Promoting Renewable Energy Technologies in Smallholder Agriculture: Examining Factors Influencing Smallholder Farmers Adoption of Renewable Energy Technologies in Lawra, Upper West Region-Ghana.

Ransford Teng-viel Karbo

A thesis submitted for the degree of
Doctor of Philosophy

School of Natural and Environmental Sciences
Newcastle University

January 2024

Abstract

Integrating renewable energy (RE) into agricultural practices can contribute to sustainable environmental and economic benefits. In Ghana, RE resources include solar and biomass that can support agronomic activities. Although policies and interventions exist to promote RE development in Ghana, it is unclear what factors motivate farmers to adopt RE technologies in agriculture. This research seeks 1) to review policies in Ghana that promote RE adoption in agriculture, 2) to examine theories applied to understand farmers' technology adoption behaviour in LMICs in general, 3) to examine factors influencing farmers' adoption intention and the contributing role of non-farmer stakeholders influencing the adoption of renewable energy in Ghanaian agriculture, 4) to test a predictive model, using structural equation modelling to assess psychological factors that determine farmers' adoption of RE in Ghanaian agriculture, and 5) to discuss the theoretical implications of the research and provide evidence for Ghanaian policy development in relation to farmer adoption behaviour.

A policy review was conducted to assess Ghana's renewable energy sector and its potential to scale-up application in Ghanaian agriculture. The results showed no central policy aimed at promoting RE adoption in Ghanaian agriculture aside policies in the areas of energy, environment, and climate change. Following the policy review, a systematic review (SR) was conducted to identify an appropriate theoretical approach for the empirical research. The SR addressed 'what theoretical approaches have been used to explain farmers' adoption of agricultural technologies in LMICs?'. The Decomposed Theory of Planned Behaviour (DTPB) was found to be the most relevant theoretical approach to understanding farmers' adoption behaviour. Initial empirical research entailing qualitative research was conducted to assess potential determinants of RE technology adoption in Ghanaian agriculture involving in-depth interviews for farmers (n=36) and non-farmer stakeholders (n=7). The results showed that psychological, economic, social, and technological factors represented enablers and barriers that affected farmers' likelihood to adopt RE technology for farming. Further results indicated that a broader stakeholder constituency contributed to and influenced farmers' adoption behaviours through interventions, policies, and institutional collaborations.

Based on the outcomes of the SR and qualitative research, a survey was designed involving farmers (n=418) in Lawra Municipality, Upper West Region, Ghana. Structural Equation Modelling was applied to test and validate an adapted theoretical model (DTPB) to predict factors that influenced farmers' likelihood to adopt RE technology. Aside subjective norms which did not positively predict farmers' intention, attitude, perceived behavioural control, perceived usefulness, perceived ease of use, compatibility, risk, peer and external influences, self-efficacy, resource facilitating conditions, and technology facilitating conditions were positive and significant predictors of farmers' intention to adopt RE technology.

To ensure widespread adoption of RE in Ghanaian agricultural, policies and interventions must align with the psychological attributes of farmers. Government must establish pragmatic policy regimes, including tax and credit subsidies and green financing frameworks to increase support for farmers to adopt RE technology.

Dedication

This work is dedicated to my late father, Prof. Naaminong Karbo, for inspiring, encouraging, and fuelling my desire to pursue doctoral studies.

Acknowledgements

I would like to thank the Most High God for granting me grace, resilience, and determination to undertake this doctoral work, notwithstanding the exigencies of the COVID-19 pandemic at the start of my doctoral study. I am eternally grateful for the tremendous support and tutelage from my supervisors: Prof. Lynn Frewer, Dr. Francisco Areal Borrego, Dr. Glyn Jones, and Dr. Albert Boaitey. Their immense support, guidance, and encouragement enabled the successful completion of this PhD thesis. Working and learning under their supervision has been a great pleasure and phenomenal experience. I am truly humbled for the opportunity to benefit from their wealth of academic and research knowledge. I wish to express my profound gratitude to my progression panel Dr. Sophie Tindale and Prof. Guy Garrod for providing me with valuable and constructive perspectives that contributed to shaping and improving this PhD thesis.

I acknowledge the Ghana Education Trust Fund (GETFUND) for providing sponsorship for my doctoral study. I am grateful to the Council for Scientific and Industrial Research – Science and Technology Policy Research Institute (CSIR-STEPRI) for granting me study leave to pursue my doctoral study. I wish to extend special gratitude to my field assistants, Jacob Nangtuo and Henry Naakpe, and the team of field researchers who assisted me in remotely collecting the farmer survey data. I wish to say thank you to the farmers in Lawra and the non-farmer stakeholder institutions for their interest and voluntary participation in this research.

Finally, I am most thankful for the support, love, and prayers of my family and friends, who wished me well during my doctoral study. I am grateful for the exceptional support from Dr. Gilbert Zana Naab and Dr. Francis Zana Naab for creating a ‘home away from home’ experience for me and sharing valuable advice with me throughout this doctoral journey. I thank my PhD colleagues in CRE and the PhD Suite in the Agricultural Building for our networking opportunities and intellectual interactions during my doctoral study. Knowing you all contributed to an amazing and phenomenal doctoral journey.

Table of Contents

List of tables

List of figures

List of abbreviations

AESD	Agricultural Engineering Services Directorate
AGFI	Adjusted Goodness-of-Fit Index
ASV	Average Shared Squared Variance
AVE	Average Variance Extracted
BTS	Bartlet's Test of Sphericity
CAP	Common Agricultural Policy
CAP	Country Action Plan
CFA	Confirmatory Factor Analysis
CHP	Combined Heat and Power
CIKOD	Centre for Indigenous Knowledge and Organisational Development
CO2	Carbon dioxide
CR	Composite Reliability
CSIR-IIR	Council for Scientific and Industrial Research – Institute of Industrial Research
DOI	Diffusion of Innovation
DTPB	Decomposed Theory of Planned Behaviour
EC	Energy Commission
EnDev	Energising Development
EU	European Union
EUT	Expected Utility Theory
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GFI	Goodness-of-Fit Index
GHG	Green House Gas
GHS	Ghana Cedis
GRADE	Grading of Recommendations Assessments, Development and Evaluation
GSS	Ghana Statistical Service
IFI	Incremental Fit Index
IFJ	Investing for Food and Jobs
ISEES	Institute for Sustainable Energy and Environmental Solutions

JOM	Juaben Oil Mills
KMO	Kaiser-Meyer-Olkin
LMIC	Lower-to-Middle-Income Country
MESTI	Ministry of Environment, Science, Technology, and Innovation
MoFA	Ministry of Food and Agriculture
MSV	Maximum Shared Squared Variance
NCCP	National Climate Change Policy
NFI	Normed Fit Index
NGO	Non-governmental Organisation
PCA	Principal Component Analysis
PNFI	Parsimony Adjusted Measures Index
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PV	Photovoltaic
RAA	Reasoned Action Approach
RE	Renewable Energy
REA	Renewable Energy Act
REMP	Ghana Renewable Energy Master Plan
RMSEA	Root Mean Square Error of Approximation
RUT	Random Utility Theory
SDGs	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
SEM	Structural Equation Modelling
SNA	Social Network Analysis
SNEP	Strategic National Energy Plan
SR	Systematic Review
SRW	Standardised Regression Weight
SSA	Sub-Saharan Africa
TAM	Technology Acceptance Model
TLI	Tucker Lewis Index
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
UMT	Utility Maximisation Theory

UNDP	United Nations Development Programme
WEAI	Women’s Empowerment in Agriculture Index

Submitted manuscripts from the research

- Karbo, R., Frewer, L., Areal, F. and Yu, E. (2022) 'Using renewable energy to meet the energy needs of smallholder farmers: Are there policies to promote adoption in Ghana?', *Ghana Journal of Agricultural Science,* 57(1), pp. 15–29-15–29. – Chapter 4 of the thesis.
- Karbo, R. T.-v., Frewer, L. J., Areal, F., Jones, G. and Nurudeen, S. (2023) 'A Systematic Review of the Efficacy of Theories Used to Understand Farmers' Technology Adoption Behaviour in Lower-to-Middle-Income Countries', *Development Studies Research*. – Chapter 5 of the thesis.

Chapter 1. General Introduction

1.1 Background to the Research

Energy is an important resource needed for economic productivity (Martins, Felgueiras and Smitková, 2018; Ryzhkov *et al.*, 2020). Globally, energy production is predominantly fossil fuel based (i.e., coal, oil, and natural gas) and is associated with adverse effects, including contribution to Green House Gas (GHG) emissions and rising global temperatures (Chel and Kaushik, 2011; Blandford and Hassapoyannes, 2018; Koyama, 2017). The demand for global primary energy (mainly fossil fuel) is estimated at 86% and is expected to increase in future due to the growing global population and energy consumption (Abas, Kalair and Khan, 2015; Ahmad and Zhang, 2020). This potentially catastrophic development may contribute to increasing GHG emissions. This has compelled collective policy reactions by countries to address the threats of global warming and the effects of climate change.

Since the ratification of the Kyoto Protocol[1] and the Paris Agreement[2], countries across the globe have prioritised sustainable energy technology and options to achieve low-carbon emissions and improve energy security (Pestisha *et al.*, 2023). Renewable energy has gained global attention as it constitutes resources that can generate clean energy with minimal or no environmental effect (Wesseh Jr and Lin, 2017; Adams and Nsiah, 2019; Jin and Kim, 2018). Renewable energy can help meet global energy needs given its infinite resource base from sources including solar, wind, biomass, hydro, geothermal, wave and tidal energy sources (see Table 1.1) (Chel and Kaushik, 2011). In addition to the environmental benefits, renewable energy is associated with stable market conditions compared to the volatility in prices of fossil fuels (crude oil) (Ali, Dash and Pradhan, 2012; Pestisha *et al.*, 2023). Stability in renewable energy market conditions can guarantee energy security and equity economic forecasting (Sotnyk *et al.*, 2021). Renewable energy may substitute for fossil fuels in the future and contribute to attaining Sustainable Development Goals (SDGs) in relation to SDGs 7 and 12, which focus on ensuring access to affordable and clean

[1] The Kyoto Protocol constituted industrialised countries to commit to an agreement to reduce greenhouse gases (GHG) emission in 1997. By extension, the Protocol operationalises the United Nations Framework Convention on Climate Change of 1992.

[2] The Paris Agreement was an international treaty committed to by 196 parties to respond to the threat of climate change. Also known as the Paris Accord, the agreement was established in 2015.

energy and responsible consumption and production, respectively (United Nations, 2015; Schwerhoff and Sy, 2017).

Energy Sources	**Examples of Energy Conversion Options**
Hydropower	Power generation.
Biomass	Heat and power generation.
Geothermal	Urban heating, power generation, hydrothermal.
Solar	Solar home systems, solar dryers, solar cookers.
Direct solar	Photovoltaic energy, thermal power generation, water heaters.
Wind	Power generation, wind generators, windmills, water pumps.
Wave and tide	Barrage for power generation, tidal stream energy generation.

Table 1.1 Renewable energy sources and use

Source: Owusu and Asumadu-Sarkodie (2016); Panwar, Kaushik and Kothari (2011).

Energy is becoming more important because of its extensive application in different economic sectors. Important among these is agriculture, which directly supports food production, which is needed for national and global development (Best, 2014; Lawal, 2023). Due to mechanisation, agriculture has become more dependent on energy. Agriculture's dependence on energy contributes between 14 to 30 percent to global GHG emissions (Lenka *et al.*, 2015; Richards, Wollenberg and van Vuuren, 2018; Liu, Zhang and Bae, 2017; Khan, Ali and Ashfaq, 2018). In the agricultural sector, the manufacture and application of agricultural inputs, use of fossil-fuelled farm machinery, poor practices in land preparation and agronomic activities, and livestock production have been identified to be significant contributors to GHG emissions (Lenka *et al.*, 2015; Bell, Cloy and Rees, 2014; Bellarby *et al.*, 2013; Blandford and Hassapoyannes, 2018). This trend will continue if the current level of energy intensity in agriculture is increased to meet the mechanisation required to deliver future food security requirements. Food demand is projected to increase based on increasing population, and this will potentially drive energy use in agriculture because of the need to increase agricultural efficiency through technology application (i.e., water pumps for irrigation), which may use more energy (Röös *et al.*, 2017; Harvey and Pilgrim, 2011). Renewable energy utilisation in agriculture is needed to decrease the agricultural sector's carbon emissions and ensure energy self-sufficiency for farmers and other agricultural value chain actors (Pestisha *et al.*, 2023; Abaka *et al.*, 2017; Jebli and Youssef, 2017). There is evidence to show that renewable energy resources can support future agricultural energy needs and, at the same time, promote sustainable agricultural production (Smith and Gregory, 2013; Martinho, 2018). Renewable energy can support farm-based activities such as generating electricity for lighting, powering water pumps, providing heating in greenhouse farming, drying, heating and cooling for storage purposes on the farms (Bayrakcı and Koçar, 2012; Abaka *et al.*, 2017; Ali, Dash and Pradhan, 2012). As energy can be derived from renewable energy sources (i.e., solar, wind, biomass, etc.) for agricultural use, agriculture can also create raw materials in the form of biomass resources (i.e., crops/livestock residue/bioenergy crops) that can support energy generation to be used for various agricultural activities (Best, 2014). Thus, as the reliability of energy supply is improved, alternative income sources can be generated for farmers and farms. In line with the agronomic, social, and economic benefits that can be delivered from renewable energy sources, it is important for countries to invest in developing the full potential of renewable energy resources and deploy their application in the agricultural sector.

1.2 Statement of the Problem

Ghana has considerable potential for developing and applying renewable energy in agriculture. This is possible given the abundance of renewable energy resources, including sunshine for solar energy and massive raw material deposits for biomass energy (Amankwah, 2011; Afrane, 2012). Ghanaian governments, researchers, and other stakeholders have recognised the potential of renewable energy to replace fossil fuel use (Energy Commission, 2019; Energy Commission, 2019a; Energy Commission, 2020). This has generated interest in the development of sustainable energy policies and technologies with the aim of replacing fossil fuels. For example, the Renewable Energy Act-(832) (2011), the National Bioenergy Policy and the Ghana Renewable Energy Master Plan (2019-2030) are among the policies that were formulated and implemented to develop and facilitate utilisation of renewable energy.

Researchers, the government, and other stakeholders have developed and promoted renewable energy technologies to be adopted in the agricultural sector to demonstrate further commitment to developing and utilising renewable energy. Examples of these technologies include solar water pumps for irrigation, solar-powered greenhouses, mechanical solar dryers, and bioenergy crop cultivation (Asibey, Yeboah and Adabor, 2018).

However, despite efforts to promote renewable energy in Ghanaian agriculture, adoption among farmers is low (Pannell *et al.*, 2006; Yigezu *et al.*, 2018; Amankwah, 2011). Some research has focused on understanding farmers low adoption of specific agricultural technologies in Ghana (Awuni, Azumah and Donkoh, 2018; Donkoh, Azumah and Awuni, 2019; Zakaria *et al.*, 2020; Anang and Zakariah, 2022; Addison *et al.*, 2022; Ehiakpor, Danso-Abbeam and Mubashiru, 2021). Much of the previous research has focused on adopting agricultural innovations, including mechanised farm implements and improved crop varieties and agronomic practices, with a limited focus on sustainable energy technology. In line with that, the factors accounting for the low uptake of renewable energy in Ghanaian agriculture need to be investigated to enable interventions and policies to be designed and implemented to overcome these. The research presented in this thesis aims to understand factors influencing farmers' intention to adopt renewable energy technology. The results can contribute to generating evidence for policymakers, researchers, and technology-product designers to develop and promote efficient, sustainable energy policy and technology options that meet the particular energy needs of Ghanaian farmers.

1.3 Research Objectives

This research aimed to investigate determinants affecting farmers' intention to adopt renewable energy technology for farming in Ghanaian agriculture. To achieve this, the specific research objectives were as follows:

i. To review policies in Ghana that promote renewable energy adoption in agriculture.
ii. To examine theories applied to understand farmers' technology adoption behaviour in lower-to-middle-income countries (LMICs).
iii. To examine factors influencing farmers' adoption intention and the contributing role of non-farmer stakeholders influencing the adoption of renewable energy in Ghanaian agriculture.

iv. To test a predictive model, using structural equation modelling to assess psychological factors that determine farmers' adoption of renewable energy in Ghanaian agriculture.
v. To discuss the theoretical implications of the research and provide evidence for Ghanaian policy development in relation to farmers' sustainable energy adoption behaviour.

1.4 The Organisation of the Research Presented in this Thesis

The thesis has eight chapters. Chapter 1 introduces the research background, the problem statement, and the research objectives. Chapter 2 reviews relevant literature on enablers and barriers to the application of renewable energy in agriculture. The chapter identifies significant gaps in the literature regarding technology adoption in agriculture, which include limited knowledge of determinants influencing farmers' decision to adopt sustainable energy technology in Ghana. Chapter 3 presents the methodology used in the thesis. The methods used for conducting the policy and systematic literature reviews are discussed and justified, together with those used for the empirical data collection. The profile of the case study area is described, including the country and region. Chapter 4 presents a policy review (published as a review article (Karbo *et al.*, 2022)) on renewable energy development and application in Ghanaian agriculture. The review aimed to identify Ghanaian policies that promote the adoption of renewable energy technologies in Ghana's agriculture. The chapter addresses objective (i) of this research. Chapter 5 provides a systematic literature review. The systematic review sought to answer the research question, 'What theories have been applied to understand farmers' technology adoption behaviour in lower-to-middle-income countries (LMICs)?' The review (published as a review article (Karbo *et al.*, 2023)) aimed to identify an appropriate theoretical model to predict psychological factors determining farmers' adoption intention. The chapter addresses objective (ii) of this research.

Chapter 6 describes qualitative research which investigates drivers and influential factors of farmers' intention to adopt renewable energy technology from the perspectives of farmers and how these might be similar to, or differ from, non-farmer stakeholders, which may influence, for example, policy activities related to education and extension activities. In addition, the research examines the contributing role of non-farmer stakeholders in influencing farmers' adoption intention. This follows in-depth interviews with farmers and non-farmer stakeholders to understand motivations, enablers, barriers, and policy options affecting the intention to adopt renewable energy for farming. The chapter addresses objective (iii) of this thesis. Chapter 7 describes quantitative research conducted using a farmer survey in Lawra Municipality. The outcomes of the systematic review and qualitative research inform the survey. Using structural equation modelling, a predictive model is tested in relation to its predictive capacity, assessing psychological factors that determine farmers' adoption of renewable energy in Ghanaian agriculture. The chapter addresses objective (iv) of this research. Chapter 8 presents a general discussion of the thesis in relation to the initial research questions, the existing literature, the theoretical contributions of the research to the existing literature, and implications for future research. The chapter identifies evidence from the research for Ghanaian policymakers to leverage in the development of sustainable energy policy and technology options. The chapter concludes by highlighting the research limitations. The chapter addresses objective (iv) of this research. Figure 1.1 depicts a diagram outline of the thesis.

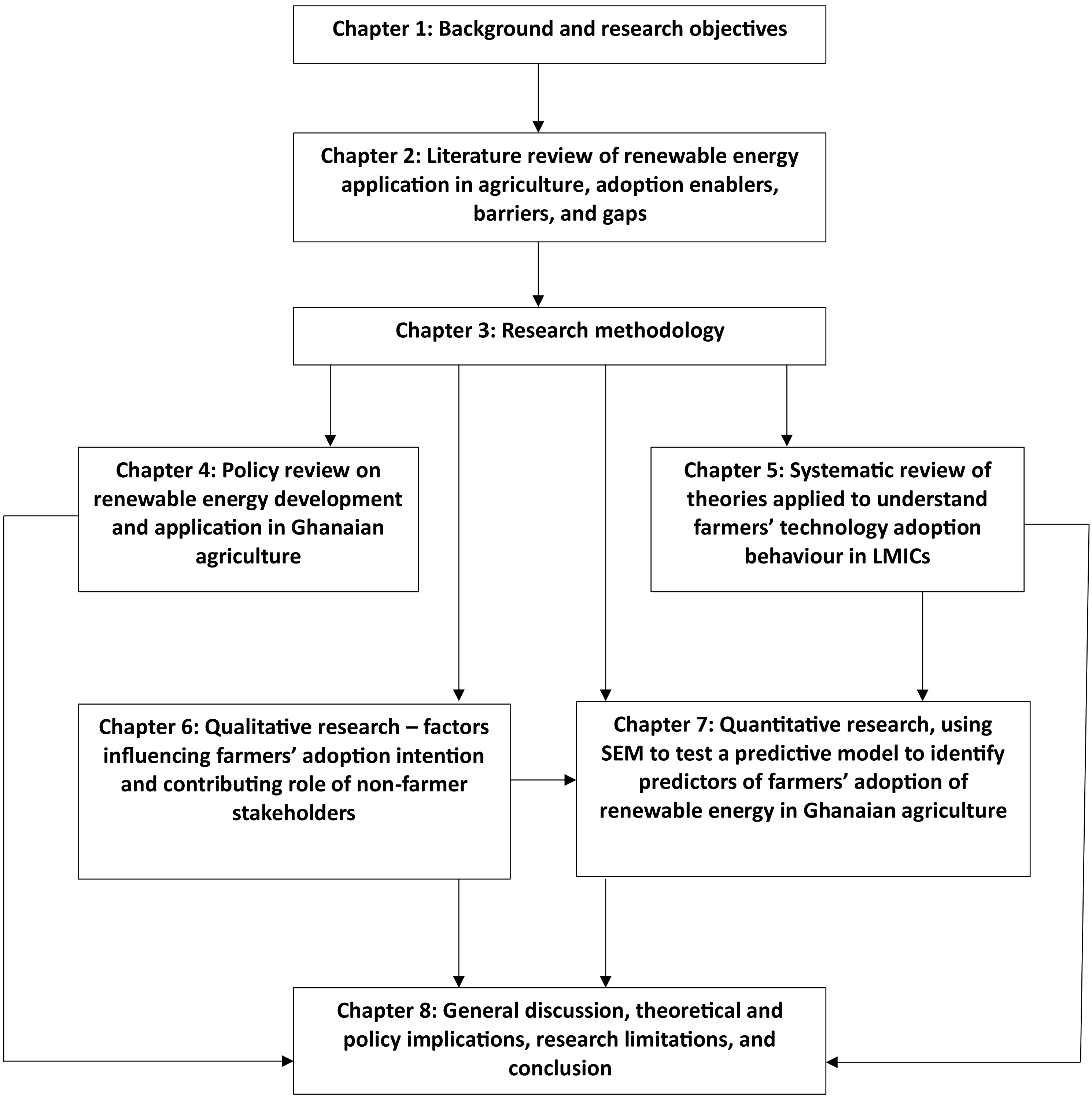


Figure 1.1 Outline of the thesis

Chapter 2. Literature Review

2.1 Introduction

This chapter provides an overview of renewable energy, its application, and potential benefits in agriculture. The chapter presents an overview of the concept of agricultural technology adoption and discusses theoretical considerations used to understand farmers' adoption behaviour. The chapter concludes by underscoring the need for a systematic review aimed at identifying an appropriate theoretical approach to understand predictors of farmers' intention to adopt renewable energy technology in Ghanaian agriculture.

