy that draws inferences from each scenario.

Keywords: Transport decarbonization, Scenario analysis, Energy transition, Emission reduction, Policy implementation

Introduction

The planetary boundary, climate change, has emerged as one of the most challenging global problems, posing dire implications for biodiversity, ecosystems, economies, livelihoods and even human health and well-being (Richardson et al., 2023). The adverse impacts of climate change are currently observed with the widespread and rapid changes in weather and ocean levels. The Intergovernmental Panel on Climate Change (IPCC) reports that approximately 3.3 to 3.6 billion people are highly vulnerable to climate hazards, including food insecurity, water crisis, and displacement. Unfortunately, the impacts of climate change are unevenly distributed, critically impacting the already vulnerable in society, which has historically contributed the least to advancing this planetary boundary (IPCC, 2023).

Notably, governments, organizations, and industries are taking steps to mitigate climate change and sponsor adaptation efforts to deal with the observed impacts. While laws, policies and international agreements have been enacted to combat climate change and limit the temperature rise well below 2°C above preindustrial levels by the end of this century, projections indicate that existing gaps in laws and policies coupled with shortfalls in financial flows threaten the ambitious Paris Agreement goal to limit warming to 1.5°C (IPCC, 2023). Thus, to achieve this goal, more decisive legislative action and increased economic investments are essential to reduce emissions and meet the net zero targets.

The transport sector is critical in this global challenge. As an important driver of economic growth, transportation is essential to the movement of goods and people, thus impacting other vital sectors such as trade, agriculture, and services. Hence, it remains one of the key drivers of climate change, accounting for about a quarter of global greenhouse gas (GHG) emissions. These emissions are mainly traced to the road transport sector, that is, passenger cars, buses, and heavy and light-duty commercial vehicles, which comprise more than 70% of the total emissions (IEA, 2021). The significant emissions from the transport sector can be attributed to the transport energy nexus; evidently, about 90% of combustion engines today rely on fossil fuels, thus contributing to the release of GHGs and, in effect, climate change (UNECE, 2023). Therefore, efforts to reduce emissions from this sector are targeted at finding alternatives for fossil-powered vehicles.

Decarbonising the transport sector requires a multifaceted approach that leverages technology and behavioural change on the back of policy. Worldwide, governments and industries are opting for a variety of solutions such as electric vehicles, the use of blended fuels, investment in infrastructure for public transport, fiscal incentives, carbon taxes and advocacy to encourage cycling, walking and other zero and low-carbon technologies (UNECE, 2023). However, the success of these strategies varies depending on regional contexts, as countries face different economic, infrastructural, and policy challenges.

In the case of Ghana, the transport sector presents significant opportunities and challenges for decarbonisation and economic development. Ghana's transport sector significantly contributes to the national economy, accounting for approximately 6.4% of the Gross Domestic Product (GDP) (Ghana Statistical Service, 2022). The sector is also a significant source of greenhouse gas (GHG) emissions, contributing around 15.4% of the national total GHG emissions (Environmental Protection Agency, 2022). This positions the sector as a vital component of the national economic fabric and a substantial contributor to climate change.

As a developing country that seeks to grow its economy sustainably, a challenge arises in bolstering the transport sector to boost socio-economic development whilst minimising environmental impact. Ghana's energy transition plan proposes electric vehicles, rail electrification, and biofuels for sustainable aviation by 2070 (Ministry of Energy, 2022). This approach towards the sustainable transport sector predominately focuses on technology-oriented strategies.

However, building a resilient, low-emitting transport industry requires a comprehensive analysis of diverse decarbonisation strategies, including behavioural and technological approaches facilitated by policy. Therefore, assessing the potential of a broader spectrum of solution scenarios to build a sustainable transport industry in Ghana is essential. This chapter, therefore, seeks to examine the potential of more sustainable transport sector to support climate action through GHG emissions reduction. The study analyses four scenarios; (1) a business-as-usual scenario (2) the Strict Implementation of Existing Policies (SIEP) scenario, (3) the Green Technology (GT) scenario and (4) the Minimalist Approach (MA) scenario.

The chapter further evaluates the potential for carbon mitigation and the opportunities and challenges associated with each scenario to facilitate informed decision-making. The goal is to explore various pathways to guide policymakers in determining the most effective strategies for reducing GHG emissions in Ghana's transport sector. The study will also contribute to the knowledge on the decarbonisation of Ghana's transport sector.

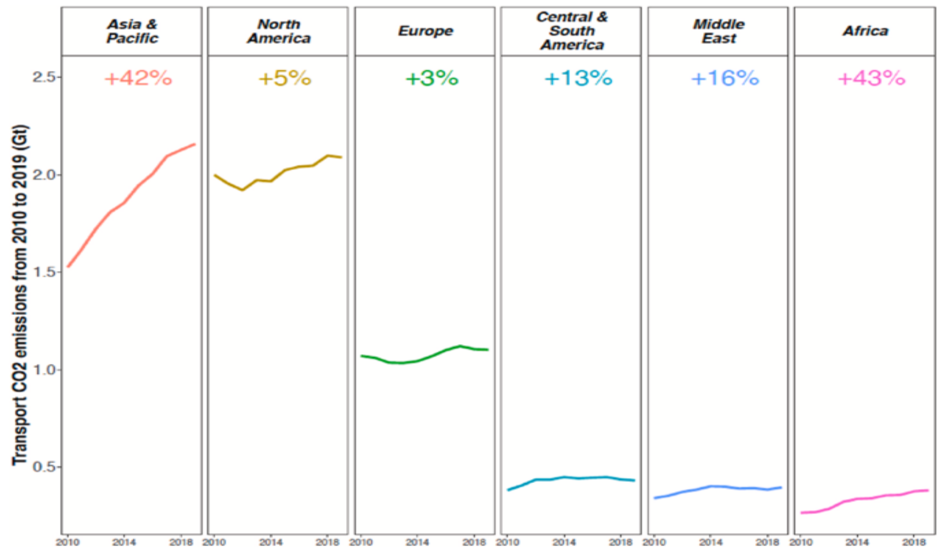
Literature Review

Considering the immense contribution of transportation to GHG emissions, its decarbonisation has gained substantial attention in the climate discourse. Projections from the IPCC reveal that global transport-related emissions are expected to grow by 50% by 2050 if no drastic action is taken (Jaramillo et al., 2022). Developing nations face an even more demanding dilemma in balancing economic development with the need to reduce emissions.

Emissions have tangibly increased in middle and low-income economies with the take-off of economic expansion and growth. Notably, the growth rate of emissions from the transport sector in developing countries has been about eight times that of the global north between 2010 and 2019. For example, transport sector emission for Europe has increased by 3% whereas that of North America has increased by 5%. In Africa and Asia, transport sector emissions have increased by 43% and 42% respectively as shown in Figure 1 (Li et al., 2024). It must be noted, however, that transport emissions in Africa remains the lowest amongst all regions (less than 0.5 Gt). Thus, the absolute increase is not comparable to the other areas. Notwithstanding, the increase in emissions from the transport sector raises significant challenges and opportunities for sustainable development.

On the one hand, most low-carbon pathways come with high costs, technological limitations, and limited access to financing. On the other hand, developing countries have a wide range of development goals to alleviate poverty and improve quality of life, posing substantial financial commitments.

Figure 1: Trend of transport emissions from different economies (Briand et al., 2023)



Thus, they are caught in the dilemma of mitigating climate change or focusing on socio-economic development. Unfortunately, developing nations are also amongst the most vulnerable to the impacts of climate change, hence are faced with the responsibility of balancing the trade-offs to foster economic growth while reducing environmental impacts.