2.2 Renewable Energy and Agriculture

Global awareness in relation to the renewable energy-agriculture nexus is increasing, and considerable gains are being made towards harnessing renewable energy resources (Gorjian *et al.*, 2022). Agriculture is beginning to witness the scaling-up and application of various forms of renewable energy technology (Baldwin, Carley and Nicholson-Crotty, 2019; Kodirov *et al.*, 2020). This can be attributed to deliberate interventions and policy options focusing on intensifying sustainable energy development to reduce carbon emissions (Rahman *et al.*, 2022; Majeed *et al.*, 2023). For example, Appel, Ostermeyer-Wiethaup and Balmann (2016) reported the growing use of farm residues to generate energy from biogas in German agriculture. Miles *et al.* (2016) reported an increasing use of anaerobic digesters on livestock farms in the United States of America (USA) to generate electricity for farm-based activities such as ventilating, heating, lighting, organic liquid fertilizer and compost. Frantál and Prousek (2016) reported the increasing cultivation of bioenergy crops and installation of anaerobic digesters on farms in the Czech Republic and the European Union (EU). Furthermore, Wahyudi (2017) reported renewable energy application in Indonesian agriculture through the generation of bioenergy from deposits of agricultural residues. Also, Ben Jebli and Ben Youssef (2017) found the application of solar, anaerobic digesters and geothermal energy in Tunisian agriculture to generate electricity for farm-based activities, including irrigation of crops, pumping drinking water for pasture and greenhouse farming.

Although there is evidence from the literature suggesting the application of renewable energy in agriculture, a careful observation indicates that countries in the global south[3] may be lacking behind (Clement *et al.*, 2018; Owusu and Asumadu-Sarkodie, 2016). The renewable energy sector is underdeveloped in many countries in the global south, thereby, limiting its uptake in agriculture (Obeng-Darko, 2019; Atuguba and Tuokuu, 2020; Baye, Ahenkan and Darkwah, 2021). There is an abundance of renewable energy resources across the globe, much of which are under exploited due to a lack of policy and investment strategy (Chel and Kaushik, 2011; Pestisha *et al.*, 2023). For instance, Atuguba and Tuokuu (2020) argued that Ghana's legislative policy on renewable energy development was dead on arrival because of ambiguous regulatory frameworks, institutional weaknesses, and the dependence on donor support for operationalisation. It is important for cogent policy frameworks to be developed to attract the necessary investments to harness renewable energy resources and increase its uptake in agriculture (Falchetta *et al.*, 2022).

Due to the underdeveloped renewable energy sector in countries in the global south, renewable energy use in agriculture is predominantly in the basic or conventional form. For example, Fami *et al.* (2010) found that farmers in Iran conventionally used heat from the sun (i.e., solar) to openly dry crops and farm waste (i.e., biomass) to make compost to be applied on farms. In Ghana, solar energy was found to be predominantly used in agriculture for drying of agricultural produce in the open using heat from the sun (Amankwah, 2015; Aroonsrimorakot and and Laiphrakpam, 2019). Using conventional forms of renewable energy may be convenient and relatively cheaper to farmers, however, these energy forms can be inefficient and laborious (Aroonsrimorakot and and Laiphrakpam, 2019).

Renewable energy application in agriculture is known to support agronomic activities (Abaka *et al.*, 2017). Nonetheless, other factors including geographical location, production methods, and environmental conditions are accounting for its growing uptake (Clement *et al.*, 2018). Although agriculture in global south countries contribute least to GHG emissions from improper agronomic practices (i.e., bush burning, indiscriminate tree cutting, etc.), GHG emissions from global north[4] countries is high and can be traced to the mechanised food production methods, much of which is fossil

[3] Global South countries constitute economically underdeveloped countries of Africa, India, China, Brazil, etc Odeh, L. E. (2010) 'A comparative analysis of global north and global south economies'.

[4] Global North countries represent economically developed countries of Europe, North America, etc ibid.

energy dependent (Chidiebere-Mark *et al.*, 2022; Anum, Ankrah and Anaglo, 2022). According to Bartolini and Viaggi (2012) and Chinnici, D'Amico and Pecorino (2015), there was a strong desire to transition from fossil based energy to renewable energy to reduce agriculture's contribution to GHG emissions while ensuring energy security, and diversifying energy markets. This development has ensured countries to establish energy transition roadmaps and set achievable targets (i.e., Net zero) (Millot, Krook-Riekkola and Maïzi, 2020; Meadowcroft and Rosenbloom, 2023).

Obviously, global south countries can emulate the successes of global north countries to augment the development of the renewable energy sector. This may begin with the development and strengthening of sustainable energy interventions and policy options that can increasingly attract investments to harness renewable energy resources. The Renewable Energy Sources Act (REA-2004) and the Common Agricultural Policy-CAP of the EU are examples of policies facilitating renewable energy development and use in the agriculture of Germany and the Czech Republic, respectively (Appel, Ostermeyer-Wiethaup and Balmann, 2016; Frantál and Prousek, 2016).

2.2.1 Benefits and uses of renewable energy in agriculture

As noted by Fami *et al.* (2010, p. 704) "renewable energy and farming are a winning combination". This implies that energy and agricultural sectors can obtain mutual benefits such that renewable energy sources can support agronomic activities, while agriculture provides resources (i.e., crop and livestock residues, bio-energy crops, etc.) for energy generation (Fami *et al.*, 2010; Behera, Behera and Behera, 2015). Renewable energy utilisation in agriculture offsets climate change mitigation, reduces the cost of energy input, and minimises heavy dependence on fossil fuels, thereby proving enormous benefits linked to the generation and utilisation of renewable (Fami *et al.*, 2010; Chikaire *et al.*, 2010; James, Janine and Brian, 2006).

For example, the application of solar energy represents a case in point. Abaka *et al.* (2017) and Bayrakcı and Koçar (2012) have observed that solar energy technology (PV) can be potentially used for many farm-based activities such as generating electricity to provide lighting, powering water pumps, providing heating in greenhouse farming, and drying and heating and cooling for storage purposes on the farms. Solar energy technology is particularly important for farms which are beyond the reach of local or national grid lines. In addition, wind energy can be used through small system setups to generate power for pumping water from near or far water sources, grinding grains, or feeding excess power into local or national grids for additional farm/farmer revenue. Furthermore, geothermal energy technology can provide regulated heat for greenhouse farming, aquaculture, mushroom culture, and crops such as onions and garlic. Biomass energy is used to generate solid, liquid, and gas energies suitable for drying, producing organic fertilizer, and fuelling farm equipment.

2.3. Potential of Renewable Energy Use in Ghana’s Agriculture

There are compelling reasons for renewable energy use in Ghana’s agricultural sector. Notable reasons are long-term cost-effectiveness, availability of renewable energy resources, farm and household energy sufficiency, and decentralised or farmer/self-energy-generation (Bardi, El Asmar and Lavacchi, 2013). The literature on renewable energy use in Ghana’s agriculture is limited, with exceptions being provided by (Duku, Gu and Hagan, 2011; Thomsen, 2014; Afrane, 2012; Amankwah, 2011; Arranz-Piera *et al.*, 2016; Bayitse, Tornyie and Bjerre, 2017; Kemausuor *et al.*, 2014; Osei *et al.*, 2013; Otchere-Appiah and Hagan, 2014). These studies suggest that full-scale application of biomass and solar energy may be beneficial to Ghana’s agriculture, in particular because of the availability of huge deposits of agricultural waste and abundance of solar energy.

Biomass exploitation as renewable energy in Ghana’s agriculture is widely considered practical since agriculture produces large quantities of biodegradable residues (Thomsen, 2014; Asibey, Yeboah and Adabor, 2018; Quartey, 2012; Kemausuor *et al.*, 2014). The common practice of integrating crops and livestock farming in Ghana contributes to generating biodegradable resources like crop and livestock residues for biomass energy (Amankwah, 2011; Mohammed *et al.*, 2013).

Amankwah (2011) identified the possibility of integrating biogas technology into the farming system of northern Ghana. It was found that mixed farming (crop and livestock) was a prevalent farming system in Northern Ghana and capable of generating the required feedstock (crop and livestock residues) for anaerobic digesters. It was also reported that organic manure could be produced from the slurry content (representing waste from energy generated). This would imply a considerable minimisation of excessive application of chemical fertilizers in Northern Ghana due to the area’s low soil fertility.

Ayamga, Kemausuor and Addo (2015) assessed the potential for generating biomass energy from crop residue in the Lawra-Nandom District (now Lawra Municipality and

Nandom Municipality) of Ghana. With an annual agricultural crop residue of about 272,000t, the research suggested that it was possible to generate energy from this residue. Using only 40 percent of the average annual crop residues generated between 2003 to 2012, the authors estimated that about 40 million litres of ethanol could have been produced. This has the potential to contribute to achieving the objective of assimilate 20 percent of biofuels in the transport sector energy mix by 2030, as contained in the National Bioenergy Policy (Iddrisu and Bhattacharyya, 2015).

Research focused on the trigeneration (i.e., concurrently generating energy including electricity, heating, and cooling (CHPC)) based on biomass from crop residues in some selected districts in Ghana suggests that energy can be generated to capacities of 600kWe and 1MWe CHP (Arranz-Piera *et al.*, 2016). Since crop residues were generated from small farm holdings, residues from various small farm holdings are gathered or "cogenerated" to create a bulk biomass resource feedstock. For instance, in one of the field-case areas included in the research, Lawra district (now Lawra Municipal), crop residues from a minimum total of 280 small farm holdings with an average farm size of 1 hectare could enable an energy generation capacity of 600kWe. Crop residues from 56 or 28 small farm holdings with average farm sizes of 5 and 10 hectares were estimated to enable an energy generation capacity of 600kWe. To enable an energy generation capacity of 1MWe, crop residues were estimated from a minimum of 467 farms with an average farm size of 1 hectare, or 93 farms with an average size of 5 hectares, or 47 farms with an average size of 10 hectares. The energy generation at this level can potentially improve the rural electrification programme that aims to extend electricity to rural communities not connected to the national grid. Similarly, farmers could increase income generation by 29 to 64US$ per tonne of crop residues sold for biomass energy generation, resulting in a significant increase in income for households with large farm sizes.

Similarly, Otchere-Appiah and Hagan (2014) identified the potential generation of biomass energy (electricity) from maize residue in rural agricultural areas in the Brong Ahafo Region of Ghana (now Ahafo, Bono and Bono East regions), based on estimates of energy production from the huge dry maize residue produced in the region (329,059 tonnes annually). Given the average annual maize residue, the authors estimated an electricity generation capacity of close to 494 GWh. This development would contribute towards improving rural electrification.

Daniel, Pasch and Nayina (2014) investigated biomass energy generation using an anaerobic digester and biomass feedstock such as livestock residues, crop residues and municipal sewage. With particular emphasis on crop residues, secondary waste was generated from agri-food processing of oil palm, fruits, cocoa, cashews, and even by-products of the breweries. This suggests the agricultural sector's capacity to provide significant biomass resources for energy generation (see Table 2.1).

As Ghanaian agriculture has the potential to provide crop residues for renewable energy generation which offers environmental benefits, the question of an opportunity cost arises with reference to soil fertility and crop nutrients due to potential excessive exploitation of crop residues. This may occur due to a heavy dependence and indiscriminate removal of crop residues from farm fields for energy generation (Ayamga, Kemausuor and Addo, 2015; Wu and Liu, 2012). This practice may potentially expose farmlands and crops to pests and disease attacks increasing the risk of food production losses for farmers. In this case, it is important to use sustainable agricultural practices to balance the agricultural and environmental benefits of crop residues uses. For example, energy generation from crop residues may be exploited only when there is an excess crop residues generated on farms. This approach can ensure sustainable agronomic practices which protects the soil from losing fertility.

In the case of solar energy use, Kalogirou (2004) and Amankwah (2015) found that it was possible to generate electricity to power water pumps for crop irrigation and lifting water for livestock. Kunen *et al.* (2015) positively assessed the economic viability and reliability of using solar energy to pump water for irrigation. In addition to the potential use of solar energy in food crop production, there is a greater potential to use solar energy in cash crops production such as cocoa. Globally, Ghana is the second largest producer of cocoa beans contributing about US$2 billion in foreign exchange annually (van Vliet *et al.*, 2021; Awafo and Owusu, 2022). This reflects the economic importance of cocoa production, in the face of the negative effect of climate change such as drought and erratic rainfall patterns (Bunn *et al.*, 2019; Ameyaw *et al.*, 2018). Sarpong *et al.* (2022) reviewed the sustainable financing ecosystem for cocoa irrigation in Ghana reported on cases of solar water pumps use for irrigation of cocoa production in the Bono, Bono East and Ahafo regions of Ghana. Similarly, Gbodji, Quarmine and Minh (2023) reported a potential case for solar technologies application for cocoa irrigation in Ghana. Kuwornu, Egyir and Anyinam (2011) reported that solar energy was potentially useful for activities focused on powering mechanised dryers.

Likewise, Atepor (2020) identified that cocoa pod husk fuelled dryers had potential in Ghanaian rural cocoa areas. This could substantially improve the effectiveness of drying agricultural produce and minimise potential contamination with dust and pest and diseases after post-harvest (Duah, 2014). Table 2.1 constitutes selected cases of biomass and solar energy application in Ghana’s agriculture.

RE Energy Technology	Area Used in Ghana	Agronomic Impact	Socioeconomic impact	Barriers to Adoption	Facilitators of Adoption	Reference
Biomass	Accra	Generate biofertilizer & grow seedlings sold to farmers	Biogas to generate electricity of about 0.1MW fed into the national grid	Lack of proper segregation of agricultural/urban waste	Agricultural/urban and human faecal waste used as feedstock	https://www.safisana.org/en/ 07/09/2020, 10:43AM.
Biomass	Juaben Juaben Oil Mills (JOM)	Use oil palm residues to generate electricity	Employment for out-grower scheme (1659ha) & smallholder farmers (2323ha)	N/A	Electricity generation (installed capacity of 424kW that could generate about 1.5GWh annually)	Asibey, Yeboah and Adabor (2018)
Biomass	Kwa (Ghana Oil Palm Development Company Limited)	Use farm residues (empty fruit bunches, fibre & nut	Out-grower scheme creates employment for smallholder farmers	N/A	Self-generate electricity for on-farm industrial facilities (i.e. mill/refinery etc.)	Asibey, Yeboah and Adabor (2018); http://www.gopdc-ltd.com/company-profile/ 07/09/2020, 11:05AM

		shells) as feedstock to generate electricity				
Solar	Techiman, Goaso, Sankore & Nkrankwanta	All year-round irrigation of cocoa production with solar water pumps.	It is a cheaper source of electricity compared to the national grid or fossil fuels.	N/A	Convenient approach of irrigation compared to the manual method	(Sarpong *et al.*, 2022)
Solar	Bono, Bono East and Ahafo regions	Solar-powered mist-blowers, solar-slashers and pruners for cocoa production.	It is a cheaper source of power compared to the national grid or fossil fuels to fuel mechanised farm tools.	N/A	Convenient approach to farm/land preparation and maintenance compared to the manual method	(Sarpong *et al.*, 2022)

Solar (traditional form)	Nationwide	Drying agricultural produce using heat from the sun in the open	N/A	Laborious techniques compromise product quality with stones, insects, dust, etc.	Easily accessible and available all year round	(Amankwah, 2015; Aroonsrimorakot and and Laiphrakpam, 2019)
Solar	EnviroDome & NewEnergy/Hikma Farms	Generate electricity for Greenhouse farms (power water pumps & mechanical ventilation)	It is a cheaper source of electricity compared to the national grid	Increases cost of greenhouse setup	Complement erratic power supply from the national grid	Elings, Saavedra and Nkansah (2015)
Solar	Tamalgu, Napkanduri, Datoyili and	All year-round irrigation of vegetable	Increase in production and farmer income	Initial high cost of solar panels	Convenient approach of irrigation	UNDP (2018)

	Fooshegu areas, Northern Region	crops & fruits with solar water pumps			compared to the manual method	
Solar	Nabio-Navorongo, Upper East Region	Generate electricity to power 1000MW solar water pumping system for irrigation	Providing portable water to about 350 people in the community	Initial high cost of solar panels	Convenient approach of irrigation compared to the manual method	Energypedia (2018)

Table 2.1 Selected cases of biomass and solar energy application in Ghana's agriculture

Source: Author's construct, (2020).

2.4 Gaps in Renewable Energy Use in Ghana’s Agriculture

Notwithstanding the benefits of biomass energy use in agriculture, competition for land use appears to be an inherent challenge. Researchers have identified evidence of farmers concerned about the use of arable land for renewable energy-based activities (i.e. cultivating bioenergy crops) in place of food crops (Hellmann and Verburg, 2011; Vrolijk, 2013; Thomsen, 2014; Amigun, Musango and Stafford, 2011; Schoneveld, German and Nutakor, 2011).

For example, Yankey, Hofer and Kraft (2011) in a research found potential replacement of cultivation of food crops like cassava and maize for bioenergy crops (i.e. jatropha). The potential competition for land use is can be attributed to the growing influx of foreign investors for lands in Ghana to commercially cultivate bioenergy crops (Vrolijk, 2013; Addo, Bessah and Amponsah, 2014; Amigun, Musango and Stafford, 2011; Nnanna, 2010). With similar trends occurring in other parts of sub-Sahara Africa, Amigun, Musango and Stafford (2011) and Thomsen (2014) note with worry that Africa may become fertile ground for cultivating bioenergy crops to meet the swelling demand of Europe’s biofuel market. This development may negatively impact the sub-region's capacity to self-sufficiently produce food, posing threats to food security and nutrition. In Northern Ghana, livestock production is prevalent in addition to food crop production. In that context, livestock residues can provide potential feedstock for biogas energy generation. However, Daniel, Pasch and Nayina (2014) found that livestock was mostly reared on the basis of free-range, causing difficulty in collecting animal residues. This development hinders the potential to gather sufficient feedstock from livestock farms which could be used for biogas energy generation. Moreover, agriculture is predominantly practiced on small farm holdings, thereby, generating small amounts of agricultural waste. That means, it will require an aggregation of agricultural waste from multiple smallholder farms to obtain sufficient raw materials as feedstock for biogas generation. Ideally, the waste-to-energy system in Ghana may require policy attention to streamline agricultural waste sources to contribute to the feedstock for biomass energy generation. According to Daniel, Pasch and Nayina (2014), many of the waste-to-energy projects in Ghana have focused on improving urban sanitation, therefore, relying primarily on municipal or urban waste as feedstock for generating biomass energy.

Renewable energy technology is mostly associated with high initial costs, which will be a barrier to adoption as many farmers are low-income earners. For example, Kuwornu, Egyir and Anyinam (2011) found that smallholder farmers with low incomes could not adopt and use mechanical solar dryers due to perceived high start-up costs. Similarly, Mukherji *et al.* (2017) reported that initial high costs affected the scale-up of solar-powered irrigation pumps in Nepal's agriculture. The long-term cost benefits of using renewable energy technology in agriculture is well known, however, concerns of high initial costs may impede farmers' adoption decision.

Notably, renewable energy use in Ghanaian agriculture is often on a project or pilot basis with little or no scaling-up (RenewableEnergyTechnologyTransferProject, 2018). For example, Energy Commission (2019) reported that Poldaw wind pumps for irrigation were piloted in Northern, Western and Greater Accra regions of Ghana by the Ministry of Food and Agriculture (MoFA) – Agricultural Engineering Services Directorate (AESD) but failed to scale up due to high initial costs, limited expertise, and lack of equipment for maintenance. Policy cohesion is required to ensure appropriate conditions are provided to facilitate scaling-up of renewable energy technology beyond pilot projects.

2.5 Technology Adoption in Agriculture – Gender and Agriculture in LMICs

The importance of agricultural technology is predicated on the susceptibility of the agricultural sector to the negative effects of climate change and potential threats to food security and nutrition (Abdul-Majid *et al.*, 2024). There has been significant introduction of innovative agricultural technologies which are focused on improving agronomic practices and modernising agricultural production techniques (Jara-Rojas *et al.*, 2020; Weyori *et al.*, 2018; Abdul-Majid *et al.*, 2024). Improved agricultural technologies which are being introduced for agricultural purposes, may be classified as follows: A) Sustainable agricultural practices and innovations, B) Digital agriculture and information technology, C) Precision farming and resource management, D) Financial inclusion and agricultural transaction, and E) Remote sensing and satellite technology (Abdul-Majid *et al.*, 2024; Carter, Laajaj and Yang, 2021; Yogarajan *et al.*, 2023).

Although technology adoption in agriculture is often targeted at different categories of farmers (e.g., smallholder and commercial farmers), the rate and level of adoption may vary between male and female farmers (Rola-Rubzen *et al.*, 2020). In LMICs, female farmers' adoption of agricultural technology has been reported to be lower than male farmers due to reasons including limited access to resources such as land, credit, extension services and infrastructure (Rola-Rubzen *et al.*, 2020; Satyavathi, Bharadwaj and Brahmanand, 2010; Huyer, 2016). For example, Gebre *et al.* (2019) explored gender differences in the adoption of agricultural technology and found that, female farmers adoption of improved maize variety was lower compared to male farmers because of low economic status associated with the inability of female farmers to access economic empowering resources such credit. Similarly, Ndiritu, Kassie and Shiferaw (2014) found that female farmers had lower likelihood of adopting sustainable agricultural intensification practices in Kenya because of socioeconomic inequalities.

Research into technology adoption has found that female farmers' low agricultural technology adoption was potentially due to technologies designed to suit male farmers characteristics. Such technologies were designed with attributes like heavy-weight parts which were difficult to use by female farmers (Huyer, 2016). Kawarazuka (2018) found that female farmers in Uganda and Bolivia had low adoption rates in relation to sweet potato silage chopping and grading machines because of technology incompatibility due to less physical strength and smaller body sizes relative to male farmers.

Most female farmers perceived mechanisation and use of farm machinery to be the domain of male farmers (Rola-Rubzen *et al.*, 2020). Most often, traditional, and cultural underpinnings defined and labelled farmers as predominantly males. This development inescapably hindered female farmers ability to obtain information and training on agricultural technologies (Rola-Rubzen *et al.*, 2020). For example, agricultural extension agents most often overlooked women in the household when introducing agricultural technologies due to traditional and cultural norms which identified males as the immediate reference to a farmer and women as wives (Peterman, Behrman and Quisumbing, 2014).

Other factors resulting in female farmers' low adoption of agricultural technology include failure to include female farmers in decision-making processes and stakeholder engagement exercises, and inadequate formal education opportunities for women generally, and in relation to agriculture specifically (Kawarazuka *et al.*, 2018; Fischer *et al.*, 2018; Peterman, Behrman and Quisumbing, 2014; Huffman, 2020). For example, Ogunlana (2004) in a research conducted to investigate alley farming in Nigeria reported that female farmers' inability to adequately adopt agricultural technology was due to lack of knowledge regarding the benefits technologies could deliver. This was primarily because of female farmers' inability to participate in information sharing workshops or meetings because of conflicting meeting times when women were obliged to attend to household duties. Similarly, Obisesan (2014) found that technology adoption level among female farmers was lower than male farmers due to lower levels of education and participation in off-farm activities.

Gender-inclusive mechanisms should be embedded in technology adoption processes (Rola-Rubzen *et al.*, 2020). According to Rola-Rubzen *et al.* (2020) and Satyavathi, Bharadwaj and Brahmanand (2010), integrating a gender lens into the design and implementation of policies and interventions can significantly lead to addressing the gender gap in agricultural technology adoption. It is anticipated that when gender-linked needs are considered in the design and implementation of new technologies, more people, especially female farmers can benefit from adopting new agricultural technologies (Rola-Rubzen *et al.*, 2020). Specific gender-inclusive mechanisms that may be considered to address the gender gap, include those which appropriately define target groups (i.e., male and female farmers) when introducing new technology. In rural agriculture, male and female farmers often undertake different farm activities where for example, male farmers engage in land preparation activities and female farmers engage in sowing of seeds. This implies that appropriately targeting and defining farmers by their roles in farming can enable the development of technologies relevant to the wide-ranging needs of male and female farmers, or that gender roles in themselves should be more inclusive.

It is important to improve women' access to resources to increase their potential rate of adopting agricultural technologies. When female farmers have control of resources such as land, credit, and training, it is expected that they will have the capacity to easily adopt new agricultural technologies (Sraboni *et al.*, 2014; Rola-Rubzen *et al.*, 2020; Razavi, 2012). Another important mechanism to improve female farmers' uptake of agricultural technologies is for researchers and other non-farmer stakeholders to develop participatory approaches to agricultural issues and policies which include female farmers, and community-based technology transfer mechanisms which consider female farmers as important stakeholders in the design and implementation stages of new agricultural technologies (Paris, Diaz and Hossain, 2011; Rola-Rubzen *et al.*, 2020). Farmer associations and cooperatives may be dominated by male farmers thereby enabling male farmers needs to overshadow female farmer's needs (Peterman, Behrman and Quisumbing, 2014; Rola-Rubzen *et al.*, 2020). Therefore, it is important to encourage the establishment and strengthening of networking groups for female farmers to enable a prioritisation of their farming needs (Bantilan and Padmaja, 2008; Rola-Rubzen *et al.*, 2020).

2.6 Concept of Technology Adoption and Theoretical Considerations

The power of technology in driving change and improvement cannot be overemphasised (Ugochukwu and Phillips, 2018). In line with this, agricultural technology adoption can ensure efficiency, bolster food productivity, and increase income (Bhuyan *et al.*, 2023). On that score, it is important to understand how and under what circumstances agricultural technology is adopted in order to promote and increase farmers' chances of adoption (Yokamo, 2020; Doss, 2006).

Researchers have attempted to understand the determinants of agricultural technology adoption using different theoretical approaches (Rauniyar and Goode, 1992; Lai, 2017; Chima, 2015; Nyamwena-Mukonza, 2012). Much of the theoretical approaches used by previous research included the Diffusion of Innovations (Rogers, 2003), the Technology Acceptance Model (Davis, 1989), the Unified Theory of Acceptance and the use of Technology (Venkatesh *et al.*, 2003), the Theory of Reasoned Action (Fishbein and Ajzen, 1977), and the Theory of Planned Behaviour (Ajzen, 1991).

The theoretical approaches used in previous research have often provided 'discipline-guided explanations' for agricultural technology adoption (i.e., economic, psychological, etc.) (Boahene, Snijders and Folmer, 1999; Rauniyar and Goode, 1992). Theoretical approaches which provide 'discipline-guided explanation' often explain some aspects of the adoption process, leading to explanatory gaps (Borges, Foletto and Xavier, 2015; Flett *et al.*, 2004; Boahene, Snijders and Folmer, 1999).

For example, Boahene, Snijders and Folmer (1999) employed the Utility Maximization Theory[5] to examine the socioeconomic analysis of hybrid cocoa adoption in Ghana. Similarly, Awotide, Karimov and Diagne (2016) used the Utility Maximization Theory to determine farmer adoption of improved rice varieties, commercialization and

[5] Utility maximisation theory assumes that an individual adopts a new technology to reap the highest level of satisfaction from its use Curwen, P. (1976) 'Utility Maximisation', *The Theory of the Firm*: Springer, pp. 127-134.

smallholder rice farmers' welfare in rural Nigeria. This implied that early research applied economically based theories to explain farmers' adoption behaviour, depicting a linear process of adoption (Silva, Canavari and Sidali, 2018; Chima, 2015).

The vast scope of literature on understanding farmers' adoption of agricultural technology suggests a complex interaction of factors including, economic, social, psychological, and environmental factors (Kabwe, Bigsby and Cullen, 2009; Kuehne *et al.*, 2017; Obiero *et al.*, 2019). According to Feder, Just and Zilberman (1985), factors determining farmers' adoption of agricultural technology were interrelated and interacted continuously until the final decision to adopt or not to adopt.

In that context, researchers have aimed to use theoretical approaches that comprehensively understand and explain predictors of farmers' technology adoption behaviour. For example, Uaiene, Arndt and Masters (2009) proposed a theoretical approach grounded on three underlying paradigms (the innovation-diffusion models, the perception adoption models and the economic constraints models) to explain farmer adoption behaviour. Borges, Foletto and Xavier (2015) also proposed an integrated economic and psychological theoretical approach (i.e., the Expected Utility Theory[6] and the Theory of Planned Behaviour[7]) to explain farmers' adoption behaviour.

Based on the broad range of theories used to understand and explain farmers' technology adoption behaviour, this research finds it necessary to evaluate these theories to identify an appropriate theoretical approach to be adapted. On that basis, a systematic review is conducted in Chapter 5 to address the question: "What theoretical approaches have been employed to explain farmers' adoption of agricultural technologies in LMICs?". The outcome of the systematic review will identify a theoretical approach to be used in the empirical research to understand the predictors of farmers' intention to adopt renewable energy technology for farming.

2.7 Factors Determining Renewable Energy Adoption in Agriculture

Factors influencing renewable energy adoption can be classified under three broad categories: economic, social, and institutional. Economic factors constitute the cost of

[6] an adoption behaviour is conditioned by risk and uncertainty, and an individual is likely to adopt a technology if the expected utility from the new technology surpasses the old or existing technology Mongin, P. (1998) 'Expected utility theory'.

[7] an individual's behaviour can be predicted when an intention is developed based on the influence of three main psychological constructs: attitude, subjective norms, and perceived behavioural control Ajzen, I. (1991) 'The theory of planned behavior', *Organizational Behavior and Human Decision Processes,* 50(2), pp. 179-211.

technology, expected benefits of using the technology, and farm size. Social factors include age, education level, and gender of the farmer. Institutional factors include farmers' access to information and extension services. Table 2.2 provides selected research which identified the determinants of farmers' adoption of renewable energy technology.

Factors	Findings	Reference
Economic	Income diversification significantly influenced the adoption of bioenergy crops (jatropha) by smallholder farmers in Kenya's Bondo, Kibwezi and Kwale districts. Farmers' desire to self-generate energy and minimise dependence on the high cost of traditional fuels (fossil fuels) significantly influenced the decision to adopt.	Mogaka *et al.* (2014)
	Labour type significantly influenced farmers' adoption of Zimbabwe's bioenergy crops (jatropha). Family labour was noted to be the most common labour type for jatropha cultivation.	Nyamwena-Mukonza (2012)
	Farm size significantly influenced farmers' adoption of bioenergy crops (jatropha) in Central Eastern Malawi. Farmers with farm sizes (i.e., 3 acres and above) most likely adopted jatropha cultivation under land use diversification.	Mapemba, Grevulo and Mulagha (2013)
	The number of cattle and household income significantly influenced farmers' adoption of biogas technology as livestock waste management in Indonesia. The high number of cattle increased the capacity to generate adequate dung as feedstock for the biogas plant. Also, farmers with high cattle numbers depict a robust capital asset.	Putra, Czekaj and Lund (2019a)
	Perception of farmers and related socio-cultural uses of bioenergy crops (jatropha) significantly influenced the decision not to adopt. Traditional	Mogaka *et al.* (2014)

Social	healers mostly use jatropha, hence a perception about the crop being associated with societal adversities (i.e., bad luck, illness, death, etc).	
	Gender significantly influenced the adoption of bioenergy crop (jatropha) cultivation in Zimbabwe. Male farmers were most likely to adopt it when compared to female farmers due to constraints with labour and land tenure systems affecting female farmers. Farmers with higher education were most likely to adopt bioenergy crop cultivation. Age significantly influenced middle-aged farmers to adopt the cultivation of bioenergy crops. Young-aged farmers did not adopt it due to the unprofitability of the technology compared to other cash crops.	Nyamwena-Mukonza (2012)
	The gender of the household head significantly influenced farmers' decision to adopt bioenergy crops (jatropha) in Central Eastern Malawi. Male household heads were most likely to adopt jatropha as socio-cultural norms predisposed males to have access and control of assets, including land, thereby rendering them adequately resourced to take up new technologies. The education of household heads significantly influenced the decision to adopt bioenergy crops. Education was assumed to refine a farmer's ability to process information. Farmers with literacy education were deemed to understand information about technology easily and	Mapemba, Grevulo and Mulagha (2013)

	translated it into adoption. As highlighted in the study, “educated people act as pioneers in most innovation adoption”.	
	Education significantly influenced farmers' decision to adopt biogas technology as livestock waste management in Indonesia. Farmers with higher literacy education better appreciate information on a new technology objectively and act swiftly in adopting new technologies.	Putra, Czekaj and Lund (2019a)
Institutional	The availability of external funding for biogas installation significantly influenced farmers’ decision to adopt biogas technology as livestock waste management in Indonesia. Farmers most likely adopt biogas technology because an external funding source absorbs the cost. When the external funding regime ended, adoption was automatically discontinued. Contact with biogas promotion stakeholders influenced farmers’ decision to adopt biogas technology. Stakeholders such as researchers, NGOs and extension officers used various platforms, including field demonstrations, to facilitate farmers’ adoption of technologies (Cheteni, Mushunje and Taruvinga, 2014; Pattanayak *et al.*, 2003).	Putra, Czekaj and Lund (2019a)

Table 2.2 Selected studies examining the determinants of renewable energy adoption in agriculture

Source: Author’s construct, (2020).

2.7.1 Barriers affecting renewable energy adoption in agriculture

A review of previous research identified barriers to farmers' adoption of renewable energy technology. For example, Kalinda (2019) found that the high cost of technology, limited access to credit facilities, limited technical knowledge about the technology, and limited awareness about the technology impeded farmers' adoption of biogas technology in Zambia. In addition, farmers perceived renewable technology to be associated with high costs, partly due to the use of expensive technologies in pilot projects. Also, farmers' limited access to credit facilities resulted in their inability to meet loan requirements. Expertise in constructing and maintaining biogas plants was scarce within the farming communities, creating the perception that incurring additional costs by engaging expertise outside the community acted as a barrier to the adoption of the technology.

Mogaka *et al.* (2014) identified various barriers including a lack of ready market, inadequate energy-generation facilities and appropriate agricultural skills affected farmers' adoption of bioenergy crop (jatropha) cultivation in Kenya. Farmers in the Bondo, Kibwezi and Kwale areas expressed concern about the unavailability of viable markets to sell bioenergy crops, with the exception of a few foreign companies and biofuel generation companies. Farmers who aimed to self-generate energy from jatropha were constrained by the absence of energy-generation facilities in communities. Also, it was reported that farmers lacked adequate knowledge and limited experience in jatropha cultivation.

Mwakaje (2008) found that perceived high costs, scarcity of water, and limited technical know-how were barriers to the adoption of biogas technology in dairy farms in the Rungwe district of Tanzania. Costs relating to constructing biogas digesters were found to be high and above the affordability of most dairy farms. This resonates with An, Preston and Dolberg (1997) and Mukherji *et al.* (2017) who indicated that perceived high cost negatively affected farmers' adoption of biogas and solar water pump technology, respectively.

2.8 Summary

The extant literature suggests that integrating renewable energy in agriculture can deliver socioeconomic and agronomic benefits for smallholder farmers. Substantial decreases in GHG emissions, alternative income sources for farms/farmers, and energy supply reliability are justifying renewable energy deployment in agriculture.

Unlike in global north countries where renewable energy use in agriculture is more advanced, its adoption in global south countries is relatively low and slow, necessitating research to understand the determinants of adoption.

Previous research used different theoretical approaches to understand predictors of farmers' adoption of behaviour, demonstrating an interaction of multiple factors. Given farmers' complex decision-making process, applying a holistic (i.e., interdisciplinary) theoretical approach is useful to understand the predictors of farmers' adoption behaviour comprehensively. In line with this, a systematic review is conducted in Chapter 5 to evaluate various theories used to explain farmers' adoption behaviour. The systematic review aims to identify an appropriate theoretical approach to be used in the empirical research to understand predictors of farmers' intention to adopt renewable energy technology for farming.

Chapter 3. Research Methodology

3.1 Introduction

The chapter examines the research methods used in this thesis. The methods and materials used to perform the policy and systematic reviews in Chapters 4 and 5 are discussed. A mixed-method approach combining qualitative and quantitative methods was used for the empirical research. The chapter discusses the justification for selecting the research approach employed in the research. An overview of the research area, including the country's profile and research location, is provided.

3.2 Profile of the Study Area

3.2.1 Country profile

Ghana, a middle-income country in West Africa, covers a landmass of about 238,535 km2. Ghana shares a border with Burkina Faso to the north, Ivory Coast to the west, Togo to the east, the Gulf of Guinea, and the Atlantic Ocean to the south. With an annual average population growth rate of 2.5 percent, Ghana's total population is estimated to be over 30 million (Country STAT Ghana, 2021). Administratively, Ghana is divided into 16 regions and 261 Metropolitan, Municipal, and District Assemblies.

Agriculture contributes about 20 percent to Ghana's GDP (Ghana Statistical Service, 2020). The importance of agriculture sector is further seen as a major source of employment, employing about 36 percent of Ghana's workforce (ibid). Ghana's agricultural sector is predominantly dominated by smallholder farmers in rural areas. Out of a Total Land Area of about 23,884,245 hectares, the Agriculture Land Area in Ghana is estimated to be about 13,600,000 hectares (Essegbey and MacCarthy, 2020). However, only 50 percent (6,421,450 hectares) of the total land area is under cultivation, and 3 percent (221,000 hectares) constitutes land area under irrigation (MoFA, 2016). Ghana has six agroecological zones: the Rain Forest, Deciduous Forest, Transitional Zone, Coastal Savannah, Guinea Savannah, and Sudan Savannah. The Guinea and Sudan Savannah agroecological zones cover the northern parts of Ghana and have one rainy season, thereby supporting only one farming season. The other agroecological zones cover the southern parts of Ghana with two rainy seasons, enabling a major and minor farming season.

3.2.2 Profile of the study location

Lawra Municipality is geographically located in Guinea Savanah Zone, in the north-western corner of the Upper West Region of Ghana. The Municipality shares boundaries with Nandom Municipality, Lambussie-Karni District and the Republic of Burkina Faso to the north, east and west (GSSa, 2014). Lawra Municipality has a total area size of about 1,051.2 square km, forming about 5.7 percent of the Upper West Region's total land area, estimated at 18,476 square km. Lawra Municipality has an estimated population density of 89 per square km and a total of 98 communities, with about 95 percent of the population living in rural areas. In respect of governance and institutional administrative structure, Lawra Municipality has four sub-districts: 1) Lawra Town Council, Babile, Zambo and Eremon Area Councils. The Lawra Traditional Council represents the traditional administrative system of the area.

3.2.3 Demographic characteristics

The estimated population of Lawra Municipality by 2017 was 62,672, constituting 30,082 males and 32,589 females (Lawra Municipal Assembly, 2018). There are three main religious groups in the Municipality, namely Christians, Traditional believers, and Muslims. Christianity is the predominant religious group represented by 61 percent of the population. Traditional believers and Muslims are represented by 26.6 percent and 6.6 percent of the population, respectively. About 5.7 percent of the population does not practice any religion. The Dagaaba is the dominant ethnic group in the Municipality, and other minor ethnic groups include Hausa and Asante (Lawra Municipal Assembly, 2018).

3.2.4 Topography and drainage

Lawra Municipality is endowed with hills projected to be in the range of 180 – 300M above sea level (Lawra Municipal Assembly, 2018). The Black Volta is the main river in the Municipality and forms a boundary to Burkina Faso to the west. Notable tributaries to the Black Volta include Kamba/Dangbang, Nawer, and Duodaa (Lawra Municipal Assembly, 2018).

3.2.5 Geology and soil

The rock formation in the Lawra Municipality is characteristically Birimian with patches of granite. Studies have revealed evidence of mineral resources in the municipality, including manganese, gold, diamond, iron ore, and clay. However, these potential mineral resources have been left untapped. Access to groundwater in the Municipality is considered very high due to the formation pattern of the rocks. As a result, groundwater can be used to support agricultural and domestic activities. The type of soils in the Municipality as well as identified factors, including inadequate rainfall and traditional land use practices, negatively affect crop production (Lawra Municipal Assembly, 2018).

3.2.6 Vegetation and climate

The location of Lawra Municipality in the Guinea Savannah agroecological zone makes it home to short grasses and few woody plants. Notable trees in the municipality include Boabab, Dawadawa, Shea, and Acacia. The Municipality has a total of 127 hectares of forest reserves, known as the Lawra Station Forest Reserve, located in the north-eastern part of the Municipality. A protected area has been carved out of the total forest reserves, constituting about 39.5 hectares. The climate of Lawra Municipality records a mean annual temperature of 27°C - 36°C. The hottest period is from February to April. There is only one wet season that spans between April to October. Evidence of changing climatic conditions is manifesting in the Municipality, resulting in unpredictable rainfall patterns (Lawra Municipal Assembly, 2018).

3.2.7 Agriculture and food security

The major economic activity in Lawra Municipality is agriculture, with an employment rate of 78 percent of the working population (Lawra Municipal Assembly, 2018). Agriculture is predominantly subsistence, involving the cultivation of maize, millet, groundnuts, soya beans and cowpeas. In addition, livestock includes goats, pigs, sheep, poultry, and cattle. The challenges confronting the agricultural sector include but are not limited to, depleting soil fertility, erratic rainfall patterns, pests and diseases, limited access to credit, and inadequate access to extension services and markets for agricultural products. These challenges threaten the sustainability of the sector and, importantly, local food security. There are signs of potential food insecurity for some households during the non-farming season (Lawra Municipal Assembly, 2018).