Despite the challenges in the global south context, an opportunity exists for sustainable transportation as most of these countries are currently actively developing transportation infrastructure (Briand et al., 2023). Therefore, policies can be aligned to promote sustainable transportation practices such as public transit, cycling, walking, ride-sharing and electrified passenger transportation systems. The implementation of these measures will not only contribute towards global climate mitigation targets but will further enhance urban mobility, mainly by reducing congestion and improving air quality. To capitalise on this double-edged opportunity, it is necessary to assess the potential of the different decarbonisation strategies for the transportation sector.

Decarbonization Strategies for the Transportation Sector

A wide range of decarbonisation approaches may be based on different philosophies for emission reduction. Holden et al., (2020) proposes three grand narratives which give an idea of the fundamental philosophies underlying different decarbonisation strategies, namely low mobility societies, Collective Transport 2.0, and electromobility. These narratives are derived from a conceptual review of diverse strategies and their respective actors over 30 years.

The low mobility societies narrative is based on ecological approaches which seek to reduce travel demand by promoting city densification, shifting away from private cars, and encouraging walking and cycling. This narrative mainly challenges current lifestyles, boldly proposing car-free cities in its quest to reduce fossil-powered mobility. Despite the frugal-like stance of this narrative, it still adopts fewer and/or shorter trips by cars (and planes), preferably electric ones. Thus, this strategy aligns with ecological modernization without challenging the growth-based economic paradigm. On the other hand, Collective Transport 2.0 emphasises public transportation and shared mobility services without necessarily reducing travel demand. These two narratives promote a shift in travel behaviour and thus are based on behavioural changes; therefore, such strategies usually include public awareness campaigns coupled with investments in reliable and pedestrian-friendly transportation infrastructure to facilitate modal shifts to buses, trains, cycling and walking.

For instance, policies encouraging ridesharing and telecommuting can reduce the demand for personal vehicle use, contributing to lower overall emissions. Again, promoting a walking and cycling culture by developing pedestrian-friendly infrastructure can cut short-distance car trips, particularly in urban areas. While a decarbonisation strategy based on behavioural change on the surface may be the most straightforward and affordable option, the approach faces significant limitations due to the complex nature of human behaviour (Garcia-Sierra et al., 2015). Recognising these complexities and the diverse factors influencing human behaviours beyond environmental concerns (e.g. affordability, social norms, time, safety etc.), changing ingrained travel habits through behavioural interventions alone can be challenging to implement successfully.

The last main narrative, electromobility, is mainly hinged on ecological modernisation. It advocates decarbonising the electricity value chain and the subsequent electrification of transportation modes such as trains, vehicles and motorcycles. While this approach essentially facilitates world economic growth, it also increases demand for renewable energy technology, which largely depends on critical raw materials, thus raising long-term sustainability concerns. (Valero et al., 2018) identified 13 high-risk elements - cadmium, chromium, cobalt, copper, gallium, indium, lithium, manganese, nickel, silver, tellurium, tin and zinc that could impede a global climate change mitigation scenario based on green technology. However, the opportunity exists to overcome these challenges by increasing recycling rates of these elements to overcome the potential shortages.

Each of the strategies mentioned above presents unique opportunities towards decarbonisation. However, their effectiveness is driven by policies and regulatory structures. Government policies and regulations are essential in driving decarbonisation efforts as they set the frameworks within which the strategies under the grand narratives may be developed. For instance, government policies such as tax incentives for electric vehicle owners such as discounted import duties can accelerate the adoption of electric vehicles. In most developed economies, like France and Germany, regulations implementing stricter vehicle emission standards have challenged auto manufacturers to improve technologies and enhance efficiencies towards lower emissions (Lee et al., 2010). Furthermore, a successful implementation of the Collective Transport 2.0 narrative requires policies that drive investments in public transportation infrastructure, such as rail and road networks. Additionally, low-mobility societies require advocacies and public education, investments in green walkways, bike lanes and pedestrian safety initiatives.

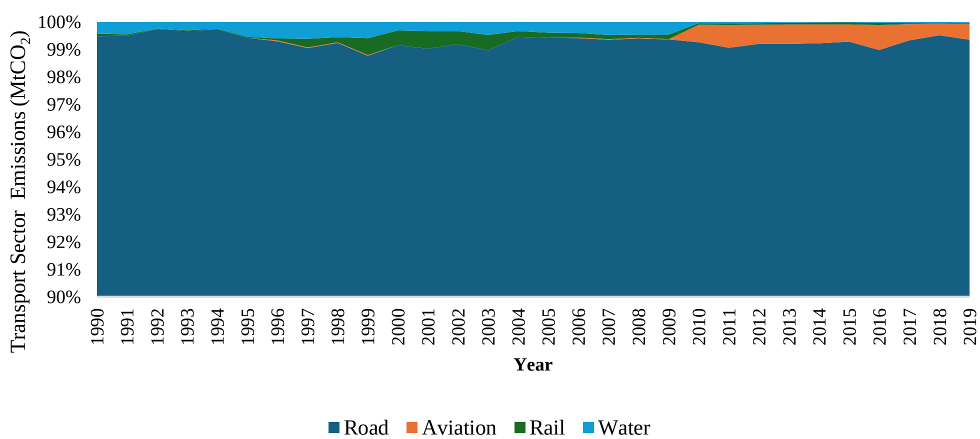
Notably, many developed economies adopt a combined approach with elements of technology and behavioural strategies backed by comprehensive policies to promote decarbonisation of the transport sector (Lefevre, 2021). Relying solely on policy actions under one grand narrative, such as electromobility, is insufficient to achieve decarbonisation goals. Instead, mixing policies from various grand narratives (e.g. promoting low-carbon vehicles, shifting to more sustainable modes of transport, and redesigning urban spaces to encourage cycling and walking) is essential. Such a multifaceted strategy will facilitate the reduction of emissions across multiple fronts. However, to effectively implement demand-driven solutions, that is, low mobility and Collective Transport 2.0 Strategies to complement the technology-based options, there is a need to understand the underlying social dynamics of the respective different societies (Creutzig, 2016).

Ghana's Transport Sector Context

Like the African transport emissions growth trends, Ghana's transportation sector emissions have increased over the years. The sector's emissions grew by around 46% from 2016 to 2019 and by approximately 441.2% between 1990 and 2019 (Environmental Protection Agency, 2022). This significantly growing trend depicts the impact of the economic development and growth agenda on transportation emissions with the rise in the movement of goods and services.

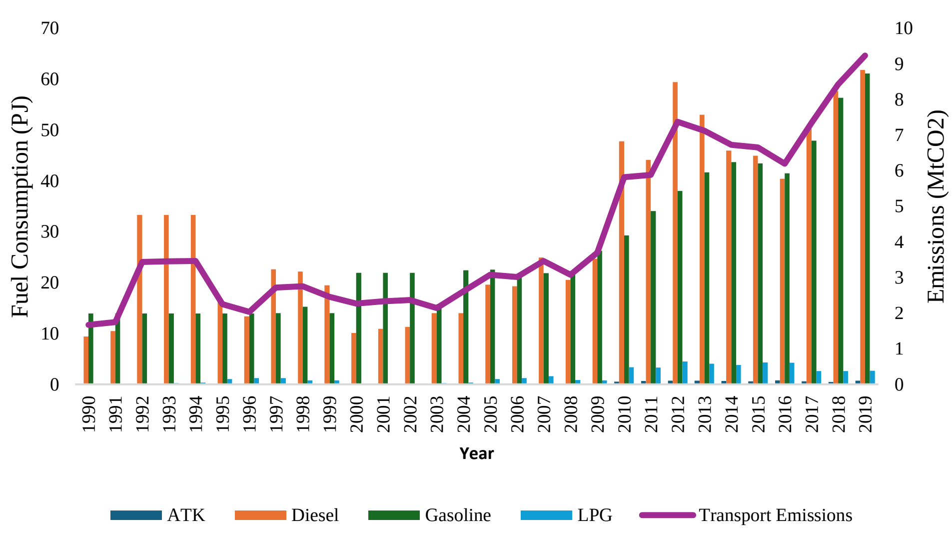
Figure 2 shows a breakdown of Ghana's transport sector emissions categorised under civil aviation, road transportation, railways and inland water-borne navigation. The road transportation category represents the leading contributor to the emissions, accounting for over 99% of transportation-related emissions yearly. The category includes all forms of mobility on the country's road network, including trucks, buses, cars, motorcycles and heavy-duty vehicles. Recognising the dominance of the road transportation category, it is pertinent that the subsector is mainstreamed in emission mitigation efforts.