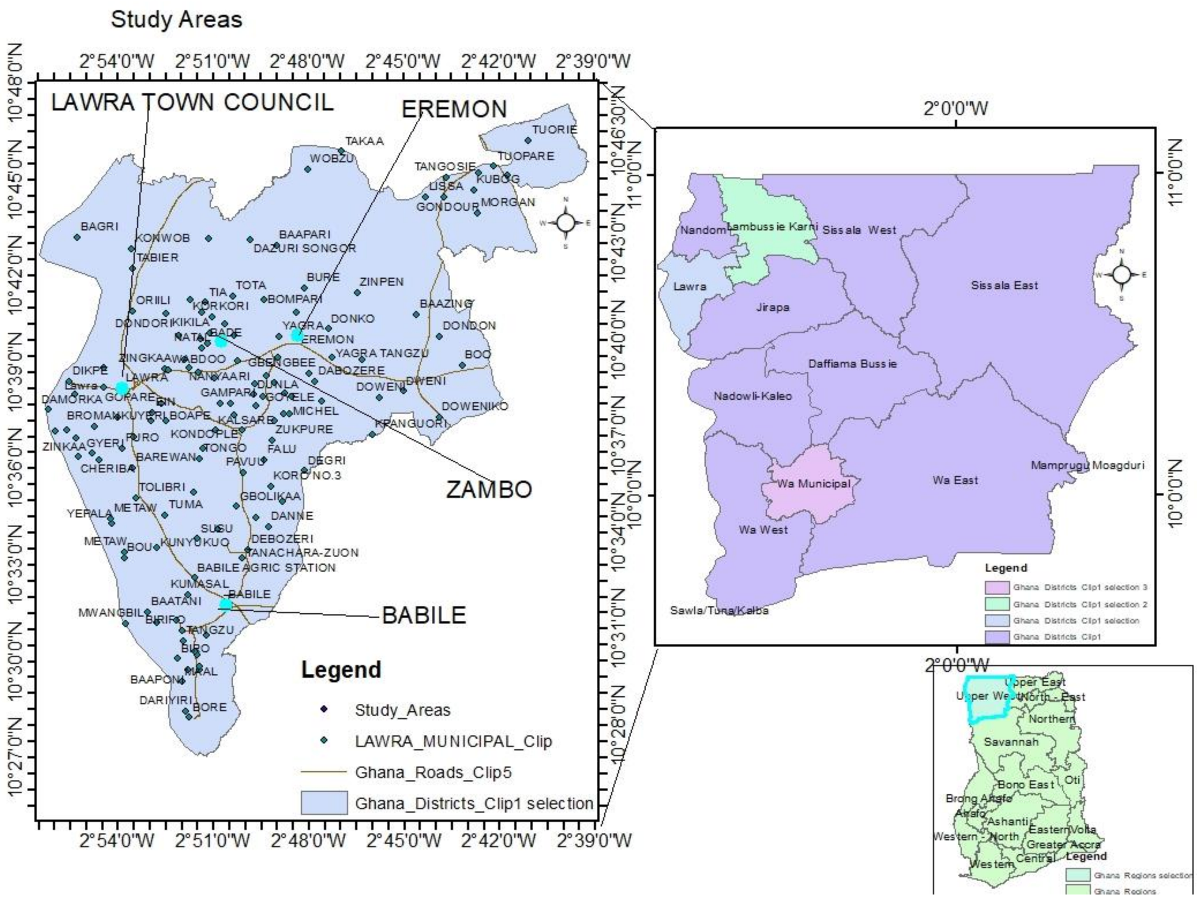


Figure 3.1 Map of Lawra Municipality showing the research area

Source: Author’s construct (2023).

3.3 Research Approach and Methodology

The research sequentially applied a series of approaches to achieve the research objectives. First, a policy review was performed to identify and evaluate Ghanaian policies that promoted farmers’ adoption of renewable energy technology in Ghanaian agriculture. This approach enabled the research to ascertain the extent of renewable energy application in Ghanaian agriculture. Secondly, a systematic review was conducted to assess various theoretical approaches applied by previous research to understand farmers’ adoption behaviour in relation to adopting agricultural innovations. This approach was essential to identify an appropriate theory for the empirical research to explain farmers’ intention to adopt renewable energy technology predictors. Lastly, a mixed method approach was used in the empirical research to investigate predictors which determined farmers’ intention to adopt renewable energy technology for farming.

3.3.1 Policy review method

A range of Ghanaian policies were identified and reviewed. An online search was performed using websites and data repositories of Ghanaian ministries and government agencies to obtain policy documents. Aside from the potential access to vast data sources, an online search approach was efficient and convenient, enabling the researcher to access up-to-date data remotely. In addition, requests for relevant policies that could not be found from online sources were sent to Ghanaian public agencies to retrieve relevant data for review. In addition to the policies sought, strategic plans and frameworks that operationalised policies that impacted renewable deployment in Ghanaian agriculture were also searched and included in the review. All policies and data retrieved from the online search were analysed using a thematic framework to extract relevant data to answer the research question. The thematic framework applied to extract information from the policies included policy name, goal and year, and the strategy for renewable energy adoption in agriculture. Since the policy search was mainly from online sources, the search results may not be comprehensive, as not all policy documents may have been published online.

3.3.2 Systematic review method

A systematic review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher *et al.*, 2009; Page *et al.*, 2021). A systematic review was essential to enable a comprehensive review of the literature devoid of bias and subjectivity. The research question was: what theoretical approaches have been employed to explain farmers' adoption of agricultural technologies in LMICs? To answer the research question, an online search was performed using Scopus and Web of Science databases to identify articles for the review. The online search applied specific search terms as part of the online search string (see Table 5.1). A set of inclusion and exclusion criteria was developed and applied to screen and select articles for the review. The criteria applied were developed to ensure the identification of articles that relied on a theory to explain farmers' adoption of agricultural technology in LMICs. Two independent researchers performed this. Data was extracted and analysed using a thematic framework, which entailed the name of the theory and an overview, the location where data were collected, the advantages and disadvantages of the theory used in the research and full references of the articles (see Appendix A). A meta-analysis was not possible because the selected articles for the review applied quantitative, qualitative, and mixed methodologies, implying that different dependent variables and assessment methods (parametric, non-parametric and narrative synthesis) were used to explain determinants of technology adoption by farmers. The quality of the articles reviewed was evaluated using a critical appraisal tool developed by Clark *et al.* (2016). The Grading of Recommendations Assessments, Development and Evaluation (GRADE) was used to assess the overall quality and strength of evidence in the research presented in the articles (see Appendix B).

3.3.3 Empirical research method (Qualitative and Quantitative)

Research methodology in social science is key and influenced mainly by a philosophical worldview (i.e., an assumption underpinning a researcher's approach to investigating a phenomenon) (Shah, Shah and Khaskhell, 2018). Researchers in the past have held opposing views regarding the philosophical paradigm upon which research must be rooted (Maarouf, 2019; Johnson and Christensen, 2019). At the core of the 'paradigm war'[8] was a discussion of the merits of qualitative and quantitative research approaches (Maarouf, 2019). Some researchers argued that the qualitative approach was the most appropriate paradigm. Others counter-argued that the quantitative approach was the ideal strategy to underline research. Therefore, it was assumed impossible to combine qualitative and quantitative paradigms to undertake research, a development known as an 'incompatibility thesis'[9] (Maarouf, 2019; Hall, 2013).

From the 1990s, researchers disputed the assumption of the 'incompatibility thesis' and began adopting a combination of the two paradigms (qualitative and quantitative) to undertake research (Maarouf, 2019; Biddle and Schafft, 2015; Glogowska, 2015; Johnson and Christensen, 2019). The justification for this development, according to researchers, is rooted in the pragmatism philosophical worldview (Maarouf, 2019; Shah, Shah and Khaskhell, 2018; Biddle and Schafft, 2015; Hall, 2013; de Gialdino, 2009; Hathcoat and Meixner, 2017; Yvonne Feilzer, 2010). The pragmatic philosophical paradigm extensively strings together multiple methodological approaches to enrich researchers' knowledge of understudying social phenomena (Shah, Shah and Khaskhell, 2018). This implies that pragmatist researchers often

[8] The quantitative and qualitative paradigms compete for superiority.

[9] The assumption that quantitative and qualitative paradigms were incompatible due to differing principles.

attempt to address research problems by resorting to practical methods or approaches rather than being restricted to a particular method (Acquah-Coleman, 2018; Shah, Shah and Khaskhell, 2018; Maarouf, 2019). The research presented in this thesis is rooted in the pragmatic philosophical worldview, hence, an application of a mixed methods approach involving qualitative and quantitative methods.

Fundamentally, a mixed methods approach entails “employing rigorous quantitative research assessing magnitude and frequency of constructs and rigorous qualitative research exploring the meaning and understanding of the constructs” (Creswell *et al.*, 2011, p. 4). Applying a mixed methods approach to research is evident in social science literature and traditions (Ivankova and Creswell, 2009).

A mixed methods approach can be justified as it draws on the strength of qualitative and quantitative methods to answer research questions (Creswell *et al.*, 2011; Bryman, 2003). Essentially, a mixed methods approach addresses data interpretation from two perspectives, breadth and depth (i.e., extent or scope), enabling the research to render multiple perspectives in answering a research question (Creswell *et al.*, 2011; Ivankova and Creswell, 2009).

In principle, applying a mixed methods research approach can be in the form of an explanatory design, exploratory design, triangulation design and embedded design (Ivankova and Creswell, 2009). Under an explanatory design, the quantitative and qualitative methods are applied sequentially, thus employing the quantitative method before the qualitative method (Creswell and Creswell, 2017; Ivankova and Creswell, 2009). The importance of this design is that the results from the qualitative method can be used to explain findings from the quantitative method. In contrast, the exploratory design requires the qualitative method to be employed first and the data tested using the quantitative method (Morgan, 1998; Ivankova and Creswell, 2009). The triangulation design involves concurrently applying quantitative and qualitative methods to compare and contrast results from both research methods to arrive at a validated conclusion (Ivankova and Creswell, 2009; Creswell and Creswell, 2017). Lastly, the embedded design answers multiple research questions based on two or more data types (Ivankova and Creswell, 2009; Andrews, 2006). Therefore, qualitative and quantitative research methods can be embedded with each other to collect data required to answer secondary questions.

3.3.4 Qualitative research method

Although it can be complex to arrive at a single definition for qualitative research methodology, the approach can be defined as a "research strategy that usually emphasises words rather than quantification in data collection and analysis (Bryman, 2008, p. 366). This implies that a qualitative research method is appropriate to extensively explore a phenomenon that is not numerically or statistically quantifiable. Unlike the quantitative research method, which is numerically data-driven, qualitative research methodology attempts to unravel a deeper understanding of a phenomenon by investigating beliefs, experiences, and perceptions (Tenny *et al.*, 2017; Mohajan, 2018). This is achieved mainly by probing the "how" and "why" of a research problem (Tenny *et al.*, 2017; Korstjens and Moser, 2018; Cleland, 2017). The results of using a qualitative research method lead to filling the gap(s) embedded in quantitative research (Moriarty, 2011; Thorogood and Green, 2018; Hammersley, 2000; Shaw, 2003; Acquah-Coleman, 2018).

Several approaches exist in applying a qualitative research method, including case study, ethnography, action research, and narrative inquiry (Croker, 2009; Ritchie and Lewis, 2006) (see Table 3.1 for qualitative research approaches and characteristics). Additionally, techniques used to obtain qualitative data vary, including interviews, observation, and field notes (Croker, 2009; Denzin, 2005). Due to the extensive investigative nature of qualitative research, it is often used for small sample sizes and does not seek to generalise findings (Moriarty, 2011).

Qualitative Approach	**Focus**	**Unit(s) of Analysis**	**Data Collection Methods**
Narrative Inquiry	To explore the life of one or more individuals using in-depth interviews.	One or more individuals.	One main source: interviews.
Case Study	To provide an in-depth description and analysis of a case(s) using	An individual learner or teacher, a class, school, education area, or country, a class	Multiple sources: interviews, observations, diaries and verbal reports, discourse

	multiple data sources.	activity or language program.	analysis, documents and records.
Ethnography	To describe and interpret the common patterns of a culture-shaping group through prolonged participant observation.	A group that shares the same culture – a group of learners with the same first language, a class or year of students, the students or teachers of one department or school.	Two main sources: interviews and observations.
Action Research	To explore problems or questions in your teaching or learning context by systematic data creation and analysis.	An individual or group of learners or teachers, one group or class of students, the teachers in a department or language program.	Multiple sources: interviews, observations, recordings of classrooms or natural settings, questionnaires, diaries, and verbal report documents.

Table 3.1 Characteristics of qualitative research approaches

Source: Croker (2009).

3.3.5 Quantitative research method

Quantitative research is "the numerical representation and manipulation of observations to describe and explain the phenomena that those observations reflect" (Sukamolson, 2007, p. 2). Applying quantitative research methods generates numerical data that is analysed using mathematical methods (Aliaga and Gunderson, 1999; Apuke, 2017; Creswell and Creswell, 2017). Different quantitative research approaches have been applied in conducting research, including survey, correlational, experimental, and casual-comparative research (Sukamolson, 2007; Bloomfield and Fisher, 2019).

Quantitative research methods are appropriate for 1) targeting large sample populations, 2) comparing and contrasting statistical data between distinct groups, 3) measuring patterns and occurrence, 4) allowing the results to be generalisable, and 5) allowing complex research data to be condensed into statistical variables (Sukamolson, 2007; Watson, 2015; Goertzen, 2017).

3.4 Justification of Mixed Methods Methodology

The use of a mixed methods approach enables more thoroughness in conducting research. For some researchers, the mixed methods approach allows the qualitative methodology to address the gaps or weaknesses of the quantitative method and vice versa (Bryman, 2003; Creswell *et al.*, 2011). Due to the growing application of mixed methods research approaches, multiple perspectives and understanding of a research problem are achieved, adding to knowledge more than would be the case when using only either research method (i.e., qualitative or quantitative methodology) (Creswell *et al.*, 2011). Applying a mixed method approach allows for triangulation, comparability, and data validation from qualitative and quantitative methods, enabling researchers to arrive at formidable research conclusions (Ivankova and Creswell, 2009; Jick, 1979).

This thesis applies the mixed method approach to achieve the research objectives. Quantitative research was used to test and evaluate a predictive research model on psychological predictors of farmers' intention to adopt renewable energy technology for farming. Qualitative research was used to investigate additional determinants influencing farmers' likelihood to adopt renewable energy technology. The role of non-farmer stakeholders influencing farmers' intention to adopt renewable energy technology was investigated using qualitative research. Based on the research objectives, a single research method may not sufficiently explain farmers' adoption behaviour in relation to renewable energy technology for farming, indicating the need for a mixed-method approach.

3.5 Research design

In the empirical phases of the research, an initial exploratory research design was used to inform the qualitative phase, together with the outcomes of the systematic review of the literature. Findings from the qualitative data were used to develop the survey for the quantitative research. An exploratory research design was used because of the limited amount of previous research regarding farmers' adoption of sustainable energy technology in Ghana's agricultural sector. Consequently, qualitative research was used to gather initial data on the research subject. Therefore, data collection for this research was in two phases. Phase one entailed qualitative research, while phase two involved quantitative research. The qualitative and quantitative data were independently analysed in Chapters 6 and 7. The qualitative and quantitative research was conducted from October to December 2021 and April to May 2023, respectively. Figure 3.2 depicts the procedure of an exploratory research design.

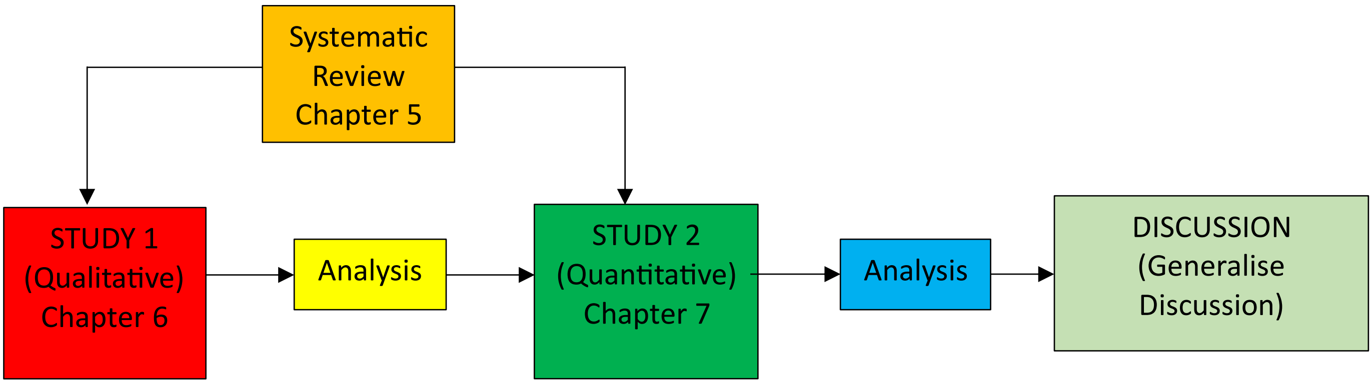


Figure 3.2 An exploratory mixed methods procedure

Source: Adapted from Morse (1991) and Acquah-Coleman (2018).

3.6 Sources and Types of Data

Primary and secondary data constituted the sources of data for the research. Primary data was obtained from empirical research involving qualitative and quantitative research. The qualitative research included a semi-structured questionnaire serving as a guide for in-depth interviews with farmers and non-farmer stakeholders. The quantitative research involved using a well-structured questionnaire to conduct a survey for farmers. The qualitative research informed the design of the quantitative research. The systematic review to identify the theoretical approach used in the empirical research formed the secondary data. In addition, secondary data was obtained from a literature review on sustainable energy technology development, enablers and barriers of adoption among farmers to support agronomic practices.

3.7 Sample Design

3.7.1 Sample design for in-depth interviews

The sample design of the qualitative research for farmers was based on the local administrative structure determined by Ghana's Local Government Act. The Local Government Act decentralises central governments' administrative power mainly into jurisdictions of regions, metropolises, municipalities, districts, zonal, town, council, and unit committee areas. In the research area (Lawra Municipality), there are four administrative sub-districts which include 1) Lawra Town Council, 2) Babile, 3) Zambo and 4) Eremon Area Councils. Therefore, farmers were recruited to participate in the research from communities under the four administrative sub-districts of Lawra Municipality.

A purposive non-probability sampling technique was used to select farmers for the in-depth interviews due to the technique's flexibility (Etikan, Musa and Alkassim, 2016; Tongco, 2007). The essence of this technique was to enable the research to recruit farmers with knowledge and experience in renewable energy applications in agriculture. Snowballing was used as an additional sampling technique to identify appropriate farmers to participate in the research. Following the principles of snowballing sampling technique, a farmer was asked to refer the researcher to another farmer who had knowledge and experience using solar or biomass energy for farming. For the non-farmer stakeholder interviews, initial reference was made to Ghana's Renewable Energy Act, which outlines institutions mandated to facilitate the development and promotion of sustainable energy use in Ghana. Relevant policy documents related to energy and agriculture were also reviewed to identify suitable stakeholders for the interviews. Additionally, an internet search was conducted to map out stakeholders with interest and expertise in sustainable energy development and integration in agriculture. The number of non-farmer stakeholders identified for the interviews was 30.

3.7.2 Sample estimation for survey

The quantitative research design used a systematic sampling technique to select farmer participants for the survey. This technique selected farmer participants from the research population at regular intervals (Singh and Singh, 1977; Cochran, 1977; Sharma, 2017). Household sampling after every 10^{th} interval, a count of households was used to identify farmer participants.

The sample size for the survey was determined using Yamane's formula (Bala and El-jajah, 2019; Branch, Okere and Nwagwu, 2021; Yamane, 1967) propounded in 1967:

$$n=N/(1+N(e)^2)$$

Where n is given as the sample size, N is the household size, and e is the level of precision (95% confidence level: p=0.05). According to the Lawra Municipal Medium-Term Development Plan (2018-2021), there is a projected total population of about 62,672, comprising 30,082 males and 32589 females. There is a projected household population of 15,000. The Municipal Medium-Term Development Plan (2018-2021) notes that nearly 80 percent of households depend on agriculture as a primary source of livelihood. It should be noted that households that depend on other primary sources of livelihood rely on agriculture as a secondary source of livelihood. Recruiting farmers through the households was the most adequate strategy since the farms were widely apart and, most often, in the outskirts, rural areas.

Calculation of sample size:

$N=15{,}000$

$n=15{,}000/(1+15{,}000(0.05)^2)$

$n=15{,}000/38.5$

$n=389.61$ Therefore: n (sample size) =390

Using Yamane's formula, the determined sample size was 390. However, this research considered an additional 10 percent of the sample size for non-responses. Therefore, the actual sample size for the quantitative research was 429.

3.8 Summary

The chapter presents the methodology guiding the research presented in this thesis. A profile description of the research area, which is Lawra Municipality in the Upper West region of Ghana, is presented to set the context where the research was carried out. An exploratory research design was employed. In terms of the research methodology, mixed methods entailing qualitative and quantitative approaches were presented and discussed. The sampling design applied a purposive sampling technique for the qualitative research. The sampling estimate for the farmer survey was 429 farmers. Analysis of the qualitative data applied a thematic analysis procedure using Nvivo software. Quantitative data analysis employed structural equation modelling using SPSS AMOS software to test a predictive research model in relation to farmers' likelihood to adopt renewable energy technology.

Chapter 4. A Review of Policies in Ghana Promoting Renewable Energy Adoption in Agriculture

4.1 Introduction[10]

The chapter presents a review of Ghanaian policies that can promote the application of renewable energy technology in agriculture. The review relies on a search for Ghanaian policies published on online databases. Identified policies are discussed in the context of the potential utilisation in agriculture.

4.2 Background

Energy and agriculture are interlinked sectors with implications for sustainability at national and global development levels. Both sectors warrant considerable attention and investment (Best, 2014). Agriculture at various scale levels has become increasingly dependent on energy and, until recently, has largely been fossil fuel-based (Best, 2014; Abaka *et al.*, 2017). Energy is used in agriculture directly in the form of diesel/petroleum fuels, electricity, natural gas (to power farm machines, and heating, cooling, and lighting systems, etc.) and indirectly through the energy requirements involved in the manufacture of fertilizers, pesticides, and other farm chemicals (Abaka *et al.*, 2017; Best, 2014; Clement *et al.*, 2018; Hitaj, 2016; Sutherland, Peter and Zagata, 2015).

There is increasingly a policy requirement in lower middle-income Countries (LMICs) and more affluent countries to replace fossil fuel consumption with renewable energy to reduce the environmental impacts of conventional energy production. Fossil fuels are known to release carbon dioxide (CO2), a greenhouse gas (GHG), which causes global warming (Elum, Modise and Nhamo, 2017). Agriculture is reported to contribute between 14-30 percent of global GHG due to agronomic practices, which include fossil fuel-based energy uses (Bardi, El Asmar and Lavacchi, 2013; Abaka *et al.*, 2017; Lawler *et al.*, 2013). It is observed that agricultural emissions of GHG in developing countries are growing considerably faster than in developed countries (Tubiello *et al.*, 2013; Tongwane and Moeletsi, 2018). Between the period 1994 to 2010, agriculture emissions of GHG were reported to see an annual increase of 2.9 percent to 3.1 percent (Tongwane and Moeletsi, 2018). There are concerns about a further increase, considering the need to increase food production to feed the growing population.

---

[10] This chapter has been published in a peer-reviewed journal.

There are potential environmental and economic gains to be made from adopting renewable energy in agriculture. Adopting renewable energy use in agriculture can minimize carbon emissions, thus contributing to climate change mitigation. In addition, renewable energy adoption in agriculture may result in the improved cost-effectiveness of energy inputs, improved availability of and accessibility to farm energy sources, improved farm and household energy sufficiency, and decentralized energy generation, which is of particular relevance to smallholder farmers in LMICs (Abaka *et al.*, 2017; Jebli and Youssef, 2017; Bardi, El Asmar and Lavacchi, 2013). Agricultural use of renewable energy technologies can also contribute to the circular bioeconomy, as resources for renewable energy generation can be obtained from agricultural wastes. In this context, Fami *et al.* (2010, p. 704) have noted that “renewable energy and farming are a winning combination”. Materials such as crops, livestock residues, and bioenergy crops can be used as feedstock to generate various biomass energy forms. Farmers can earn additional income by selling these materials to energy-generating companies (Fami *et al.*, 2010; Behera, Behera and Behera, 2015). In the most advanced case, farmers can independently generate energy (i.e., electricity) and feed into the national grid at a tariff, thus creating an additional income stream.

In sub-Saharan Africa (SSA), agriculture has long been an essential sector but has yet to see significant transformation compared to the Green Revolution of Asia (Feder and Savastano, 2017). Agriculture employs 65% of the SSA population and contributes about 29% of the Gross Domestic Product (GDP) across the sub-region (Gollin, 2014; Feder and Savastano, 2017). Typically, the sector is dominated by smallholder farmers relying on mixed farm power, including human labour, draft animals, and machines (Mrema, Baker and Kahan, 2008; Best, 2014; Bishop-Sambrook, 2005). At present, there is limited use of machinery in the smallholder sector. However, increasing productivity in smallholder agriculture may require agricultural mechanization (Best, 2014), increasing the demand for energy for agricultural use (PracticalAction, 2010).

In Ghana, agriculture represents an important part of the economy, and a drive for mechanization is a critical priority for policymakers and stakeholders. The Energy Commission (2019a) has indicated that fuel types constituting the energy demand in Ghana’s agriculture, including electricity, diesel, gasoline premix, and renewable energy, are presently marginal. Total energy demand in agriculture is expected to increase between 2020 and 2030. Based on two scenarios, thus the current economic performance and an accelerated economic growth, agricultural energy demand will increase from 185 ktoe[11] to 437 ktoe and 200 ktoe to 489 ktoe, respectively. Although the energy demand by agriculture is marginal in view of a total energy demand of 9,753 ktoe in 2020 and a projected increase to 15,552 ktoe by 2030, a question arises as to whether RE represents a potential sustainable source of energy that can also meet this demand.

The benefits of renewable energy use are potentially extensive but require pragmatic efforts, including policy direction to facilitate adoption in the agricultural sector. To this end, successive Ghanaian governments have implemented policies to develop Ghana's renewable energy sector. This research identifies policies in Ghana that can promote renewable energy adoption, including within agriculture. Understanding the effectiveness of these policies will provide evidence upon which future policies relevant to diffusing renewable energy technologies in Ghanaian agriculture can be developed and strengthened and provide information of relevance to policy development in other LMICs.

4.3 Overview of Renewable Energy in Ghana's Agriculture

In Ghana, agriculture represents an important element within the economy. As a sector, Ghanaian agriculture is predominantly occupied by smallholder farmers (ISSER, 2014; Tetteh *et al.*, 2014). These farmers primarily use simple manual farm tools. At the same time, there is also a trend towards the adoption of new or improved agricultural technologies applied to agronomic practices and mechanized farm tools/equipment within the country (Kemausuor *et al.*, 2014), linked to increasing demand for energy inputs such as diesel, fertilizer, and electricity (Fami *et al.*, 2010; Kansanga *et al.*, 2019).

Renewable energy is a useful source for meeting farmers' energy needs sustainably (Aroonsrimorakot and Laiphrakpam, 2019). The abundance of renewable energy resources, such as solar radiation, and biomass (Bessah and Addo, 2013; Kuamoah, 2020) can generate energy to support farm-based activities including irrigation, drying, and lighting (see Table 4.1) (Afrane, 2012; Amankwah, 2011; Arranz-Piera *et al.*, 2016; Bayitse, Tornyie and Bjerre, 2017; Duku, Gu and Hagan, 2011; Kemausuor *et al.*, 2014). However, increased demand for energy is associated with a need for increased

[11] Kilo Tonnes of Oil Equivalent

supply (MoFA, 2007), and failure to meet this demand potentially threatens farm-based activities that depend on energy. Despite its relatively cheap cost, Ghana's agricultural use of energy from renewable resources is generally low (Kuamoah, 2020). Where renewable energy is used, it is in the traditional form despite the potential efficacy of more technologically advanced forms. Biomass energy is known to be the oldest form of renewable energy and is primarily utilised through the burning of wood (Elum, Modise and Nhamo, 2017). Biomass energy is used indirectly in agriculture as input through compost/organic fertiliser generated from crops and livestock residues. Solar energy is traditionally used for drying farm produce directly under the sunlight (Aroonsrimorakot and Laiphrakpam, 2019; Amankwah, 2015). While this practice incurs no costs, it tends to be less efficient and more labour-intensive than mechanised solar drying. It compromises the quality of farm produce by including stones, insects, and dust (Amankwah, 2015).

In some cases, renewable energy adoption is applied on a pilot or project basis with little or no scale-up (RenewableEnergyTechnologyTransferProject, 2018). Nevertheless, solar-powered water pumps, mechanized solar dryers, and biofuels represent advanced forms of renewable energy that have the potential to support Ghana's farm-based activities (UNDP, 2018; Energypedia, 2018; Amankwah, 2015; Aroonsrimorakot and Laiphrakpam, 2019). For example, the Energy Commission (2019) reported that about 30 solar Photovoltaic (PV) water supply and irrigation systems had been installed in northern Ghana in pilot projects and programmes supported by donor partners and the government. In another pilot programme, farmers were assisted under an Energising Development (EnDev) programme to replace diesel generators with solar PV systems for irrigation. About 25 solar dryers were installed nationwide in a pilot programme by the Ministry of Food and Agriculture, Agricultural Engineering Services Directorate (AESD). These forms of renewable energy demonstrate the utility of RE, for example, for farms located outside local or national grid connections (Abaka *et al.*, 2017; Bayrakcı and Koçar, 2012).

Various factors may account for the low adoption of renewable energy exploitation and use in agriculture. One barrier to smallholder adoption of renewable energy may be the underdevelopment of the Ghanaian renewable energy sector. In addition, most developing countries prioritize the use of renewable energy to improve household access to modern energy (i.e. electricity) (Bartolini and Viaggi, 2012; Chinnici, D'Amico and Pecorino, 2015), which eclipses the potential of rapidly integrating renewable energy into other key energy-dependent sectors including agriculture.

If Ghana's agricultural sector is to increase its energy use from renewable resources, coherent policies must be developed and implemented to drive that transition. This approach has been successful in the Global North. For example, the Renewable Energy Sources Act (REA-2004) and the EU Common Agricultural Policy-CAP have facilitated renewable energy use in German and Czech Republican agriculture (Appel, Ostermeyer-Wiethaup and Balmann, 2016; Frantál and Prousek, 2016). In German agriculture, the Renewable Energy Sources Act (REA-2004) is reported to have stimulated biogas production in farms after 2004. Under the REA-2004, a guaranteed feed-in tariff was initiated to incentivise farmers to adopt biogas production on farms. This meant that farmers were provided with a ready market and a fixed price to take up electricity generated from biogas production for 20 years. By 2013, a total capacity of 3543MW from 7850 biogas plants was installed across German farms and mainly operated by farmers, with agricultural produce serving as feedstock (Fachverband, 2011). In Czech Republican agriculture, farmers adopted renewable energy technologies due to incentives in the form of production quotas and subsidies granted by the EU's Common Agricultural Policy-CAP and Energy Policy. These economic incentives motivated farmers to incorporate bioenergy crops, biomass production, and solar farms in addition to conventional farming.

In Ghana, there are similar regulations, such as a feed-in tariff regime and subsidies for the renewable energy sector. So far, commercial power producers in the energy sector seem to be taking advantage of these incentives. The agricultural sector can benefit from these incentives to significantly increase renewable energy adoption. However, this may require the development of tailored incentives targeting the peculiar nature of smallholder farmers, who dominate the agricultural sector.

Energy Resources	**Potential Energy Usage in Agriculture**
Small/Mini Hydropower – (water bodies including lakes, rivers etc)	Generation of electricity to power water pumps for irrigation, lighting, cooling, etc.
Biomass – (bioenergy crops, agricultural and urban waste)	Generation of solid, liquid and gas energy to fuel farm machinery/equipment, biofertiliser, etc.

Solar	Solar (PV) generates electricity to power water pumps for irrigation, solar dryers, heating and supporting ventilation in greenhouse farms, lighting, etc.
Geothermal	Generation of heat for greenhouse farming, aquaculture, mushroom culture, drying of crops, etc.
Wind	Power generation, wind generators, windmills, water pumps etc.

Table 4.1 Renewable energy resources and their potential uses in agriculture

Source: Bayrakcı and Koçar (2012); Owusu and Asumadu-Sarkodie (2016) and Abaka *et al.* (2017).

Year	**Off-grid**		**On-grid**				**Mini-Grid**		**Installed**
	Solar	**Wind**	**Distributed PV**	**Utility Solar**	**Waste-to-energy**	**Hydro**	**Solar**	**Wind**	
2013	-	-	495	2,500	-	-	-	-	2,995
2014	1,350	-	443	-	-	-	-	-	1,793
2015	4,003	20	700	20,000	100	4,000	256	11	29,090
2016	1,238	-	2626	-	-	-	-	-	3,865
2017	678	-	4,266	-	-	-	58	-	5,002
2018	4	-	9,441	20,000	-	-	-	-	29,445
2019	-	-	6,426	-	-	-	-	-	6,426
TOTAL	**7,273**	**20**	**24,396**	**42,500**	**100**	**4,000**	**314**	**11**	**78,614**

Table 4.2 Installed renewable energy generation capacity (kW)

Source: Energy Commission (2020).

4.4 Policies Promoting Renewable Energy Development and Use in Agriculture

Table 2 summarises policies that potentially promote renewable energy adoption in Ghanaian agriculture. The policies were primarily obtained from online sources, which may not be comprehensive as not all policy documents may have been published online. Strategic plans and frameworks that operationalized policies that impacted renewable energy deployment in Ghanaian agriculture were also reviewed.

Policy	Goal	Strategy to Promote RE Adoption in Agriculture	Year
National Energy Policy	To make energy services universally accessible and readily available in an environmentally sustainable manner.	Convert agricultural waste to energy.	2010
National Bioenergy Policy (Draft)	To modernise and maximise the benefits of biomass energy utilisation on a sustainable basis.	Incentivise farmers to cultivate biofuel crops and to obtain feedstock from agricultural waste for energy generation.	2010
Strategic National Energy Plan (SNEP)	To comprehensively look at Ghana's available energy sources and resources and how to tap them economically and in a timely manner to ensure a secured and adequate energy supply for sustainable economic growth now and into the future.	Substituting diesel with biodiesel in agricultural mechanisation encourages more drying of exportable farm produce such as pepper with solar dryers, displacing the use of diesel for irrigation with grid electricity and mechanical wind pumps.	2006-2020
Sustainable Energy for All (SE4ALL)	To ensure sustainable energy for all by the year 2030.	Establish 5000 hectares of small-scale irrigation schemes on the banks of the White and Black Volta rivers, install 2000 Poldaw windpumps to irrigate 4000 hectares of farmlands, establish 55MW[12] mini-hydro plants/irrigation infrastructure	2012

[12] Megawatt

		for 1000 hectares each on the Black Volta, White Volta, Oti River, Tano River, and Pra River, establish 100,000 x 1000kg natural convection solar dryers, and establish 5000 small-scale oil palm processing plants.	
National Climate Change Policy	To ensure a climate-resilient and climate-compatible economy while achieving sustainable development through equitable low-carbon economic growth for Ghana.	Seeking low carbon emissions and aiming to achieve this through the conversion of agricultural waste to energy.	2013
National Environment Policy	To guide environmental governance, serving as reference material for research and development, guiding the country's development along a sustainable path, and ensuring the country's commitment to conventions, protocols and international agreements.	To promote waste-to-energy practices by converting agricultural waste to energy.	2014
Strategic National Energy Plan II (SNEP)	To provide a framework which guides decision-makers to ensure that all reasonable demands for energy in the economy are met sustainably.	Promote alternative energy forms, including natural gas, wind, biomass, and solar, to ensure sustainability and energy security.	2016-2030
Investing for Food and Jobs (IFJ)	To modernize Ghana's agriculture sector to maximize contributions to the economy.	To promote the adoption of technologies, including solar and wind energy for irrigation.	2018-2021

Ghana Renewable Energy Master Plan (REMP)	To provide investment-focussed framework for the promotion and development of the country's rich renewable energy resources for sustainable economic growth, contribute to improved social life and reduce adverse climate change effects.	To promote solar crop dryers' use by organizing training for farmers and other end-users about sustainable models for financing, operating solar dryers, and indigenising solar drying technology.	2019-2030
COCOBOD Productivity Enhancement Programmes (PEPs)	To assist cocoa farmers in minimising the damaging effects of the dry weather and illegal mining activities that have destroyed water bodies on coca production.	To promote solar water pumps use for irrigation of cocoa production all year round.	2018

Table 4.3 Ghanaian policies with potential to promote renewable energy adoption in agriculture

Source: Author's construct (2022).

4.5 Discussion

About 176 countries have implemented renewable energy policies (Baldwin, Carley and Nicholson-Crotty, 2019; REN21, 2017). This indicates the policies' role in accelerating renewable energy resource exploitation and utilization across many economic sectors, including agriculture (Baldwin, Carley and Nicholson-Crotty, 2019). In Ghana, governments, in line with stakeholder priorities (i.e. donor/development partners), have put into place policies and legislations that aim to facilitate and increase renewable energy exploitation and use (Gyamfi, Modjinou and Djordjevic, 2015; Iddrisu and Bhattacharyya, 2015). The enactment of the Renewable Energy Act (832) (2011) signified a major step in this regard. In addition, fiscal/financial schemes may provide policy levers that aim to provide tax reductions and exemptions on renewable energy technologies, enabling longevity and security of investments in the renewable energy sector (National Renewable Energy Action Plan, 2015). Notable legal frameworks include the Ghana Investment Promotion Act 2013 (865), Internal Revenue Act 2000 (592), VAT Act 1998 (546), Customs Harmonised Commodity and Tariff Code Act 1993 (PNDCL 330), and the Energy Fund Act 541. For example, the Energy Fund Act 541 seeks to promote the development and deployment of renewable energy resources by providing financial support through financial incentives, feed-in-tariffs, capital subsidies, and production-based subsidies (National Renewable Energy Action Plan, 2015).

As of 2019, a total of 78,614kW renewable energy generation capacity was installed, an increase from 2,995kW in 2013 (see Table 4.2). Although the renewable energy installed generation capacity is marginal compared to Ghana’s total installed electricity generation capacity of 5172MW in 2019, it is a manifestation of the roles various renewable energy policies and legislations play in promoting the renewable energy sector's development. The low renewable energy installed generation capacity has accounted for the government’s extension of a set goal to achieve a 10 percent contribution of renewable energy into the national energy mix from 2020 to 2030. This implies that policies should be strengthened to speed up development in the renewable energy sector.

Different policies with potential impacts on agriculture, energy, environment, and Climate Change are being developed to promote renewable energy exploitation and adoption (see Table 4.3). At the moment, contributions from renewable energy to

Ghanaian agriculture appear to be minimal despite the potential of renewable energy to meet farm energy needs (Amankwah, 2011; Asibey, Yeboah and Adabor, 2018; Kuamoah, 2020). This may be attributable to the cost of financing to fund renewable energy adoption with high-interest rates for loans, insufficient incentives (tax rebate, subsidies), inadequate access to finance and long-term capital, or insufficient technical know-how for the operation and maintenance of renewable energy technologies (Mahama, Derkyi and Nwabue, 2020). Some specific policies that promote renewable energy adoption in the agricultural sector can be identified. Solar and biomass energy from solar radiation and biofuel energy from agricultural wastes are included in these policies, specifically in relation to the adoption of renewable energy in agriculture.

The Ghanaian National Energy Policy was formulated in 2010 to enable energy services to be universally accessible and readily available in an environmentally sustainable manner (National Energy Policy, 2010). The policy does not explicitly address the promotion of energy adoption in agriculture. However, it does outline a strategy to convert agricultural waste to energy and improve the renewable energy contribution to the national energy mix. This strategy may indirectly promote renewable energy adoption in agriculture, as it has been reported that in addition to using RE technologies (i.e. solar, biomass, wind, etc.) to support farm-based activities, biomass feedstock could be obtained from agricultural waste and used for energy generation (Fami *et al.*, 2010). In another example, oil palm residues from Ghanaian farms have been used to generate electricity (Asibey, Yeboah and Adabor, 2018). Generation of energy at the farm level can serve farm-energy needs and facilitate a potential scale-up to rapidly accelerate the rural electrification programme that aims to extend electricity to rural communities not connected to the national grid. The National Bioenergy Policy (Draft) was formulated in 2010 with an over-arching goal to modernize and maximize bioenergy's economic and environmental benefits in a sustainable manner. In 2015, biomass (firewood, charcoal, and agricultural residues) became the second most used energy in Ghana (40 percent), after petroleum products (gasoline, diesel, LPG, and jet fuel) (47 percent) (Energy Commission, 2019). As for the 2010 National Bioenergy Policy, the policy action's focus is not the accelerated adoption of renewable energy in agriculture *per se*. However, a future strategy is being implemented to incentivize farmers to cultivate biofuel crops and industry players to obtain feedstock from agricultural waste for energy generation. This will take the form of fiscal incentives and favourable pricing mechanisms. As of October 2014, a Feed-in Tariff of 56.0075 GHp/KWh[13] and 59.0330 GHp/KWh was set for biomass from enhanced technology and biomass from plantations feedstock, respectively (Netherlands Enterprise Agency, 2016). These are beneficial and can indirectly promote renewable energy adoption in agriculture. A study by Arranz-Piera *et al.* (2016) found that energy could be generated to capacities of 600kWe[14] and 1MWe[15] based on biomass from crop residues. In one of the field-case areas, Lawra district (now Lawra Municipal), it was estimated that crop residues from a minimum total of 280 small farm holdings with an average farm size of 1 hectare could enable an energy generation capacity of 600kWe. However, the energy generation capacity of 1MWe required crop residues from a minimum of 467 farms with an average farm size of 1 hectare, suggesting that farmers can potentially increase income generation by 29US$ to 64US$ per tonne of crop residues sold. This means a significant increase in income for farmers or households with large farm sizes.

A Strategic National Energy Plan I, SNEP 1 (SNEP 2006-2020) supported National Energy and Bioenergy policies. One of the plan's objectives was to increase access to modern energy in the agricultural and fisheries sectors. The SNEP 1 aimed to encourage the substitution of diesel with biodiesel in agricultural mechanization, encourage more drying of exportable farm produce such as pepper with solar dryers, displace the use of diesel for irrigation with grid electricity and mechanical wind pumps, and encourage large-scale commercial poultry farmers to meet at least 10 percent of their electricity needs from biogas, using the droppings from the birds. The SNEP I has been revised to a second iteration, Strategic National Energy Plan II (SNEP, 2016-2030), which acknowledges agriculture as an energy-demanding economic sector. However, this framework does not focus on the extensive utility of renewable energy in agriculture. Rather, a policy objective is to consider alternative energy forms, including natural gas, wind, biomass, and solar, to ensure sustainability and energy security.

The Government of Ghana in 2012 implemented a United Nations (UN) led initiative known as the Sustainable Energy for All (SE4ALL). Key among this initiative's objectives was to ensure universal access to modern energy services, double the rate

[13] GHp/KWh – Ghana pesewas per Kilowatt-Hour
[14] Kilowatt-electric
[15] Megawatt electric

of improvements in energy efficiency, and double the share of renewable energy in the global energy mix. A Country Action Plan (CAP) for Ghana was developed to promote renewable energy utilization in agriculture by 2030. For instance, the CAP sets to conduct a feasibility study and implement a total of 5000 hectares of small-scale irrigation schemes on the banks of the White and Black Volta rivers in the Northern, Upper East and Upper West regions, conduct a feasibility study and install 2000 Poldaw windpumps to irrigate 4000 hectares of farmlands in Central, Greater Accra and Volta regions, and conduct a feasibility study and establish 55MW[16] mini-hydro plants/irrigation infrastructure for 1000 hectares each on the Black Volta, White Volta, Oti River, Tano River, and Pra River. Other strategies in the CAP are to establish 100,000 x 1000kg natural convection solar dryers for cassava, maize, and vegetables for small-farmer cooperatives in all regions and to conduct a feasibility study and establish 5000 small-scale oil palm processing plants in oil palm producing areas in Central, Western, Eastern and Ashanti regions. Implementing these strategies has the potential to significantly support the government's flagship programme of constructing irrigational dams in the northern part of Ghana, thereby increasing renewable energy adoption in Ghanaian agriculture.

A Ghana Renewable Energy Master Plan (2019-2030) (REMP) has been implemented with the goal "to provide investment-focussed framework for the promotion and development of the country's rich renewable energy resources for sustainable economic growth, contribute to improved social life and reduce adverse climate change effects'' (Energy Commission, 2019, p. iv). The REMP has set strategies and targets to scale up utilisation of solar and wind energy technologies for agricultural purposes, including irrigation and crop drying. Strategies are being put into place to promote solar crop dryers' use by organizing training for farmers and other end-users about sustainable models for financing, operating solar dryers, and indigenize solar drying technology. As of 2015, there were 70 solar crop dryer units, and it is targeted that 150, 400, and 700 units will be installed by 2020, 2025, and 2030, respectively. Strategies to promote solar irrigation systems include partnering with and incentivizing financial institutions to develop cost-effective financing packages to promote solar irrigation and build the capacities of farmers and other end-users to install, operate, and maintain solar irrigation facilities. The ambition is to install solar irrigation systems

[16] Megawatt

over 6150, 26150 and 46150 hectares by 2020, 2025, and 2030. Also, there are strategies to promote wind energy irrigation systems by reviewing the status of existing installations and conducting studies to identify potential areas and niche markets for implementation. By 2020, 2025, and 2030, it is targeted that 35, 65, and 100 wind irrigation systems will be installed, respectively.