Figure 2: Ghana's Transport Emissions per Sub-Sector



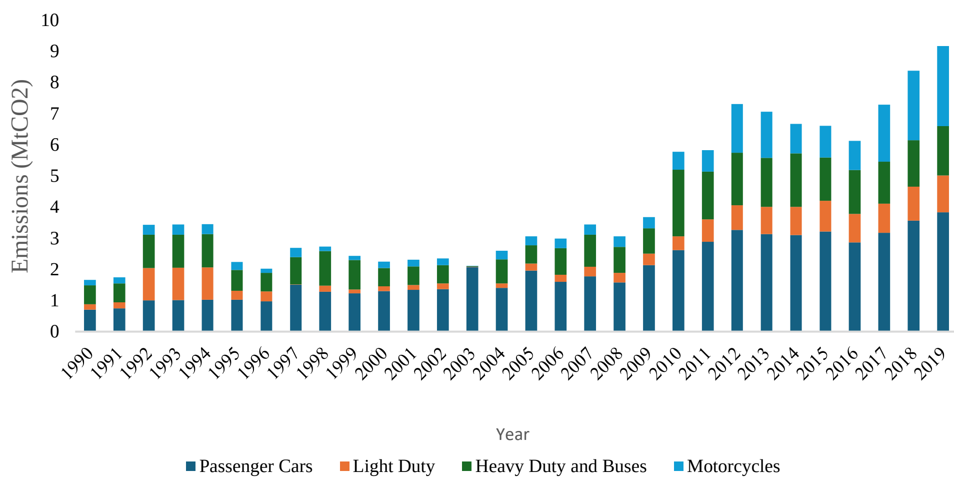
Emissions from the transport sector have mainly been estimated based on the fuel consumption of each category as it reflects vehicle technology, number of vehicles, speed and distance covered. The primary fuel types that drive mobility in Ghana are gasoline, diesel and Aviation Turbine Kerosene (ATK) and Liquified Petroleum Gas (LPG). As observed in the trend in Figure 3 below, burning these fossil fuels directly drives the release of GHG emissions. Thus, a reduction in fuel consumed for transportation will directly reflect in emission reduction in the sector (Environmental Protection Agency, 2022). Figure 3 also shows that diesel and gasoline are the most consumed in the transport sector, followed by LPG and ATK. While gasoline and diesel power road transport, railways and inland water-borne transport, ATK powers the civil aviation sector. LPG is primarily used by commercial vehicles under the Passenger Cars mode of the road sub-sectors; however, LPG use has declined since 2015, which could be attributed to the removal of government LPG subsidies (Environmental Protection Agency, 2022) and the persistent shortage of LPG across the nation between 2013 and 2015 (Ackah & Tetteh, 2016; Broni-Bediako & Amorin, 2018).

Figure 3: Fuel Consumption by the Transport Sector



The road transportation sector is sub-divided into four modes based on vehicle type: passenger cars, light-duty vehicles, heavy-duty vehicles and buses, and motorcycles. The leading source of road transport emissions is the passenger cars mode, which comprises privately used cars and commercial vehicles with engine capacities less than 2000 cc. The motorcycle mode emissions have been on the rise since 2016, which can be attributed to the increase in commercial bike delivery and transportation services. In 2019, the transport sector's passenger cars mode accounted for almost half of the total road subsector emissions. There is also a steady rise in emissions from the passenger car mode; this is widely attributed to rising vehicle ownership and traffic congestion due to urbanisation.

Figure 4: Breakdown of Road Emissions by mode



Ghana's Transport Sector Decarbonization Framework

Considering the significant contribution of transportation to Ghana's GHG emissions, its decarbonisation is crucial to achieving national climate targets and sustainable development goals. Recognising this need, the government has developed various strategies to promote cleaner, more efficient modes of transport. These strategies include the adoption of electric vehicles (EVs), the promotion of public transport and the use of biofuels. Therefore, policies and strategies have been enacted to improve infrastructure and enhance renewable energy integration. Table 1 below summarises each of the policies and their respective policy targets. A review of the policies reveals that most targets for decarbonising the transport sector have focussed mainly on the electromobility grand narrative, as evidenced in the NDCs, National Energy Transition Plan and the National Electric Vehicle Policy. It is worth noting that

Ghana has a non-motorised transport (NMT) strategy to promote walking and cycling; however, this strategy has not been mainstreamed as an emission mitigation strategy.

Table 1: Main Transport Sector Decarbonisation Policies

Main Policies and Strategies	Targets
Updated Nationally Determined Contribution	i. Expansion of inter-and-intra-city transportation modes
Energy Transition Plan (2022 – 2070)	i. Introduce a 10% ethanol blend in major petroleum products by 2030. ii. More than 70% of road vehicles are electricity and hydrogen fuelled by 2050. iii. All road and rail mobilities are electricity and hydrogen fuelled by 2070.
National Electric Vehicle Policy	i. Create an enabling environment for the uptake of electric vehicles in Ghana.
NMT Strategy 2019-2028	i. To promote non-motorised transport modes in urban areas with populations above 200,000.

Methodology

Following the assessment of the current decarbonisation efforts in the transport sector, it is imperative to further explore a more comprehensive range of decarbonisation strategies and their respective emission reduction potentials using scenario analysis. Scenario analysis is a generally used tool for decarbonisation and climate research efforts which allows the exploration of different pathways towards carbon emission reductions. The scenario analysis approach also facilitates the assessment of several state variables, such as economic viability, social acceptance, gender sensitivity, and technological feasibility (Aversa, 2024). This approach allows policymakers to weigh different strategies' potential benefits and trade-offs, facilitating more informed decision-making.