The Ghanaian government's response to Climate Change included formulating the National Climate Change Policy (NCCP) in 2013. The policy aims to promote effective adaptation, mitigation, and social development. The NCCP acknowledges that agriculture and energy-sector-related activities are among the factors that directly and indirectly account for the changing climatic conditions. Between 1990 to 2000, the agriculture sector contributed about 44 percent of Ghana’s carbon emissions (MESTI, 2015). Therefore, the NCCP advocates for low carbon emissions and aims to achieve this through the conversion of agricultural waste to energy. The National Climate Change Policy Action Programme and Implementation (2015-2020) that operationalizes the NCCP strategically advocates promoting and using more efficient solid and liquid biofuels. To that effect, agriculture may provide feedstock, including bioenergy crops and crops and livestock residue, to generate more efficient biofuels. Biofuel energy may be utilized in support of farm-based activities, including powering farm machinery.

The National Environment Policy was formulated in 2014 to guide environmental governance, serving as reference material for research and development, guiding the country’s development along a sustainable path, and ensuring the country’s commitment to conventions, protocols and international agreements. One proposed approach to achieve the stipulated policy goals is to promote waste-to-energy practices (and achieve a more circular bioeconomy) by converting agricultural waste to energy. Though this approach primarily aims to improve environmental sanitation, it can also promote the adoption of renewable energy in agriculture. Otchere-Appiah and Hagan (2014) identified the potential generation of electricity from maize residue in rural agricultural areas in the Brong Ahafo Region of Ghana (now Ahafo, Bono and Bono East regions). Based on annual maize residue production estimates of 329,059 tonnes, electricity could be generated at a capacity of about 494 GWh[17]. This energy

[17] Gigawatt hours

can be beneficial for meeting farm energy needs and contribute towards improving rural electrification.

Investing for Food and Jobs (IFJ) (2018-2021) is currently one of Ghana's agriculture sectors' main policy frameworks. The framework aims to modernise Ghana's agriculture sector to maximize contributions to the economy. Though renewable energy utilization in agriculture is not central to this policy's goal, the issue of low adoption of technology among smallholder farmers is acknowledged within the policy to be affecting efficiency and yields. Therefore, there is a strategy to promote the adoption of technologies, including solar and wind energy for irrigation. In line with this, the government of Ghana through its agency COCOBOD, which oversees the country's cocoa production has implemented the COCBOD Productivity Enhancement Programmes (PEPs). This policy aims to intensify cocoa production in Ghana to increase annual tonnage yields. Various strategies are embedded in the policy, for example: solar water pumps for irrigation of cocoa farms are promoted for adoption among farmers to enable all year-round cocoa production against the effects of changing climatic conditions. Other renewable energy technologies promoted for farmer adoption in the policy include solar-powered mist-blowers, solar-slashers and pruners. Although it is still at the pilot stage involving selected farms in the Bono, Bono East and Ahafo regions, the policy aims to extend coverage across all cocoa growing areas in Ghana.

Notably, this paper finds no Ghanaian policy with an over-arching goal to promote renewable energy adoption in agriculture. To a greater or lesser extent, these identified policies may address the issue of renewable energy adoption in agriculture. However, the impacts of these policies are limited because renewable energy adoption in the agricultural sector is not the primary focus. For example, as one of its goals, the National Environment Policy has improved sanitation by converting waste from agriculture to energy. However, Municipal waste has been found to constitute the predominant feedstock for Ghanaian energy generation (Daniel, Pasch and Nayina, 2014). The authors reported that many of the waste-to-energy projects in Ghana focused particularly on improving urban sanitation, hence the dependence on municipal waste as feedstock for generating energy.

The policies that promote renewable energy technologies in agriculture predominantly focus on biomass and solar energy, perhaps indicating more investments and exploitation. As noted in the Ghana Renewable Energy Act, 2011 (Act 832), adopting approaches to exploit renewable energy resources, including wind, geothermal, and ocean, as energy sources is not a policy priority. However, the policy consideration of these alternative sources is required.

Overall, it is worth noting that the policies reviewed above can potentially accelerate the development of Ghana's renewable energy sector, which the agricultural sector can leverage to serve farm energy needs. Nonetheless, this paper proposes that for Ghanaian agriculture to see considerable contributions from renewable energy sources, an agricultural sector-led policy tailored with incentives including subsidies, tax reduction or exemption, financing and training on renewable energy technologies should be implemented to suit the peculiar nature of smallholder farmers. Although there are existing institutional frameworks as well as policy and legislative incentives that give subsidies and tax reductions on renewable energy technologies, applying these incentives does not significantly impact the agricultural sector. As the dominant group in the agricultural sector, smallholder farmers are typically low-income earners and are widely constrained with adopting new agricultural technologies that have associated costs. Farmers may be provided with incentives in the form of finance schemes through cooperative membership, start-up loans, and microfinancing to support the adoption of RE technologies. Renewable energy technologies arguably have high costs in the initial or setup stage, although they have long-term cost-effectiveness. In view of that, a policy framework that seeks to reduce the initial high-cost component of renewable energy technologies drastically is a major boost towards smallholder farmers adopting renewable energy technologies.

Agricultural activities vary among smallholder farmers and are by far determined by different production methods and geographic locations. For that matter, a policy may precisely promote the adoption of renewable energy-specific technologies to serve farm-based needs. For instance, a policy may target farmers in Northern Ghana to adopt solar technologies due to the abundance of sunshine. Solar technologies may include solar-powered water pumps for irrigation and solar dryers for drying crops. This move may be feasible as Mensah, Oyewo and Breyer (2021) in their study found that many of Ghana's solar PV installations were in the north. Other studies have even indicated that more solar PV installations could be established in northern Ghana in future due to the abundance of sunshine (Quansah and Adaramola, 2018; Agyekum, 2021). Also, a policy may consider developing and building the capacity and knowledge of smallholder farmers on renewable energy technologies, possibly through agricultural extension services and programmes. Such capacity building can involve educating farmers on the potential for cultivating bioenergy crops, especially on lands less suitable for food production. The risk of using arable land for bioenergy cultivation will be minimised by doing so.

4.6 Conclusion

At present, the integration of renewable energy into Ghana’s agriculture is low, in part because of the underdevelopment of the renewable energy sector (Amankwah, 2011; Asibey, Yeboah and Adabor, 2018; Kuamoah, 2020). Some reasons for this under development include the cost of financing, with high interest rates, insufficient incentives (tax rebates, grants), inadequate access to finance and long-term capital, and insufficient technical know-how for the operation and maintenance of renewable energy technologies (Mahama, Derkyi and Nwabue, 2020). Nonetheless, various policies include interventions and strategies that can indirectly promote RE adoption in agriculture. These are the National Energy Policy, National Bioenergy Policy, National Climate Change Policy, National Environment Policy, Strategic National Energy Plan I, Ghana Renewable Energy Master Plan, and Investing for Food and Jobs Policy, and COCOBOD Productivity Enhancement Programmes (PEPs). These policies promote renewable energy adoption in agriculture pertaining to solar energy from the sun and biomass energy by converting agricultural and other waste to the energy available to the circular bioeconomy within Ghana. The energy generated can support farm-based activities and other energy needs, including rural electrification. However, to fully realize the potential of RE adoption in agriculture, policymakers must implement all provisions of the Renewable Energy Act-(832) (2011) to accelerate the sector's development. The government and its stakeholders should implement a policy with an overarching goal to promote RE integration into agriculture directly.

Chapter 5. A Systematic Review of Theories Applied in the Study of Farmers' Technology Adoption in Low-Income and Lower-Middle-Income Countries.

5.1 Introduction[18]

Agriculture remains an important economic sector in many low to middle-income countries (LMICs). The sector represents an important employer, serving as a source of livelihood. The production methods are mainly traditional and unmechanised; hence, a policy need to introduce technological interventions has been identified. This chapter provides an overview of the theories which underpin our understanding of the adoption of agricultural technology among end-users, particularly farmers in low to middle-income countries.

This chapter reports on conducting a systematic review of different theoretical underpinnings of farmers' technology adoption in LMICs to identify the relative effectiveness of different theoretical approaches and to identify knowledge gaps in the existing literature. The chapter presents and discusses findings from the review and concludes by proposing a theoretical approach for the empirical research (Chapter 7).

5.2 Background

Research into technology adoption in agriculture has received attention in the literature since the middle of the last century (see (Ryan and Gross, 1943) and Griliches (1957)) (Kumar, Engle and Tucker, 2018; Ruzzante, Labarta and Bilton, 2021). Various theories have been developed and evaluated which aim to explain farmers' adoption of existing and emerging agricultural technologies, including within LMICs[19] (Obiero *et al.*, 2019; Kuehne *et al.*, 2017; Kabwe, Bigsby and Cullen, 2009; Khandker and Gandhi, 2012).

According to Wacker (1998, p. 2), a theory is "a statement of relationships between units observed or approximated in the empirical world". By this definition, a theory applied in technology adoption research is meant to identify and explain conditions that have a causal effect on adopters or end-users (Abend, 2008; Ajibade, 2018). A theory may include the following features 1) uniqueness- [differentiated from other theories], 2) conservatism-[withstand change unless replaced by a superior version],

[18] This chapter has been published in a peer-reviewed journal.

[19] According to the World Bank, Low-income countries are economies with a Gross National Income (GNI) per capita of $1,045 or less. Lower Middle-Income Countries are economies with GNI per capita of more than $1,045 but less than $4,125 (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519, 13/02/2023, 16:08).

3) generalisability-[broad scale applicability], 4) fecundity-[expandable to generate new models and hypothesis], 5) theory parsimony-[less complex with simple and coherent explanation], 6) internal consistency-[identify all possible relationships to offer adequate explanation], 7) empirical riskiness-[superior capability of predicting less expected events], and 8) abstraction-[potential to integrate many relationships and variables to constitute a superior theory] (Wacker, 1998; Popper, 1957).

Initial research published on technology adoption has offered different perspectives within psychology, sociology and economics explaining farmers' adoption of agricultural technologies. Much of the previous research has used theories that can be classified based on their focus on either the technology to be adopted or the adopter (Hillmer, 2009; Fadeyi, Ariyawardana and Aziz, 2022; Melesse, 2018; Dissanayake *et al.*, 2022). Accordingly, Hillmer (2009) and Fadeyi, Ariyawardana and Aziz (2022) propose that technology adoption-related theories may be classified based on their focus under five broad categories. These included 1) Diffusion theories, 2) User acceptance theories, 3) Decision-making theories, 4) Personality theories, and 5) Organisational structure theories. "Diffusion theories" focus on how new technologies were transferred to their adopters using different means in a system over a period. The "user acceptance theories" predict if and how behavioural intention influences a user to adopt a new technology. The "decision-making theories" analyse the process an adopter of a new technology may undergo while considering a range of variables, including risk, uncertainty, and profitability. The "personality theories" predict how the characteristics of the adopter influenced the adoption of technology. Finally, "Organisational structure theories" assume farm characteristics (i.e., farm size, farming system type, etc.) explain a farmer's technology adoption.

While many theories have been developed and are useful to researchers in explaining agricultural technology adoption, theories are further useful in contributing to policy development and implementation. This is because theories create a link between farmers' adoption behaviour and agricultural technologies and, thus, can predict the best interventions for farmers (Moerkerken *et al.*, 2020; Despotović, Rodić and Caracciolo, 2019).

As there is increasing research interest in assessing farmers' adoption behaviour, it is relevant to evaluate the various theoretical approaches that have been applied. This will enable mapping the strengths and weaknesses of the multiple theories, thereby identifying appropriate theories for future technology adoption research. A systematic review was conducted to determine a suitable theoretical approach to guide the empirical research.

5.3 Materials and Methods

A systematic literature review was conducted to develop a conceptual framework by assessing the application of theoretical approaches in studying farmers' adoption behaviour towards agricultural technologies in the context of LMICs. Agriculture remains a significant contributor to Gross Domestic Product (GDP) growth in LMICs, with smallholder farmers dominating the workforce in the sector (Atangana, 2022; Sertoglu, Ugural and Bekun, 2017). Agricultural technologies may, therefore, be applied to transform farming and production methods in less developed countries (Islam *et al.*, 2018; Lowder, Skoet and Raney, 2016).

Systematic literature reviews are useful for mapping current research and identifying gaps in knowledge that may be relevant for future research (Fadeyi, Ariyawardana and Aziz, 2022; Alvesson and Sandberg, 2018). “A systematic review attempts to collate all the empirical evidence that fits pre-specified eligibility criteria to answer a specific research question” (Higgins *et al.*, 2019, p. 3). This type of review applies a protocol-driven methodology to ensure thoroughness (Shamseer *et al.*, 2015). Systematic reviews aim to assess relevant data to answer a proposed research question based on evidence derived from the review while at the same time attempting to minimise biases in the selection of articles (Fadeyi, Ariyawardana and Aziz, 2022; Mallett *et al.*, 2012; Van der Knaap *et al.*, 2008). According to Briner and Rousseau (2011) and Frewer *et al.* (2016), a systematic review is based on five steps, which include 1) identifying the review question, 2) searching for and identifying relevant studies, 3) evaluating the identified articles for relevance to the research question, 4) evaluating data or relevant results, and 5) synthesising and reporting the review findings.

The systematic review for this study relied on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher *et al.*, 2009; Page *et al.*, 2021). A set of inclusion and exclusion criteria was applied to select articles for the review. The criteria applied were developed to ensure the identification of articles that relied on a theory to explain agricultural technology adoption by farmers. A critical appraisal was conducted for articles included in the review using an appraisal tool developed by Clark *et al.* (2016). The Grading of Recommendations

Assessments, Development and Evaluation (GRADE) was used to assess the overall quality and strength of evidence in the research presented in the articles.

5.3.1 Search methodology

The research question was: what theoretical approaches have been employed to explain farmers' adoption of agricultural technologies in LMICs? The review context in LMICs was chosen because the empirical research was to be conducted in an LMIC country (Ghana). Unlike in advanced economies or countries that have fewer smallholder farmers, the agriculture sector in less developed countries is dominated by smallholder farmers who are characteristically constrained with access to farming resources (Aliber and Hall, 2012; Zerssa *et al.*, 2021; Sertoglu, Ugural and Bekun, 2017). Due to the LMIC focus, only articles reporting on primary research involving smallholder farmers were considered. Articles were included in the review if they considered farmer adoption of existing and new agricultural technologies ranging from mechanical tools, e-services, and improved crop varieties and practices. The emphasis of the review was only on technology application in crop-based agriculture. This was to ensure consistency in the articles to be reviewed.

Only research articles that explicitly stated the use of a theory or theories to explain farmers’ adoption were included. Articles that reported only econometric or statistical analytical models to explain farmers’ technology adoption were excluded. The timeframe of the search ranged from 1960 to 2022. This was because the period from 1960 was when smallholder farmers in LMICs were introduced to agricultural innovations, including improved crop varieties, fertilisers, and farm implements (Evenson and Gollin, 2003; Khush, 1999; Eliazer Nelson, Ravichandran and Antony, 2019). The databases searched included Scopus and Web of Science. These databases contain abstracts and peer-reviewed articles relevant to the systematic review. In addition, these databases report records from social science journals.

5.3.2 Search

Specific search terms were used as part of the online search string to identify relevant articles for the review. A combination of the search terms applied included "technol*" and "agric*" and "adopt*". Additional search terms were "theor*" or "model*" and "farm*" and "energy*". Table 5.1 summarises the search terms used and returned search value. Only peer-reviewed journals were considered in the search to ensure the quality of the articles. Results obtained from the search (i.e., article titles and abstracts) were exported into an Endnote library. The search was conducted between June 29th, 2022, to September 19, 2022. A total of 36542 articles were obtained following the initial search.

Search String Applied in the Search	
Search term 1	technol* and
Search term 2	agric* and
Search term 3	adopt* and
Search term 4	theor* or model* and
Search term 5	farm* and
Search term 6	energy* or solar* or biomass*

Table 5.1 Detailed online search string

5.3.3 Inclusion and exclusion criteria

Inclusion and exclusion criteria were developed to facilitate the screening process. The inclusion criteria were as follows.

1) Articles that demonstrated the use of a theoretical approach. It was noted that theoretical approaches may vary between disciplines.
2) Articles which reported on adopting or using an agricultural technology/ innovation/practice were included. These addressed existing and new agricultural technologies, including mechanical tools/implements, e-services, and improved crop varieties and practices.
3) Articles focusing on only crop-based agriculture were included. Articles reporting with a focus on livestock-based agriculture were excluded because the drivers of decision-making were much broader (for example, more likely to relate to the ‘one-health agenda or regulatory enforcement) and because of the additional consideration of animal welfare.
4) Articles published on research on agricultural technology adoption in LMICs were included, but in other countries were excluded.

In the first stage, a researcher, RTK, conducted a search to identify articles. Following the removal of duplicates, an initial screening of titles for relevance to the research question was conducted. Subsequently, two researchers, RTK and SN, independently evaluated the abstracts of the remaining articles using the inclusion and exclusion criteria to assess further whether the articles aligned with the research question. Abstracts which did not meet the inclusion criteria were excluded. Where there was a divergent outcome between researchers in applying the inclusion and exclusion criteria, a discussion between the researchers allowed consensus to be reached in all cases. Abstracts that satisfied the inclusion criteria were searched for partial or full-text reading.

5.3.4 Data extraction and synthesis

The articles extracted for review included quantitative, qualitative, and mixed methodologies. Different dependent variables and assessment methods (parametric, non-parametric and narrative synthesis) were used to explain determinants of technology adoption by farmers in LMICs. Therefore, a meta-analysis was not possible. The extracted data from the included articles were analysed using a thematic framework. The thematic framework captured themes, including the name of the theory and an overview, the location where data were collected, the advantages and disadvantages of the theory used in the research and full references of the articles. See Appendix A for summary of extracted data from the articles reviewed.

5.3.5 Critical appraisal

The quality of the articles was examined through the application of a critical appraisal. This was performed to check for bias and validity. The critical appraisal document Clark *et al.* (2016) developed was adapted to achieve this. The document was relevant due to its applicability in the context of non-healthcare research. The appraisal document contained key criteria questions on research aims and design, recruitment of participants, data collection, data analysis, the study's ethical considerations, and the discussion of findings. A 5-point scale was used to measure the risk of bias under each criterion. The scale ranged from very high to very low. Since articles applied a variety of research methods, separate appraisal tools were used to assess quantitative and qualitative methodological approaches. Where mixed methods were applied, the assessment considered was based on each research method separately. A cumulative verdict on the quality was made for each article. Subsequently, the Grading of

Recommendations Assessments, Development and Evaluation (GRADE) was adapted to assess the overall quality and strength of evidence within each article. A rating structure was used based on four ranks: high, moderate, low, and very low (Guyatt *et al.*, 2011).

Although many articles did not explicitly address ethical considerations (for example, whether an ethics committee had approved the research), this did not result in the exclusion of any article as the overall quality of evidence was satisfactory. See Appendix B for summary of the critical assessment and findings from the review.

5.4 Results

5.4.1 Characteristics of selected articles

At the end of the process, 17281 articles were removed because of duplication. Sixteen thousand five hundred seventy-nine (16579) articles were excluded after screening the articles' titles. Two thousand four hundred sixty-four (2464) articles were retrieved for eligibility assessment. Three hundred fifty-three (353) articles were excluded as data were collected outside LMICs. One hundred thirty-two (132) articles were excluded due to the non-crop-based agriculture context. One thousand six hundred thirty-four articles (1634) were excluded due to the unexplicit use of a theory. Two hundred sixty-eight (268) articles were excluded for non-relevance to study and subject areas. In effect, a total of 77 articles were selected for the review. Fig 5.1 represents the PRISMA flow diagram depicting the articles' selection process.

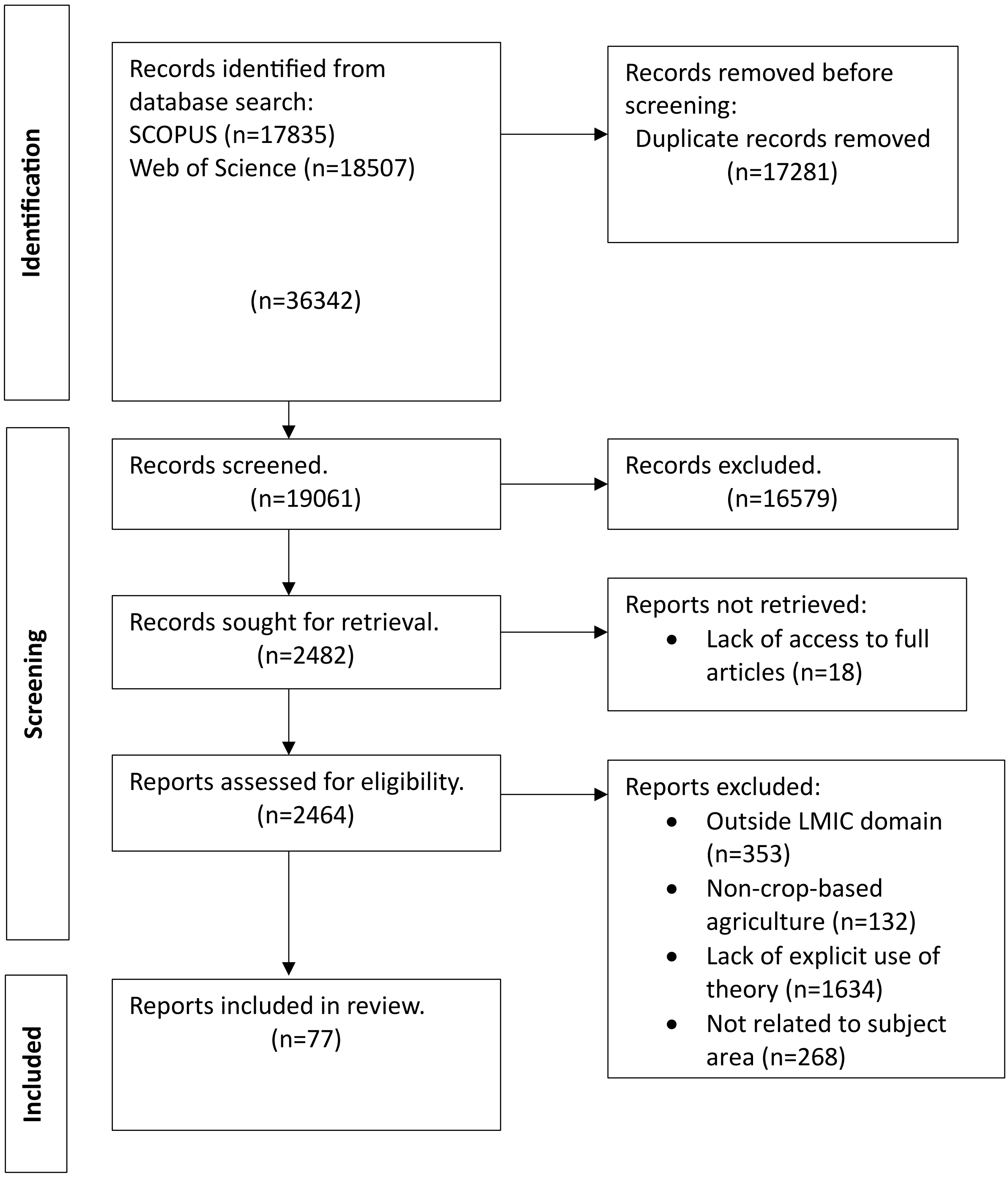


Fig 5.1 PRISMA flow diagram

Source: Authors' construct (2022).