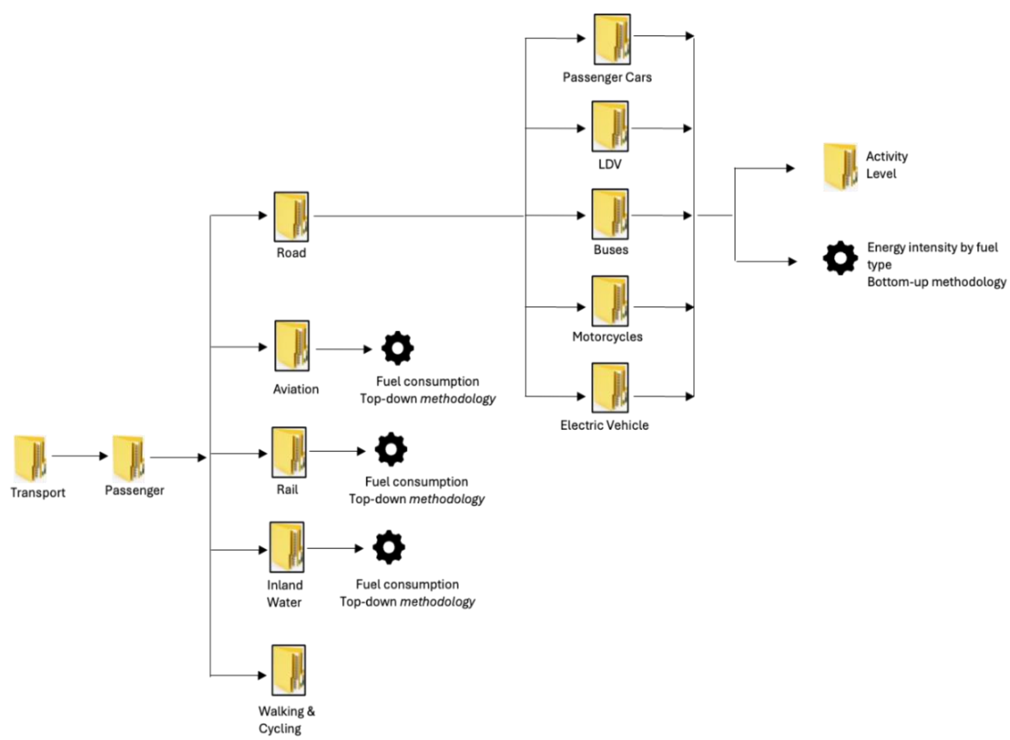
By building on this existing body of literature, this paper aims to contribute to understanding how different decarbonisation strategies can be effectively implemented in Ghana's transportation sector. Considering the reliance of Ghana's transport sector decarbonisation plan on the electromobility narrative, it is pertinent to assess the emission reduction potential of other strategies under the low mobility and Collective Transport 2.0. Through the development of four distinct scenarios: the Business As Usual (BAU), Strict Implementation of Existing Policies (SIEP), Green Technology (GT) and Minimalist Approach (MA), this chapter provides a comprehensive analysis of the opportunities and challenges associated with each approach, offering valuable insights to guide the transition towards a more sustainable transportation future.

To assess the potential of various decarbonisation strategies in the transport sector, the four scenarios were modelled and analysed using the Low Emissions Analysis Platform (LEAP). LEAP is a widely used energy modelling and policy analysis tool that provides insights into current and future energy demand figures and their respective emissions projections under different assumptions and policy interventions. Considering the need for a detailed scenario analysis despite challenges with data availability, this tool provides a unique opportunity to undertake this study due to its low initial data requirements.

LEAP is also the preferred choice for this study because it presents outputs transparently and intuitively. The emissions generated from each scenario are calculated in LEAP using either the top-down or bottom-up methodology (Sheldon et al., 2022). While both methods are dependent on emission factors, the top-down approach uses a product of an aggregated input value, such as total fuel/energy consumption and an emission factor, to compute emissions. On the other hand, in the bottom-up method, the total energy consumption term is disaggregated into vehicle distance and fuel economy before multiplying by an emission factor for that specific mode and activity. Generally, the top-down method provides a simplified approach for assessing emissions from different sectors; however, it limits scenario and sensitivity analysis, considering that there is only one variable (total energy consumption) to manipulate. Thus, it is not easy to ascertain the specific impact of policies on the model with this method. The bottom-up method provides a more robust technique that facilitates the scenario and sensitivity analysis as it accommodates the estimation of the impact of various policy tools.

The flowchart shown in Figure 5 below represents the subsectors of the transport sector and the approach used in modelling with LEAP. For the modes of rail, aviation and inland water transport, the top-down approach was adopted; thus, only total energy consumption values were used for the emission estimations. This approach was chosen for these modes because they constitute less than 1% of emissions hence the focus of this research was on the road transportation mode as it accounts for more than 99% of energy consumption and hence emissions.

Figure 5: LEAP Flow Model



The strategies for each scenario are structured around the Avoid-Shift-Improve-Fuel (ASIF) framework, which offers a comprehensive approach to reducing transport emissions (Creutzig et al., 2018). This framework effectively models actions aimed at lowering greenhouse gas (GHG) emissions in the transport sector by aligning policies with its four key components. The 'avoid' pillar focuses on minimising unnecessary travel, particularly in fossil-fuel-based vehicles. The 'shift' pillar encourages transitioning to lower-emission transport options, such as public or non-motorized modes. The 'improve' component aims to enhance the efficiency of existing transport systems, and the 'fuel' pillar emphasizes the use of cleaner, low-carbon fuels. The combination of the LEAP model with the ASIF framework provides a robust analysis of each scenario's greenhouse gas (GHG) mitigation potential, allowing for a detailed assessment of how different strategies can influence the transportation emissions trajectory.

Assumptions

The following assumptions underpin this study, aiding the modelling and analysis of the transport sector to estimate emissions. Furthermore, these assumptions frame the scenario analysis by defining the parameters and conditions for evaluating potential outcomes.

a. The projections for each scenario were assumed to begin in 2020 because the last emissions inventory data available for the transport sector was in 2019.
b. Fuel economy data for Ghana was only available for light-duty vehicles (LDVs) (Environmental Protection Agency, 2018). To estimate the fuel economy for motorcycles, heavy-duty vehicles (HDVs), and buses, we applied factor differences based on data from Uganda (Sheldon et al., 2022). Specifically, the fuel economy values for LDVs were reduced by a factor of 4 for motorcycles and 2 for HDVs and buses.
c. Even though the emissions modelled for the transport sector include freight and passenger, the policy actions only focussed on passenger transport. However, it was difficult to distinguish between the two due to the unavailability of data on the exact proportions.
d. In modelling the Passenger Car mode, the LPG portion of the energy consumption was assumed to be gasoline because fuel economy data was unavailable for LPG. Again, the proportion of LPG was negligible.
e. A 4% vehicle distance growth rate was assumed for all scenarios. This value was estimated based on the average growth of the total fuel consumption of the transport sector from 1990 to 2019.
f. A population growth rate of 2.4% was assumed to facilitate calculations for the distance to be covered per capita in the MA scenario.
g. The average distance covered by each vehicle is assumed to be 34,400km/year. This assumption is based on the total distance calculated from the total energy consumption, and fuel economy. The

average distance was estimated by dividing the total distance by total number of vehicles in Ghana as of 2019, which was about 2.5 million.[1]

Description of Scenarios

Business As Usual (BAU)

The BAU scenario uses historical data from 1990 to 2019 to generate emissions projections from 2020 to 2050 without considering any policy actions or interventions.

Minimalist Approach (MA)

This scenario considers the implementation of only frugal measures and aligns with the low mobility grand narrative. In this scenario, the populace is expected to reduce fossil-powered travels by using bicycles, foot travel, ride-sharing or public transport.

Table 2: ASIF Framework for MA

ASIF	Policy Goals
Avoid	1. 2.5% increase in the proportion of passenger journeys by foot or by bicycle from 2025 to 2030. 2. 5% increase in the proportion of passenger journeys by foot or by bicycle from 2031 to 2040. 3. 10 % increase in the proportion of passenger journeys by foot or by bicycle from 2041 to 2050.
Shift	5% reduction in fossil powered vehicle travel distance by ride sharing or public transport.
Improve	No Goal
Fuel	No Goal

Strict Implementation of Existing Policies (SIEP)

This scenario is based on the rigid implementation of all existing policies that seek to decarbonise Ghana's transportation sector. It is based only on proven

[1] Estimated based on recorded values of total vehicles in Ghana in 2017 and 2022.

technologies that are commercialized. These technologies are technically classified as Technology Readiness Level (TRL) 9. Even though hydrogen is a significant policy target for decarbonising the transportation sector (Ministry of Energy, 2022), the TRL of hydrogen combustion engines is less than 9, meaning they are still in the early stages and not yet fully commercialized. Furthermore, other critical hydrogen storage and distribution infrastructure remains in developmental phases (Sebastian, 2023). Therefore, hydrogen was not included as a decarbonisation fuel for the transportation sector in this scenario.

Table 3: ASIF Framework for SIEP

ASIF	Policy Goals
Avoid	1. 2.5% increase the proportion of passenger journeys by foot or by bicycle from 2030 to 2050.
Shift	1. 5% shift towards electric vehicles by 2030 2. 25% shift towards electric vehicles by 2050 3. 10% shift towards renewable energy in the energy mix by 2030
Improve	No Goal
Fuel	10% blend of ethanol fuel from 2030 to 2050

Green Technology (GT)

This scenario considers the use of bioethanol, electromobility and an increase in the fuel economy of vehicles as basis for decarbonisation of the transport sector.

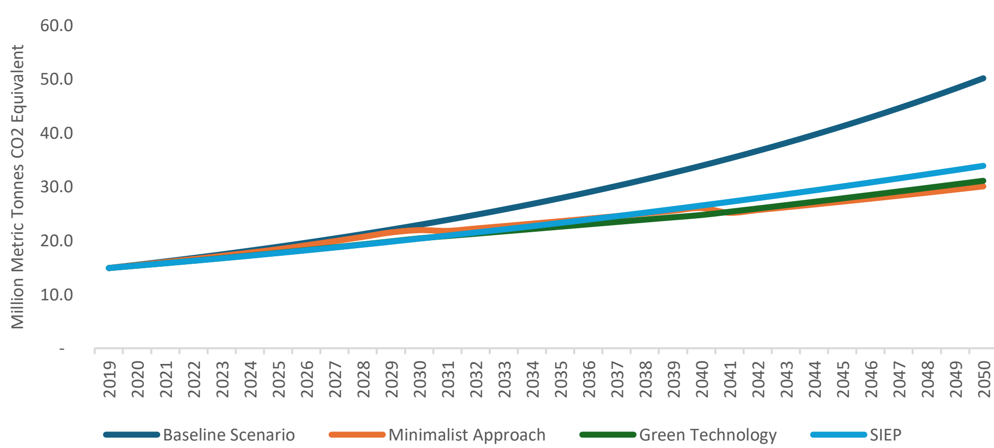
Table 4: ASIF Framework for GT

ASIF	Policy Goals
Avoid	No Goal
Shift	1. 10% shift towards electric vehicles by 2030 2. 25% shift towards electric vehicles by 2030 3. 35% shift towards electric vehicles by 2030 4. 10% shift towards renewable energy in the energy mix by 2030
Improve	1. 20% increase fuel economy of all vehicles by 2050
Fuel	1. 10% blend of ethanol fuel from 2030 to 2050

Results and Discussions

The results from the scenario analysis for the decarbonisation of the transport sector, modelled and analysed using the LEAP tool are presented in this section. The study explored various policy actions under each scenario based on the ASIF framework. The findings demonstrate the potential for significant reductions in greenhouse gas emissions, aligning with the objective of assessing viable pathways for decarbonising Ghana's transport sector. The emission result obtained from LEAP for 2019 is higher (14.9 $MtCO_2$) than the emission (9.23 $MtCO_2$) reported by (Environmental Protection Agency/EPA, 2022) in its latest GHG Inventory report. This variation may be traced to the differences in assumptions and methodology used for the calculations. While the EPA adopted the top-down approach using only energy/fuel consumption data, this study employed a combination of the top-down and bottom-up approaches. This variation does not significantly affect the accuracy of this study as the aim is not to estimate exact emissions but to evaluate the relative emission reduction potential of each scenario to inform policy decisions. Figure 6 below shows the emission reduction potentials of each scenario.

Figure 6: Emission Trends for Each Scenario (2019-2050)



From Figure 6, the highest emission was observed for the BAU scenario, which significantly increased from 14.9 $MtCO_2$ in 2019 to 49.8 $MtCO_2$ in 2050. This trend is due to the assumed 4% growth of vehicle distance and, in effect, fuel or energy consumption across the different modes of transport. Thus, if no interventions are enacted and implemented, the GHG projection in 2050 for the transport sector alone will be almost equal to total emissions from all sectors recorded in 2019.

The emission projection values for the other three scenarios were relatively close. However, among the three, SIEP scenario produces the highest emissions by 2050. The policy actions defined in the SIEP scenario gradually reduce the emissions across the years to 33.7 $MtCO_2$. This represents a 32% decrease in emissions from the BAU scenario. The GT and MA show almost the same emission values (MA: 29.9 $MtCO_2$, GT:29.6 $MtCO_2$) by 2050. While the GT trend smoothly grows to 29.6 $MtCO_2$ by 2050, there are fluctuations (2025 to 2040) in the emission trend of MA, which can be attributed to the instantaneous effect of the policy actions in the years within which implementation began. For the BAU scenario, the MA and GT scenarios reduce emissions from the sector by about 41% in 2050.

Figure 6 shows that each policy-backed scenario can reduce emissions in the sector. This emphasises the need to adopt comprehensive policies drawn from each grand narrative. Recognising that the transport sector's decarbonisation strategy primarily focuses on green technology and electromobility, it is essential that the country includes policy actions from the other grand narratives (low mobility and Collective Transport 2.0). Even though a strategy exists to promote non-motorised transport modes such as walking and cycling, particularly in urban areas, this strategy has not been mainstreamed or even referenced in the NDCs and energy transition plans. As demonstrated in Figure 6 above, the MA scenario presents a promising pathway towards a drastic decarbonisation of the transport sector. Notwithstanding, the implementation of this scenario will mean that each Ghanaian must be willing to replace some kilometres (km) of motorised distance travelled by vehicle with either walking or cycling starting from the year 2025. Table 5 details the exact distances to be covered by non-motorized modes.

Table 5: Average Motorised Distance to be Replaced by NMT

Year	Average Distance to be Replaced per Year (km/yr)
2025-2030	78.92
2031-2040	178.80
2041-2050	417.57

Achieving these targets will require social acceptance, amenities modification, and behavioural changes, meaning that policies must be targeted towards improving public awareness, providing green pedestrian and bike pathways on all roads, particularly in urban areas and ensuring pedestrian safety and comfort. Recognising Ghana's tropical climate, green pedestrian infrastructure must be developed to provide green shaded walkways to facilitate NMT and encourage active lifestyles. Strategic investments and planning are requisite to ensure effectiveness in this approach. Benton et al., 2023 reveal that a significant constraint to engendering non-motorized transport modes such as walking has been the funding bias towards large infrastructural schemes. This situation is evidenced in Ghana, which focuses mainly on technological approaches for the transport sector's decarbonisation, with huge investment requirement. Further, most urban roads are narrow and leave very little room for the construction of other NMT opportunities. Therefore, a conscious effort must be made to encourage non-motorized transport means. This could be achieved by incorporating NMT friendly systems on road networks and landscape designs. These include bicycle friendly paths, planting of avenue trees to provide shade, and improving street lighting infrastructure to promote security.

The results obtained from the SEIP scenario present evidence of the efficacy of the existing transport sector policies in drastically reducing emissions by 2050. However, this depends on the level of effectiveness of implementing all existing policies. The case in Ghana over the years has been the enactment of sound policies with huge implementation gaps. For instance, in 2010, the Ministry of Energy, in its Energy Sector Strategy and Development plan, sought to achieve 10% renewable energy integration by 2020 (Ministry of Energy, 2010). However, as of 2020, the renewable energy capacity was less than 1% (Energy Commission, 2020), which led to the timeline push to 2030 (Ministry of Energy 2022). This example signifies the need for more political will towards the timely implementation of policies.