The articles selected for inclusion review (n=77) had publication dates ranging from 2006 to 2022 when the search was discontinued. Most articles were published in 2022 (n=18). The years 2006, 2007, 2009, 2012 and 2013 had the least publications (n=1). Figure 5.2 illustrates the number of articles published per year. The articles were published in a variety of journals, and a specific journal did not dominate the publication of articles. Heliyon (n=6) and Water International (n=4) were found to have published more than 1 article. Cogent Economics and Finance, Cogent Food and Agriculture, and the European Journal of Development Research each had (n=3) publications. Most of the articles (n=62) focused on farmer adoption in sub-Saharan Africa [Ethiopia (n=10), Ghana (n=10), and Kenya (n=8)]. Outside of sub-Saharan Africa, most articles focused on Iran (n=9) and Bangladesh (n=3). Figure 5.3 illustrates the number of articles published per country.

A total of (n=24) theories were found to have been applied in the articles included. See Appendix A for summary of the theories identified from the articles reviewed. The Diffusion of Innovation theory (n=12) and Random Utility Theory (n=12) were the most frequently applied, followed by the Technology Acceptance Model (n=11) and the Expected Utility Theory (n=11). Theories such as the Decomposed Theory of Planned Behaviour and Consumptions Value Theory inter alia were used only once. Most articles (n=25) focused on the farmers' adoption of sustainable soil and water conservation practices, followed by articles on the farmers' adoption of improved crop varieties (n=15).

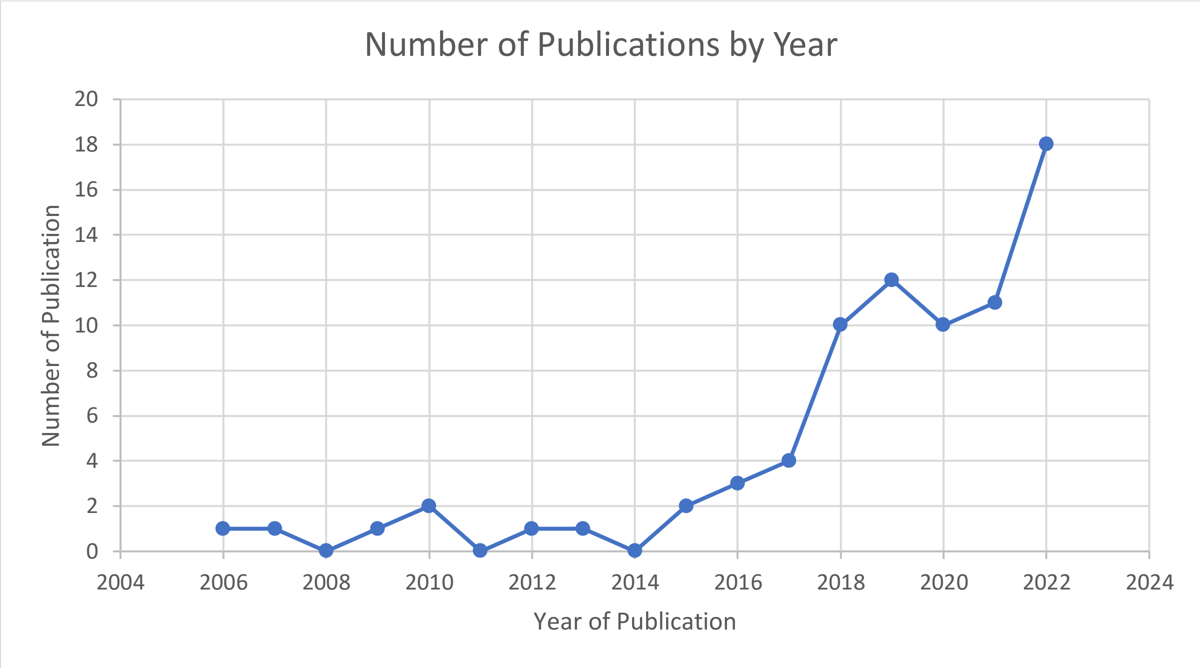


Fig 5.2 The number of review articles published per year

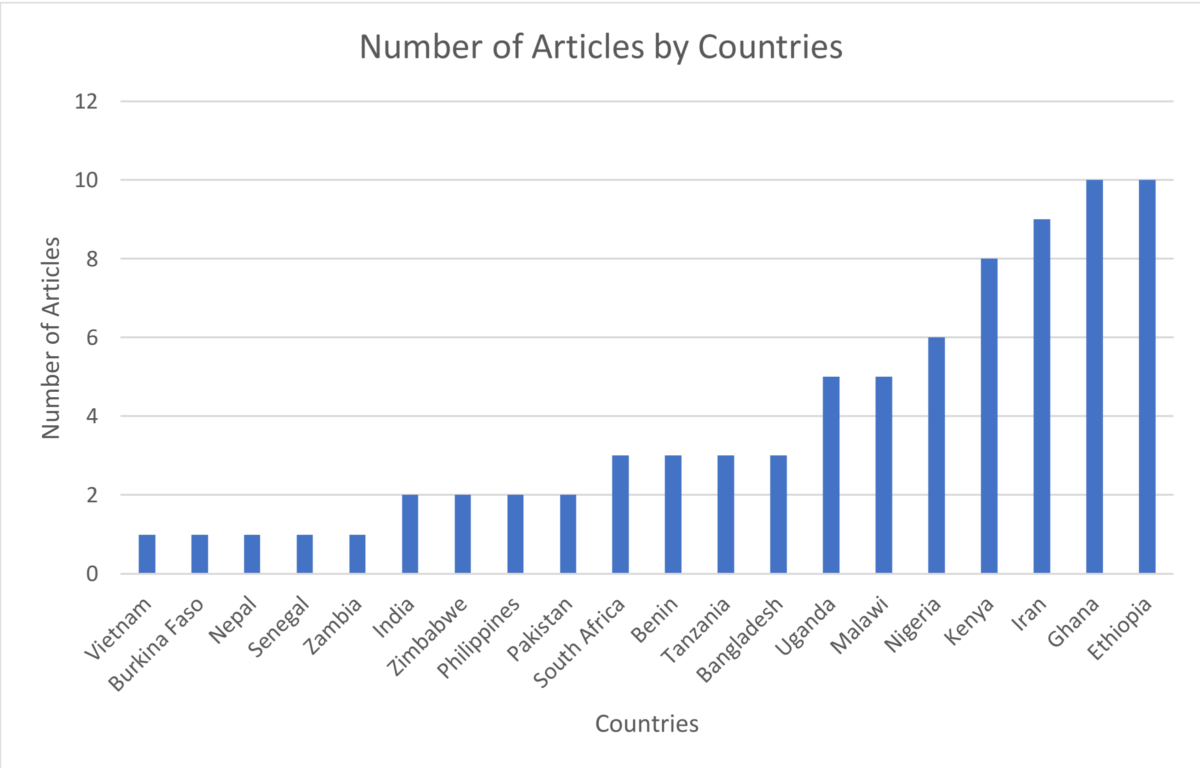


Fig 5.3 The number of review articles by countries

5.5 Discussion

The review found that diffusion theories primarily focused on the processes in which new technologies were introduced to prospective adopters in a society at a temporal scale. The diffusion of innovation theory was applied in a number of research articles to explain the transfer and adoption of agricultural technologies among farmers. According to Rogers (2003), the diffusion of innovation theory examines the process (i.e., channel, rate, etc.) an innovation must undergo to determine adoption. This follows five main phases: knowledge about the innovation, persuasion, decision to adopt or not, implementation of the innovation, and confirmation. In addition, five evaluation criteria are followed, including 1) Relative advantage [compared to those offered by existing technologies], 2) Compatibility [the extent to which new technology fits with existing cultural norms, attitudes, and beliefs], 3) Complexity [the extent to which the technology under consideration is easy to understand and use], 4) Trialability [the extent to which technology can be accessed and "tried out" by end-users], and 5) Observability [where it is possible to observe the successful application of the technology by others].

The results suggest the diffusion of innovation theory has a comprehensive assumption structure that can explain an intention to adopt technology as well as actual adoption. The "face validity" of the theory, which explicitly considers technology adoption, may account for the theory's frequent application within the articles included in the review (Dadzie *et al.*, 2022; Mihretie, Abebe and Misganaw, 2022; Nyairo *et al.*, 2022; Goswami, Choudhury and Saikia, 2012; Jha, Kaechele and Sieber, 2019; Kwade *et al.*, 2019). A strength of the theory is its generalisation and applicability across many disciplines because it encapsulates various variables and constructs (Dibra, 2015). Nonetheless, the theory seems limited in its explanatory perspective as it does not explicitly address social imperatives such as social support and the individual's resource conditions (MacVaugh and Schiavone, 2010).

The results from the review further delineate that user acceptance theories explain how behavioural intentions influence technology adoption. The results indicate that various theories, including the theory of Planned Behaviour (TPB), the Decomposed Theory of Planned Behaviour (DTPB), and the Technology Acceptance Model (TAM), were applied in research articles to investigate how farmers' behavioural intentions resulted to the adoption of agricultural technologies. Although all user acceptance theories originate from social psychology, each theory has distinct assumptions explaining the effect of intention on adoption behaviour (Fadeyi, Ariyawardana and Aziz, 2022; Lai, 2017). For example, the theory of planned behaviour (TPB) suggests an individual's behaviour can be predicted when an intention is developed based on the influence of three main psychological constructs: attitude, subjective norms, and perceived behavioural control (Ajzen, 1991). Based on the theory's underlying assumption, it extensively analyses an adoption behaviour by introducing elements of subjective norms and perceived behavioural controls as important factors in predicting behaviour (Alomary and Woollard, 2015). However, unlike diffusion theories, the results suggest that (TPB) often measures only the individual's intention to perform a behaviour, not the actual adoption behaviour. Also, (TPB) proposes an untenable monolithic belief structure (i.e., unidimensional construct) and does not take into account the diverse factors that constitute an individual's belief (Taylor and Todd, 1995a; Bagozzi, 1981).

As an extension of the theory of planned behaviour, the decomposed theory of planned behaviour (DTPB) deconstructs the monolithic belief structures into perceived usefulness, perceived ease of use, compatibility, role of peer and superior influences, self-efficacy, technology-facilitating conditions, and resource-facilitating conditions (Taylor and Todd, 1995a). On the above basis, the DTPB may offer advantages for analysing the relationship between specific variables under the belief construct, thus underscoring a multi-dimensional belief construct (i.e., encapsulating several factors) (Nyasulu and Dominic Chawinga, 2019; Taylor and Todd, 1995b). As for the technology acceptance model, two main factors (perceived usefulness and perceived ease of use) are assumed to be sufficient to explain the adoption of a technology (Davis, 1989). The theory's assumption has proven reliable in much empirical research predicting technology adoption behaviour (Bagheri *et al.*, 2021; Contillo and Tiongco, 2019; Nwokoye *et al.*, 2019). Despite the theory's easy and straightforward-to-understand assumption structure (Ajibade, 2018; King and He, 2006), the theory lacks an explicit consideration for important factors like social imperatives when investigating farmers' adoption behaviour. Usually, technology adoption among farmers occurs in an environment embedded with values, norms, and interpersonal relations (Eidt, Pant and Hickey, 2020; Huyer, 2016; Rola-Rubzen *et al.*, 2020; Tanko and Ismaila, 2021). Therefore, it may be possible for these socio-cultural variables to influence a behavioural intention to adopt a technology.

Decision-making theories describe the processes entailed in adopting a new technology under a range of economic factors. The research context is often embedded in risk, uncertainty, and profitability associated with a decision. Specifically, the results indicated that the expected utility, utility maximisation, and random utility theories were mainly applied in research articles identified in the review to explain farmers' decisions to adopt new technology. According to the expected utility theory, an adoption behaviour is conditioned by risk and uncertainty, and an individual is likely to adopt a technology if the expected utility from the new technology surpasses the old or existing technology (Mongin, 1998). A principal strength of this theory is the potential rating of an individual’s expected utility according to the weight of the expected benefit gained. However, the theory does not consider psychological constructs as predictors of adoption behaviour. Utility maximisation theory assumes that an individual adopts a new technology to reap the highest level of satisfaction from its use (Curwen, 1976). Unlike psychological constructs, the variables in this theory are more easily measured, and the results from different research activities are often comparable. Random utility theory assumes that an individual adopts a new technology with a variation in equally exclusive choices (Cascetta and Cascetta, 2001). This implies that a change in an individual’s choice of technology can be attributed to random factors. The strength of this theory resides in its potential to increase accuracy when examining factors entailed in the rationality of choice (Hess, Daly and Batley, 2018). However, there is a weakness in the theory's assumption that adoption behaviour is always rational.

The results also indicate that different personality theories have been applied to predict farmers' adoption of agricultural technologies. These theories generally assume that the adopter's character influences technology adoption. Self-determination theory and Peterson and Seligman’s theory of character strength were applied to investigate farmers' adoption of agricultural technologies (Jambo *et al.*, 2019; Bukchin and Kerret, 2020). The self-determination theory explains psychological elements such as autonomy, competence, and relatedness can influence and drive a person’s personality and motivation to adopt a technology (Adams, Little and Ryan, 2017; Deci and Ryan, 2004). Given the theory’s applicability in different disciplines, it is considered overly multifaceted and complex, which dilutes its predictive capacity.

Peterson and Seligman's theory of character strength proposes that the personal character of an adopter (i.e., creativity, curiosity, bravery, etc.) can predict the adoption of a technology (Peterson and Seligman, 2004; Park and Peterson, 2008). The assumption underpinning the theory is an effective approach to predict an adoption behaviour from the adopter's perspective. However, the theory's explanation of adoption behaviour may be limited in its perspective due to the strict focus on the adopter's personality with no consideration for external variables that can affect the adopter's personality.

Other results from the review suggest that organisational structure theories have been applied to the investigation of technology adoption among farmers in LMICs. Typically, organisational structure theories assume farm characteristics can satisfactorily explain technology adoption. These theories rely on characteristic farm structures, including farm size, farming system type, policies, and programmes, to explain an adoption behaviour. From the results of the review, it was found that institutional theory has been applied to examine farmers' adoption of agricultural technologies (Meda *et al.*, 2018), rationalising how rules and norms develop a social structure and influence behaviour to adopt a technology (Amenta and Ramsey, 2010). The theory has an underlying strength in understanding how a social structure influences behaviour compared to other theories that do not explain well. However, the theory neglects the influencing role of individual traits and sometimes presents weak social structure variables that may not be relevant to the adoption process in a specific context.

Overall, the analysis of the results from the review indicates the factors that influence technology adoption are interconnected. Therefore, some research articles in the review applied a combined theoretical approach to explain adoption behaviours (Momvandi *et al.*, 2018; Musungwini, van Zyl and Kroeze, 2022; Dadzie *et al.*, 2022). Applying an integrated theoretical approach aligns with the views of researchers who propose that an individual action (in this case, adoption behaviour) results from interrelated factors such as norms, physical activities, mental activities, technology use, knowledge, and meanings, and implying that technology adoption can be complex given the diversity in the factors or variables that are influential (Fadeyi et al., 2022; Garforth & Usher, 1997; Meijer, Catacutan, Ajayi, Sileshi, & Nieuwenhuis, 2015; Morris, Marzano, Dandy, & O'Brien, 2012). Combining theories from different perspectives or disciplines is an approach which can potentially explain farmers' adoption behaviour while avoiding explanatory gaps (Borges, Foletto and Xavier, 2015; Uaiene, Arndt and Masters, 2009).

In conclusion, applying a theory to predict or explain farmers' adoption behaviour should consider the context or focus of the research. The categorisation of theories in the review suggests that such research context may focus on the technology to be adopted by farmers and farm characteristics. Therefore, predicting and explaining farmers' adoption behaviour depends on understanding the research context and applying the most suitable theoretical approach, which also aligns with their research question.

5.6 Conclusion

The review identified articles that included theories to explain farmers' intentions and behaviours regarding the adoption of technology in LMICs. Different theories from a wide range of disciplines were identified. Following the systematic review process, theories were identified and categorised: diffusion theories, user acceptance theories, decision-making theories, personality theories and organisational structure theories were identified, in line with (Hillmer, 2009; Fadeyi, Ariyawardana and Aziz, 2022; Melesse, 2018). Based on the application of theories in the research articles, strengths and weaknesses were identified.

Diffusion theories exhibit strengths in their assumption structure that can predict an adoption intention and actual adoption. However, these theories lack consideration of possible influential social factors. User acceptance theories only predict an adoption intention and not actual adoption (although this can be added to the model where adoption behaviour is observable), these theories have proven robust in explaining an adoption behaviour because of the consideration for social determinants (i.e., subjective norms). An additional advantage is that they have the capacity to predict behavioural intention to adopt before a technology has been fully developed, and actual adoption behaviours are observable. Decision-making theories do not consider psychological factors, implying only economic factors can predict adoption behaviour. Nevertheless, all these theories have strength in easily measuring variables that determine an adoption behaviour.

Personality theories have broad applicability but are sometimes complex and may result in weak predictability. Although organisational structure theories consider social structure variables, some variables are not relevant to investigating a particular adoption process. Finally, the theories identified in the review can offer a strong or weak explanation of an adoption behaviour based on the context of what is to be investigated. Applying an integrated theory to minimise explanatory gaps and broaden the perspective of explaining an adoption behaviour may be appropriate.

Chapter 6. Farmers' Adoption of Renewable Energy Technology in Agriculture in Ghana.

6.1 Introduction

Understanding farmers' adoption behaviour in relation to new technological innovations is key to facilitating and promoting the widespread adoption of new sustainable farming practices. In this chapter, qualitative research was applied to assess the potential factors affecting farmers' likelihood of adopting renewable energy technologies in their agronomic practices. The contributing role played by the broader stakeholder community in facilitating sustainable technology adoption was also explored, and a comparative analysis enabled the identification of shared values and common objectives regarding the adoption of sustainable energy in Ghanaian agricultural practices. This followed a policy review in Chapter 4 to ascertain Ghanaian policies for sustainable energy options in agriculture. The thematic areas used to analyse farmers' qualitative data emerged from a systematic review conducted in Chapter 4, which identified the Decomposed Theory of Planned Behaviour as the appropriate theoretical approach to understanding farmers' adoption behaviour determinants.

6.2 Background

There is evidence that, to some extent, technology adoption may increase agricultural productivity in low to middle-income countries in Southeast Asia and Sub-Saharan Africa (Akudugu, Guo and Dadzie, 2012; Jama and Pizarro, 2008; Feder and Savastano, 2017; Bediako, 2008). Adoption of technology and new agronomic practices in smallholder agriculture, particularly in Sub-Saharan Africa, may contribute to increase agricultural productivity, improve food security and nutrition, climate change mitigation and poverty eradication (Muzari, Gatsi and Muvhunzi, 2012; Mwangi and Kariuki, 2015; Glover, Sumberg and Andersson, 2016; Kalungu and Leal Filho, 2018). Many agricultural technologies aim to promote sustainable and efficient agricultural practices that increase food production and income and protect the environment.

Despite the relevance of new agricultural technologies, not all technological innovations can be considered to have a positive impact (Harwood, 2020). For example, technological innovations introduced in the Green Revolution (i.e., pesticides, inorganic fertiliser, mechanised land tillage, etc.) have been identified to negatively contribute to the increase in Greenhouse gases, deforestation, land degradation, and biodiversity loss. (John and Babu, 2021; Choudhary *et al.*, 2018; Kumar, 2007).

Sustainable technology adoption in LMICs is important for smallholder agriculture (Adenle, Morris and Parayil, 2013). Smallholder agriculture is threatened notably by low and erratic rainfall patterns, low soil quality, and poor agricultural infrastructure, including a lack of irrigation facilities, credit, and ready markets (Mwangi and Kariuki, 2015). Sustainable agricultural technologies applied to smallholder agricultural practices in LMICs include the introduction of new and improved seed varieties, soil fertility management, weeds, insect and other pest management, irrigation and water management (Mwangi and Kariuki, 2015; Ainembabazi and Mugisha, 2014; Senyolo *et al.*, 2018). Although there is an increase in the adoption of sustainable agricultural technologies in LMICs, the scale and rate at which adoption occurs will also contribute to the impact in relation to sustainability (Adekunle, Osazuwa and Raghavan, 2016).