Political will reflects a conscious effort from government agencies to implement initiatives to meet targets. It goes beyond backing the policy with a comprehensive financial plan. For example, the Renewable Energy Master Plan provided was a $5.6 billion investment plan of which 80% was to be sourced from the private sector. The Energy Transition Investment Plan also identifies several plans for integrating private financing. However, without a conscious approach to providing a stable investment environment, achieving the targets under these plans would remain aspirational. Additionally, political will requires removing corruption and corruption risks in the implementation of clean energy projects. For the transport sector, it means that state-owned transport companies and other regulatory agencies must take a solid stance against mismanagement and corruption-related activities. This will drive sustainable improvements in the country's transportation systems while reducing emissions from the sector.

Implementing the Green Transport (GT) policy actions will lead to significant emissions reductions by 2050. These reductions could be further enhanced if green transportation systems are powered by electricity generated from renewable energy sources. However, realizing this decarbonization pathway requires substantial transformation across the transport and energy value chains to accommodate the projected rise in energy demand.

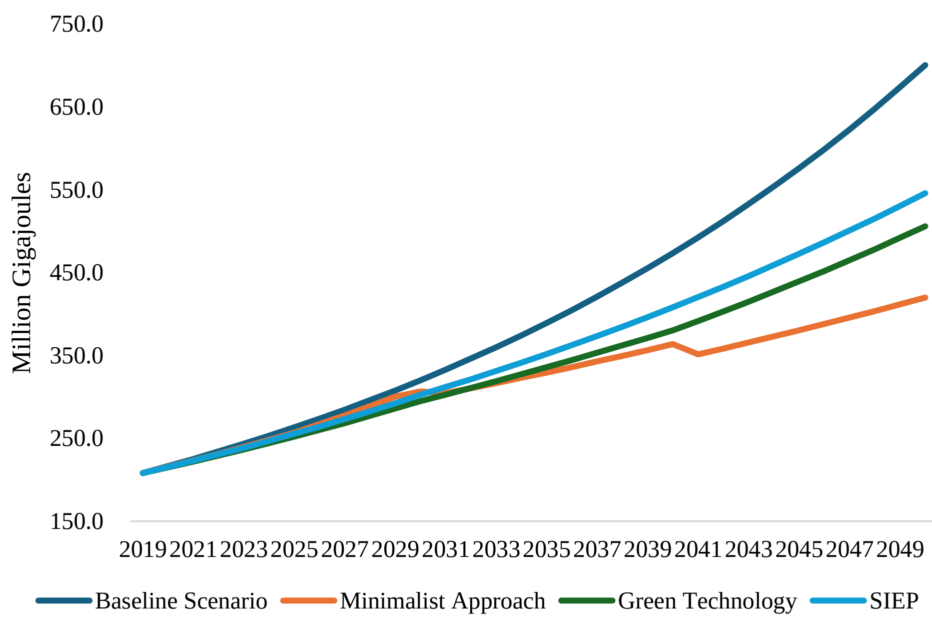
Ghana's EV policy already envisions the establishment of an electric vehicle manufacturing hub, leveraging the country's lithium resources to develop a local battery industry. Additionally, the policy emphasizes the need for widespread EV charging infrastructure. To actualize these ambitions, Ghana must transition from an import-dependent vehicle market to a structured production ecosystem. Achieving this will require targeted policies that attract investment in local vehicle assembly and battery production, alongside incentives to foster technology transfer and private sector participation.

A phased approach to local manufacturing should be considered, beginning with Completely Knocked Down (CKD) assembly plants before scaling up to full manufacturing capacity. Additionally, ensuring a robust supply chain for critical materials like lithium will be essential, necessitating partnerships with mining and processing industries. Beyond manufacturing, workforce development must be prioritized. Establishing specialized training programs in EV maintenance, battery technology, and green energy systems will be crucial for sustaining a skilled labour force. This will not only support local industry growth but also create employment opportunities within the green economy.

Moreover, integrating EVs into Ghana's transport system requires an accelerated rollout of charging infrastructure, supported by strategic incentives such as tariff adjustments for EV charging, public-private partnerships, and policy frameworks that encourage renewable-powered charging stations.

Figure 7 shows the variations in the Gross Energy Consumption for each scenario over the years. The BAU scenario consumes the highest amount of energy, steadily increasing from 208.1 million GJ in 2019 to 700.5 million GJ in 2050. In contrast, the other scenarios, show lower energy consumption patterns as the policy actions are applied over time.

Figure 7: Variation of Gross Energy Consumption for each scenario with years



Figures 8, 9, 10 and 11 show the changes in the consumption of each fuel or energy type (Electricity, Gasoline, Diesel, and Ethanol) in each scenario from 2019 to 2035 and finally to 2050. The electricity consumption in 2019 was zero since number of electric vehicles in Ghana is negligible as compared to the total number of vehicles. A slight increase was observed in 2035 and 2050 due to the effect of electric vehicle policy actions implemented within the SIEP and GT scenarios. Considering the gasoline consumption, the 2019 consumption was the same for all scenarios, as this was the base year. For 2035 and 2050, variations were observed, with the highest decrease recorded in the GT scenario, followed by MA and SIEP scenarios. A similar trend was observed in the diesel consumption variations across the years; however, the MA scenario showed the highest decrease, followed by the GT and SIEP. The ethanol consumption values increase across the years due to the 10% ethanol blend policy actions in the SIEP and GT scenarios. The SIEP consumption of ethanol is slightly higher than that of the GT because there were more internal combustion engines (ICEs) in this scenario than the latter.

Figure 8: Electricity variation for each scenario across the years

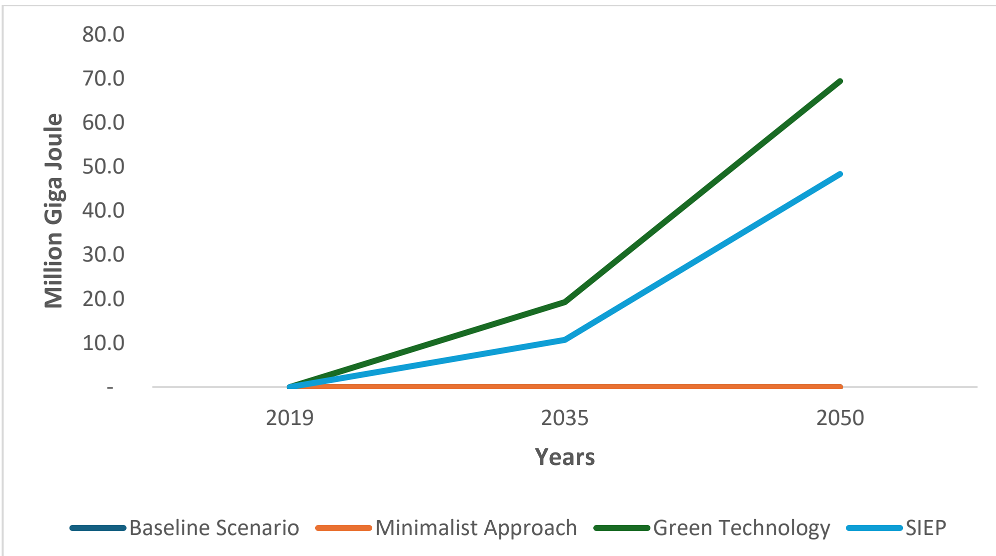


Figure 9: Gasoline Variation for Each Scenario Across the Years

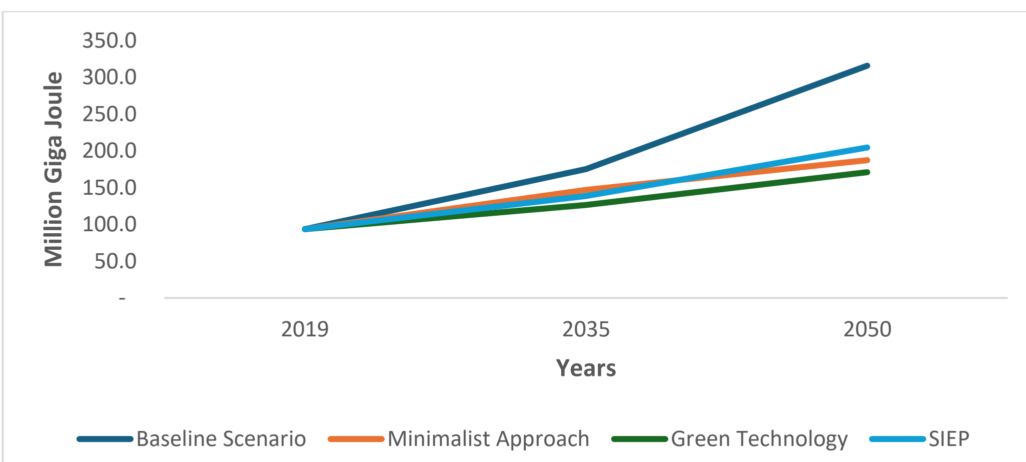


Figure 10: Diesel Variation for Each Scenario Across the Years

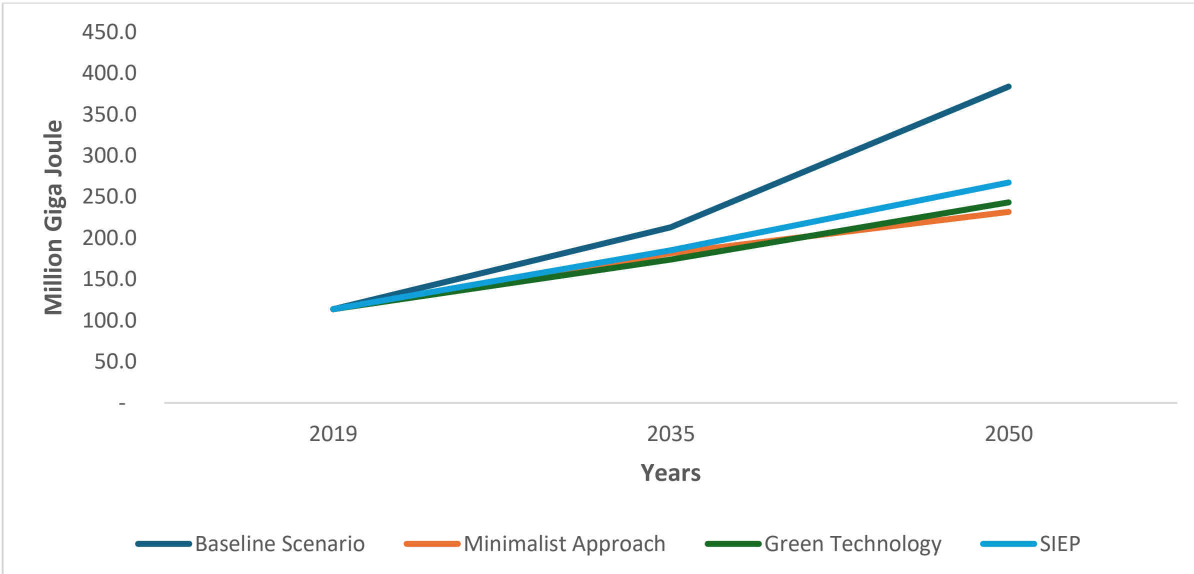
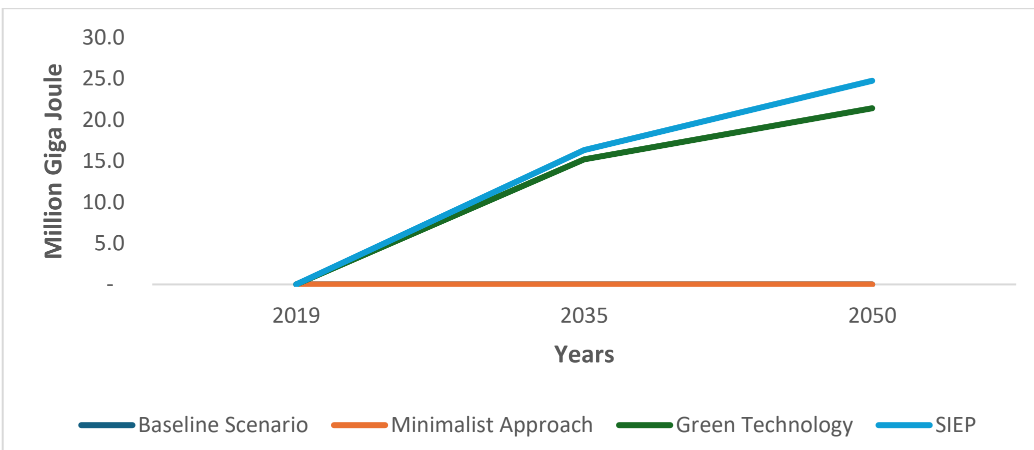


Figure 11: Ethanol Variation for Each Scenario Across the Years



Conclusion and Policy Recommendations

Ghana's transport sector presents both significant challenges and opportunities for decarbonisation. The increasing economic activities characterised by growth in both GDP and population have contributed to a rise in emissions from the sector over the years. With an urban population of almost 60% in 2022, urbanisation is also steadily driving emissions yearly. The sector's substantial contribution to the national economy (6.4%) and greenhouse gas emissions (15.4%) underscores the need for a balanced approach that promotes sustainable development while mitigating environmental impact.

Understanding the limitations in Ghana’s approach towards the sector’s decarbonisation, this study explored three policy-dependent pathways—Minimalist Approach (MA), Strict Implementation of Existing Policies (SIEP) and Green Technology (GT) — along with a Business-as-usual scenario. This study sought to highlight diverse strategies for reducing emissions and evaluate the associated opportunities and challenges. Following GHG emissions reduction potential analysis with LEAP using policy actions under the ASIF framework, the scenario analysis results reveal that each of the three policy-backed scenarios has the potential to reduce emissions drastically but requires some form of strict policy intervention to engender behavioural changes and technological advancements.

The MA scenario focuses on frugal and low mobility strategies such as increased walking, cycling, and ridesharing and offers low-cost solutions but may face cultural and infrastructural barriers. The SIEP scenario, which emphasises public transportation, electric mobility, and bioethanol use, leverages existing technologies with enacted policies; however, concerns arise from the lack of political will towards effectively implementing these policies to effect the envisioned change. The GT scenario proposes an ambitious shift to biofuels, vehicles with lower fuel economy, and electric vehicles. It offers significant emission reduction potential but requires substantial investment and technological capacity building.

Ultimately, the path forward for the transportation sector will likely involve a strategic combination of these approaches tailored to the country's unique economic, social, and environmental context. By carefully considering each emission reduction potential pathway, financial implications, and feasibility, policymakers can craft a comprehensive strategy that reduces greenhouse gas emissions and supports broader development goals. The success of these efforts will depend on strong political will, public engagement, and international cooperation to overcome financial and technological barriers.

In light of the findings, this chapter makes the following policy recommend-dations:

1. **Implement Ghana's EV Policy Through a Hybrid Sustainable Transport Approach:** The government should ensure that the implementation of Ghana's EV policy is not pursued in isolation but is embedded within a broader, phased strategy that balances green technology investments, strict policy enforcement, and cost-effective mobility solutions. While Ghana's EV policy aims to promote local EV manufacturing, charging infrastructure, and battery production, a hybrid approach would enhance its impact by integrating low-carbon public transport, non-motorized transport (NMT), and fuel efficiency measures to create a more comprehensive decarbonization pathway.
2. **Mandate Green Non-Motorized Transport (NMT) in Road Projects and Urban Redesigns**: The government should legislate the mandatory inclusion of cycling lanes, pedestrian walkways, and green public spaces in all urban road projects and redesigns. The Ministry of Roads and Highways should work with agencies like the Ghana Institute of Engineers to provide road design standards that require dedicated NMT pathways in all new road infrastructure projects. These standards must include safety and accessibility guidelines for cycling and pedestrian-friendly urban planning. Additionally, local authorities should pilot NMT-friendly city zones by redesigning urban spaces to prioritize walking and cycling, ensuring safer and more accessible pathways for pedestrians and non-motorized transport users.
3. **Strengthen Monitoring and Enforcement of Existing Transport Policies**: Given the potential of the SIEP scenario, the government should ensure a strict monitoring and evaluation of the implementation of transport sector policies. The Ministry of Transport (MoT) should conduct bi-annual performance reviews of public transport electrification, bioethanol adoption, and EV incentives. Additionally, the Ghana Statistical Service (GSS) should integrate transport decarbonisation indicators into national environmental and economic reporting to provide data-driven insights for policy improvements.
4. **Launch a National Public Awareness and Incentives Program for Green Transport Adoption:** The government should develop a targeted communication strategy to drive behavioural change toward sustainable transport options, with tailored messaging for different segments of

society. The National Commission for Civic Education (NCCE) should lead mass education campaigns promoting walking, cycling, and public transport use, particularly in urban centres.

5. **Strengthen Political Will by Establishing a Transparent and Stable Investment Environment**: Achieving Ghana's transport decarbonisation goals requires sustained political will, backed by a stable regulatory and financial environment to attract investment. The government must work to provide clear incentives for private sector participation in EV manufacturing, charging infrastructure deployment, and public transport electrification. The Bank of Ghana (BoG) should also collaborate with financial institutions to develop low-interest green transport financing options for businesses and individuals investing in electric mobility solutions. Additionally, the State Interests and Governance Authority (SIGA) should enforce anti-corruption and financial accountability measures in state-owned transport agencies to prevent mismanagement and ensure resources are used effectively.
6. **Expand Workforce Development for the Emerging EV and Green Transport Sector**: To sustain the transition to EVs and other green transport solutions, the Council for Technical and Vocational Education and Training (COTVET) should introduce specialized training programs in EV maintenance, battery technology, and renewable energy integration for transport. Universities and technical institutes should collaborate with industry stakeholders to design curricula aligned with the needs of Ghana's evolving transport sector. A National Green Transport Skills Program should be launched to equip auto mechanics, engineers, and technicians with the expertise needed to work in EV-related industries.

References

Ackah, I., & Tetteh, E. N. (2016). Determinants of autogas demand among Taxi Drivers in rural Ghana.

Aversa, D. (2024). Scenario analysis and climate change: a literature review via text analytics. *British Food Journal*, *126*(1), 271-289.

Benton, J. S., Jennings, G., Walker, J., & Evans, J. (2023). “Walking is our asset”: How to retain walking as a valued mode of transport in African cities. *Cities*, *137*, 104297.

Briand, Y., Pye, S., D’Agosto, M. D. A., Goes, G. V., Neves Schmitz-Gonçalves, D., Garg, A., ... & Trollip, H. (2023). Passenger transport decarbonization in emerging economies: policy lessons from modelling long-term deep decarbonization pathways. *Climate Policy*, 1-21.

Broni-Bediako, E., & Amorin, R. (2018). The Ghana liquefied petroleum gas promotion programme: opportunities, challenges and the way forward. Innov Ener Res, 7(197), 2576-1463.

Creutzig, F., Roy, J., Lamb, W. F., Azevedo, I. M., Bruine de Bruin, W., Dalkmann, H., ... & Weber, E. U. (2018). Towards demand-side solutions for mitigating climate change. *Nature Climate Change*, *8*(4), 260-263.

Creutzig, F. (2016). Evolving narratives of low-carbon futures in transportation. Transport Reviews, 36(3), 341–360. https://doi.org/10. 1080/01441647.2015.1079277

Energy Commission. (2020). 2020 Energy (Supply and Demand) Outlook for Ghana.

Environmental Protection Agency. (2018). Determination Of Fuel Economy Baseline In Ghana, Findings And Trends.

Environmental Protection Agency. (2022). Ghana’s Fifth National Greenhouse Gas Inventory. Ghana Environmental Protection Agency.

Garcia-Sierra, M., van den Bergh, J. C., & Miralles-Guasch, C. (2015). Behavioural economics, travel behaviour and environmental-transport policy. *Transportation Research Part D: Transport and Environment*, *41*, 288-305.

Ghana Statistical Service (2022). Economic National Account: Annual GDP by Production. From Ghana Statistical Service.

Holden, E., Banister, D., Gössling, S., Gilpin, G., & Linnerud, K. (2020). Grand Narratives for sustainable mobility: A conceptual review. *Energy Research & Social Science*, *65*, 101454.

IEA, I. (2012). CO2 emissions from fuel combustion highlights. *International Energy Agency Paris*.

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead, 2022: Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.012

JoyNews. (2010). Rot in Intercity STC exposed. Retrieved from JoyOnline: https://www.myjoyonline.com/rot-in-intercity-stc-exposed/

Lee, J., Veloso, F. M., Hounshell, D. A., & Rubin, E. S. (2010). Forcing technological change: a case of automobile emissions control technology development in the US. *Technovation*, *30*(4), 249-264.

Lefevre, J., Briand, Y., Pye, S., Tovilla, J., Li, F., Oshiro, K., ... & Zhang, R. (2021). A pathway design framework for sectoral deep decarbonization: the case of passenger transportation. *Climate Policy*, *21*(1), 93-106.

Li, S., Wang, B., & Zhou, H. (2024). Decarbonizing passenger transportation in developing countries: Lessons and perspectives1. *Regional Science and Urban Economics*, *107*, 103977.

Mensah, D. (2015). *Overriding the financial challenges of state mass transport companies in Ghana: A Case Study of Metro Mass Transit Company Limited* (Doctoral dissertation).

Ministry of Energy. (2010). Energy Sector Strategy and Development Plan. Ghana.

Ministry of Energy. (2022). Ghana's National Energy Transition Framework. Ghana.

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., ... & Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science advances*, *9*(37), eadh2458.

Sebastian, S., Wijewardane, S., & Srinivasan, S. (2023). Recent Advances in Hydrogen production, storage, and Fuel Cell Technologies with an emphasis on inventions, innovations, and commercialization. *Solar Compass*, 100065.

Sheldon, D., Skinner, I., Taeger, N., & Mugume, S. (2022). Assessment of climate change mitigation potentials and actions in Uganda's transport sector.

The Herald. (2024). STC faces financial looming crisis amid allegations of mismanagement. Retrieved from The Herald Ghana: https://theheraldghana.com/stc-faces-financial-looming-crisis-amid-allegations-of-mismanagement/

UNECE. (2023). *At COP28, UNECE and partners highlight need to decarbonize inland transport and how UN tools and legal instruments can help*. Retrieved from unece.org: https://unece.org/media/press/386256

Valero, A., Valero, A., Calvo, G., & Ortego, A. (2018). Material bottlenecks in the future development of green technologies. Renewable and Sustainable Energy Reviews, 93, 178-200.

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ISBN: 978-9988-52-945-1