The successful adoption of sustainable agricultural technologies in LMICs potentially depends on interacting factors. This may include the contributing roles of stakeholders (Eidt, Pant and Hickey, 2020). Stakeholders are persons or institutions with the capacity to cause change that can affect/ be affected by decision-making (Silva *et al.*, 2019; Eidt, Pant and Hickey, 2020; Freeman, 2010). Stakeholders may have different interests and respond differently to a particular issue, as they consider it from a unique perspective and in relation to their interests. Other stakeholders will interact differently within relevant Social Networks (Eidt, Pant and Hickey, 2020; Brugha and Varvasovszky, 2000; Chinseu, Dougill and Stringer, 2022). In the agricultural sector, stakeholders may include but are not limited to extension agents, government agencies, development/donor partners, non-governmental organisations, researchers, farmers, and their representatives. When it comes to farmers' technology adoption behaviours, non-farmer stakeholders are considered to be influential (Bhattacharyya, Wani and Tiwary, 2021; Wang *et al.*, 2020). Non-farmer stakeholders may influence farmers’ decision to adopt technology through interactions at various stages of the adoption process by providing financial, logistical, advisory, education and training support (Klerkx, Van Mierlo and Leeuwis, 2012; Eidt, Pant and Hickey, 2020). Among varying interests, non-farmer stakeholders enable farmers to overcome technological, social and market barriers hindering adoption (Wang *et al.*, 2020).

In Ghana, the adoption of sustainable energy technology is increasingly recognised by researchers and policymakers as an area of relevance to the agricultural sector, as it is established that potential economic and environmental benefits can be derived from its application. Solar and biomass currently represent sustainable energy forms considered appropriate for adoption in Ghanaian agriculture (Karbo *et al.*, 2022). Solar energy is used to power solar water pumps for irrigation and solar dryers for drying crops, heating, and lighting (Amankwah, 2015; Kuwornu, Egyir and Anyinam, 2011). Biomass energy is used for organic fertiliser production and to fuel farm equipment (Kemausuor *et al.*, 2014; Amankwah, 2011). To promote and integrate the application of sustainable energy technologies in Ghanaian agriculture, the government and stakeholders (i.e., policymakers, researchers, etc.) are implementing a number of policy interventions. For example, the Renewable Energy Act-(832) (2011), Ghana Renewable Energy Master Plan, and National Energy Policy are some policies being implemented. Some specific technological interventions introduced to the farmers by the government and researchers for adoption include solar water pumps, solar dryers, anaerobic digesters, and organic fertilisers.

Despite the introduction of various policy and technology interventions to promote sustainable energy uptake in Ghanaian agriculture, its adoption among farmers may represent an important implementation barrier, especially when the underlying conditions that facilitate or act as barriers to farmer adoption are not well understood. Previous research has found that agricultural technology adoption in a local farming system may depend on a wide array of factors such as economic, social, cultural, and technology (Mwangi and Kariuki, 2015; Llewellyn and Brown, 2020; Hogset, 2005; Dinh, Cameron and Nguyen, 2015; Jin *et al.*, 2022; Doss, 2006; Muzari, Gatsi and Muvhunzi, 2012; Adekunle, Osazuwa and Raghavan, 2016). The objectives of this research are 1) to determine factors influencing farmers' intention to adopt renewable energy in Ghanaian agriculture and 2) to examine the contributing role of non-farmer stakeholders influencing farmers' adoption of renewable energy in Ghanaian agriculture. Understanding differences and similarities in perspectives in relation to agronomic adoption of sustainable energy technologies can contribute to effectively targeting agricultural policies and interventions.

6.3 Methods

Qualitative methodology (structured interviews) was employed to 1) determine factors influencing farmers' intention to adopt renewable energy in Ghanaian agriculture and 2) understand the role of non-farmer stakeholders in influencing farmers' adoption of renewable energy in Ghana. A qualitative approach was applied to explore complex "culture-specific factors" associated with technology adoption processes (Acquah-Coleman, 2018; Adekunle, Osazuwa and Raghavan, 2016). The research aimed to critically examine and provide an in-depth understanding of the beliefs, perceptions, and experiences of farmers and non-farmer stakeholders in relation to renewable energy use in agriculture.

6.4 Participants Selection and Sampling Strategy

6.4.1 Farmers

Male and female farmers with different levels of farming experiences constituted the research participants. The farmers were drawn from 1) Lawra Town Council, 2) Babile, 3) Zambo and 4) Eremon. These four areas represent the administrative sub-districts of the study area (Lawra Municipality) (see Table 6.1) (see Figure 3.1 for map of the study area). A purposive non-probability sampling technique was employed to select research participants with knowledge and experience in relation to renewable energy use in agriculture (Etikan, Musa and Alkassim, 2016). Furthermore, a snowball non-probability sampling technique was applied in the selection of farmer participants. This involved farmer participants recommending potential subjects to participate based on shared traits that met the research requirements (Parker, Scott and Geddes, 2019). At the end of each interview, a farmer participant was asked to refer the researcher to the next participant with knowledge and experience in using renewable energy technology for farming. A total of thirty-six (36) farmers were interviewed against a targeted number of 40 farmers. The interviews were discontinued after the 36th farmer due to data saturation. Data saturation occurs when the interviewer no longer obtains new information from the interviewees (Fusch and Ness, 2015).

6.4.2 Non-farmer stakeholders

Seven non-farmer stakeholders outside the farmer community were selected and interviewed. The selected stakeholders had representation at the national and local levels. The categories of stakeholders comprised two research institutions, two government agencies, two non-governmental organisations, and a private sector enterprise. A purposive sampling technique was employed to select stakeholders with relevant experiences in facilitating and promoting renewable energy technologies in agriculture.

6.5 Data Collection and Procedure

6.5.1 Farmers

Prior to commencing the data collection from farmers, ethical approval was obtained from the Faculty of Science, Agriculture and Engineering, Newcastle University (Ref: 13797/2020; 21/07/2021). Through an introductory meeting at the Lawra Municipal Assembly, permission was obtained from the Lawra Municipal Agriculture Department, which represents Ghana's Ministry of Food and Agriculture (MoFA) at the local level, to introduce the purpose of the research. Additional permission was obtained from the Lawra Traditional Paramountcy to pave the way for the research team to undertake the fieldwork in the communities included in the research. A semi-structured interview guide was developed to serve as a guide for the interviews (see Appendix C). A pilot study was conducted to test the interpretation and comprehension of the interview guide. Some modifications were made to help simplify the understanding of technical vocabulary for farmer participants to easily comprehend. Face-to-face interviews were conducted on a one-to-one basis. At the start of the interview, the researcher introduced and explained the purpose of the research to the participants. The researcher obtained farmers' informed consent before proceeding with the interview.

The interviews were conducted in the local dialect (Dagaara) with the assistance of an interpreter. The interview guide solicited background information from farmers, their energy use in agriculture, and socio-economic, psychological, and external drivers facilitating and acting as barriers to renewable energy use for farming.

Each farmer interview lasted about 45 minutes. With the permission and consent of the farmers, the discussions were audio-recorded for transcription and analysis purposes. The researcher and field assistant also took field notes. During an interview, farmers expressed their views without interjection from the researcher (Acquah-Coleman, 2018). At the end of each farmer interview, a token gift was given to a farmer participant to compensate for their time. The interviews were conducted between November 2021 and February 2022.

Sub-districts	Number of Farmers
Lawra Town Council	9
Babile	9
Zambo	9
Eremon	9
Total	**36**

Table 6.1 Number of farmers interviewed from Lawra Municipality

Source: Author's construct (2022).

6.5.2 Non-farmer stakeholders

The stakeholders were selected initially by referring to Ghana's Renewable Energy Act 2011 (832), which identified designated public institutions with the mandate to facilitate and promote renewable energy development. The search then broadened to include internet sources and published reports. Twenty-seven institutions were identified with interests in promoting renewable energy development in agriculture. However, only representatives of seven institutions were interviewed. The offices of 5 institutions could not be contacted or located based on the contact information obtained from the online search. Three (3) institutions were closed and ceased operating at the time of data collection. Seven (7) of the institutions, upon contact, indicated their mandate and interest were not in renewable energy development but rather in the retail of fossil energy technologies. Despite several follow-ups, the remaining five institutions did not respond to a request to participate.

Using a semi-structured questionnaire interview guide, separate face-to-face in-depth interviews were conducted for the stakeholders. The objectives and methods of the research were described, and informed consent was obtained to have the audio of the interviews recorded for later transcription. The consent form is provided in Appendix H. The interviews were conducted in English and lasted about an hour. The interviews were conducted between November 2021 and February 2022 by the researcher (RK).

6.6 Validity and Reliability

Validity and reliability are essential aspects of ensuring the validity of research that warrant the credibility and trustworthiness of research findings (Noble and Smith, 2015; Brink, 1993). Generally, validity and reliability are important in qualitative and quantitative research but emphasise different operative connotations (Coleman, 2022). In qualitative research, validity is often concerned with the accuracy of research findings (Maxwell, 2010; Acquah-Coleman, 2018). Reliability is the consistency obtained from using qualitative research methods to generate findings (Noble and Smith, 2015), such that findings will be identical or similar if the same research methods are applied. Unlike quantitative research, techniques used in qualitative research are arguably subjective. Therefore, validity and reliability considerations in qualitative research may guard against the researcher's subjectivity in interpreting the data or research findings (Brink, 1993; Golafshani, 2003).

Strategies were adopted to control research bias to ensure the validity and reliability of the research findings. Triangulation of data sources during the data collection and analysis stages was used to obtain validation of the research findings. Data was generated from interviews with farmers and non-farmer stakeholders. Furthermore, member checking in the form of participant validation was resorted to establish the validity of the findings by informally checking with participants and recounting the information gathered from the interviews. This enabled the participants to make amendments to the data where necessary. The reliability of findings was ensured through adequate documentation of the research protocols. For instance, interviews were recorded to enable the researcher to report the accounts of the participants *verbatim*. The strategies employed above have similarly been used in qualitative research (Acquah-Coleman, 2018; Bashir, Afzal and Azeem, 2008; Yin, 2009; Golafshani, 2003).

6.7 Data analysis

Qualitative data were captured through audio recordings of interviews and the taking of notes to develop field memos. Data from qualitative research are typically rich in text material. Nonetheless, not all the information may be relevant to the research. Therefore, it is essential to analyse the data to identify information relevant to the research questions (Acquah-Coleman, 2018).

A thematic analysis approach was used. Thematic analysis is "a method for identifying, analysing and reporting patterns (themes) within data" (Braun and Clarke, 2006, p. 79). Stages included the researchers 1) familiarising themselves with the data set, 2) generating initial codes, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes, and 6) producing the report. NVivo (version 1.6.1) analytical software was used to perform the thematic analysis.

In the first phase, the researcher transcribed the audio-recorded interviews and identified initial thoughts regarding the structure of the thematic framework. This allowed the researcher to understand the information obtained from the participants. In the second phase, using the NVivo analytical tool, the transcribed data set was analysed to generate initial codes, where coding denotes sorting data under unique label sets (Tuckett, 2005; Braun and Clarke, 2006). Two types of coding were employed, predetermined and emerging codes. Predetermined codes were applied to the farmer data (i.e., theory-driven – generating codes based on variables of the Decomposed Theory of Planned Behaviour)[20]. Emerging codes were applied to the stakeholder data, resulting in the use of codes generated from the language of the stakeholders. In the third phase, themes were established using a collated list of codes after successfully assigning codes to relevant information in the data set. At this stage, codes were sorted and organised into overarching themes. For instance, some of the extracted codes were clustered to form a potential theme on perceived attitudes about renewable energy use in agriculture.

In the fourth phase, the overarching themes formed from clustering codes were reviewed and refined before arriving at the final themes. The process was conducted by thoroughly examining codes grouped under distinctive themes. In the process, some potential themes were merged while others were discarded. This ensured themes had a coherent pattern from their originating codes. The final themes were developed in the fifth phase to analyse the data. In arriving at the final themes, the key consideration was defined by the core aspect each theme would address. This phase aimed to ensure that the final themes were not complex or too diverse.

To ensure participants' anonymity and confidentiality, anonymised codes were used to illustrate participants' views, as guaranteed in the informed consent. Farmer participants 1, 2, 3… were used to illustrate farmers. Non-farmer stakeholders were illustrated as stakeholders 1, 2, 3, and their respective institutions.

6.8 Results

The qualitative research aimed to 1) determine additional factors influencing farmers' intention to adopt renewable energy in Ghanaian agriculture and 2) examine the contributing role of non-farmer stakeholders influencing farmers' adoption of

[20] The Decomposed Theory of Planned Behaviour (DTPB) is expatiated in Chapter 3 of the systematic review.

renewable energy in Ghanaian agriculture. A comparative analysis of the results from farmers and non-farmer stakeholders was conducted using thematic analysis.

6.8.1 Farmers

Data from the farmer research was analysed across three thematic areas: 1) Farmers' attitudes towards renewable energy technology, 2) Farmers' perceived subjective norms about renewable energy technology, and 3) Farmers perceived behavioural control over renewable energy technology. Appendix F provides a summary of thematic areas that emerged from the data.

Farmer participants included males (n=22) and females (n=14) with ages ranging from 25 to 70 years (see Table 6.2). The majority of the farmers (n=28) had no form of formal education. A farmer's household had an average of 6 members. Farmers cultivated 5 acres of farmland on average for food and subsistence. Major crops grown included maize, groundnuts, millet, and vegetables. Livestock reared by most farmers were goats, fowls, and pigs. Farmers use a mix of farm energy for farming, including fossil fuels and conventional human resources. In terms of renewable energy, solar and biomass energy were used for farming. Solar energy was used in two ways: 1) conventional methods of drying crops in the open relying on the heat from the sun and 2) technologically enhanced forms like solar water pumps. Biomass energy was used as organic matter from farm waste to make manure. Generally, energy was used for diverse farming activities such as ploughing, planting, irrigation, harvesting and drying.

Farmers	Male (n=22)
	Female (n=14)
Education	Formal education (n=8)
	No education (n=28)
Age	Age range (25 to 70 years)
Farm size	Average farm size (n=5)

Table 6.2 Farmer demographic characteristics

Source: Author's construct (2023).

6.8.1.1 Farmers' attitude towards renewable energy technology

Here, attitude refers to a farmer's positive or negative sentiments towards renewable energy technology for farming. Attitudes identified include perceived ease of use, perceived usefulness, and perceived compatibility with farmers' farming characteristics.

Perceived ease of use:

Farmers' perceptions of the applicability of renewable energy for farming were explored. Renewable energy was perceived as easy to use. For example, farmers perceived that as the solar water pump was often pre-installed and did not require any complex configuration before its use, it was easier to use compared to manual irrigation using handheld buckets.

"The solar water pump is less stressful when you compared to others like the manual way of fetching water with a bucket. We always get very tired using buckets to fetch water for our farms". – Farmer Participant 30.

Farmers expressed the view that they have a high likelihood of adopting a renewable energy technology that is not complex and requires less effort to adopt. Renewable energy technologies perceived to be difficult to use will be less likely to be adopted by farmers.

Perceived usefulness:

Solar energy was perceived to be useful for farming since there were many associated perceived economic benefits. For example, farmers believed using a solar water pump to be cheaper than diesel- or petrol-powered pumps. Farmers explained there was no operational cost in using the solar water pump, unlike other water pumps that required a farmer to buy diesel or petrol regularly.

"I have come to realize that the diesel machine is more costly to use than the solar pump. We spend more on buying diesel before we are able to use the water pump. So, days that you don't have money to buy enough diesel it becomes very difficult to use the diesel water pump". – Farmer Participant 27.

"We all will be happy to use it [solar water pump] for our agricultural works since it is good especially the fact that it will reduce the amount of money, we spend on buying diesel before we can irrigate our farms". – Farmer Participant 33.

Farmers perceived that renewable energy had the potential to expand the cultivation area and increase farm yields and income. Solar water pumps were perceived to enable farmers to expand the growing area under irrigation, especially in the minor farming season when there was minimal or no rain.

"Well, I know using the pump to irrigate a bigger portion of my land will enable me to increase my farm yields and also enable me make more income from the farm". – Farmer Participant 10.

Inorganic fertilisers constitute an essential component of farm inputs for farmers. The increasingly high cost of inorganic fertilisers was perceived to affect farm operational costs negatively. Organic fertiliser from biomass energy was perceived by farmers to represent a useful, locally produced substitute or complement to inorganic fertilisers, minimising the cost incurred solely relying on inorganic fertiliser. In addition, organic fertiliser or compost provides nutrients for soil and crops which addresses the issue of loss of soil fertility affecting farmers.

"…due to the high cost of fertiliser I now use compost I prepare from crop residues and also animal waste". – Farmer Participant 4.

Increased farm yields and income primarily drive the motives of farmers' use of a particular renewable energy technology.

Perceived compatibility:

Farmers perceived biomass energy to be compatible with their existing farming system. Farmers practised mixed farming that included a combination of crop cultivation and livestock rearing. Therefore, it was convenient for farmers to obtain organic matter for biomass energy, from farm waste, such as crops and animal residues. The process involved creating a dugout (digging a pit) and filling it with crop and animal residue. The content in the dugout was later removed and used as compost or manure for the farms. The local term for this process is known as 'kwoli'.

"…we normally dig a pit and bury the farm waste after harvesting for a period and unearth it and apply the content as manure on the farm". – Farmer Participant 25.

"It is the compost we prepare from the crops and livestock residue that we use as manure to apply in our farms". – Farmer Participant 29.

Farmers will use renewable energy technology for farming because it is compatible with their (traditional) farming system. Using a new technology that does not threaten existing cultural farming practices may result in widespread adoption.

6.8.1.2 Farmers perceived subjective norms about renewable energy technology

Subjective norms were defined as the “social pressures a farmer was perceived to be under that influenced their intention to adopt renewable energy for farming”. Two forms of subjective norms were identified, namely peer influence and superior influence.

Peer influence:

Farmers reported that using renewable energy for farming was, shaped by the influence of peers and close relations. Farmers directly influenced each other through advice and encouragement. Through peer influence, farmers gained awareness and learned about the benefits of using solar energy for farming.

"…it is possible for friends who also farm to influence me because we all look out for each other and advise each other on best farming practices that will benefit us". Farmer Participant 24.

"…I think my friends who are also farming can influence my adoption of the solar technology depending on the way it will benefit us". Farmer Participant 35.

Farmers perceived that they were under pressure to adopt renewable energy technology when their peers used it and obtained benefits like increased farm yields and income.

"…if many of my colleague farmers are using the technology and I see that they are benefiting I will also have to try to use it so that I can also benefit. It will be against me if I realise that there is a good practice that my colleague farmers are adopting, and I will reject it. That means they will always get good yields and I will not get any good yields at the end of the harvest". – Farmer Participant 2.

At the household level, the spouses of farmers influenced the adoption of renewable energy for farming. Female farmers were mainly influenced by their husbands to adopt renewable energy technology. The husband or male figure was frequently identified as the head of the household. Household assets, including farms, were controlled by the household head. Most often, farming decisions were taken by the household head.

"My husband is the head of the house, and we farm together under his leadership, so if he says we should use a particular practice/technology [renewable energy], that is what we will use because at the end of the day he also wants us to get a good harvest". – Farmer Participant 22.

The behaviours and beliefs of friends and family contributed to farmers' likelihood of adopting new technology. Additionally, farmers are observant and habitually monitor what other farmers practice. This process establishes contact and interactions, thereby leading to information and knowledge sharing among farmers.

External influence:

Farmers were influenced by superior or external dynamics within the farmers' wider society. Farmer-based associations, the municipal agriculture department, and non-governmental organisations influenced farmers' likelihood to adopt renewable energy technology for farming. Farmers belonged to farmer associations and were consequently guided by the group's decisions. In such instances, the group's approval influenced farmers' likelihood of adopting a renewable energy technology for farming.

"...maybe the farmer group I belong to can influence my decision because if there is a collective decision to adopt the renewable technology and I also know it will be beneficial to me I will be encouraged to also adopt". – Farmer Participant 28.

The municipal agriculture department was perceived to influence farming activities through its extension agents. Farmers reported relying on extension agents to learn new and improved farming production methods. Through this interaction, farmers noted the high probability of extension agents influencing their decision to adopt renewable energy for farming.

"…maybe the agriculture officers [Extension agents] can encourage me to use the technology and use it effectively because they teach us a lot of good practices to use on our farms…". – Farmer Participant 10.

6.8.1.3 Farmers perceived behavioural control over renewable energy technology

Perceived behavioural control is here referred to as conditions perceived by farmers that make it easy or difficult to adopt renewable energy technology for farming. Self-efficacy, technology-facilitating conditions, and resource-facilitating conditions influenced farmers' adoption of renewable energy.

Self-efficacy:

Adequate information, awareness, education, and training were perceived to be needed so that they could personally adopt a renewable energy technology for farming.

"I think that if I am given the proper training on how to operate the solar technology, I will be able to use it alone and use it effectively". – Farmer Participant 2.

"I can adopt renewable technology if I am given the necessary training and support like the way we have been trained to operate the solar pump that was installed for us". – Farmer Participant 4.

Farmers are more likely to adopt renewable energy technology for farming when they have the relevant knowledge and experience. These conditions contribute to building the capacity of farmers to enable them personally to adopt renewable energy technologies.

Technology facilitating conditions:

Farmers discussed the technological conditions of renewable energy technology perceived to control their adoption behaviour. Renewable energy technology's durability and resilience to wear and tear were important when considering its adoption. Farmers believed the solar water pump was durable when compared to petrol- or diesel-powered water pumps.

"…I also think that the machine [solar water pump] is durable and will not need to go to the repairer after every use. As for my diesel pump, it is quite old, so it gets faulty frequently when I use it for long". – Farmer Participant 1.

The availability and accessibility of spare parts represented a condition for farmers who considered adopting renewable energy technology. Farmers believed that renewable energy technology would not be sustainable without spare parts and expertise.

"Sometimes I look at the machine's durability before buying and whether it is easy to repair in case it gets faulty. But looking at the solar pump, I think it will be difficult to repair in case it gets faulty…in this our area I don't know of anyone who can repair solar machines…maybe unless we travel to Wa [Upper West regional capital] to find a repairer". – Farmer Participant 16.

Resource facilitating conditions

Farmers identified “enablers” that impacted their ability to use renewable energy technology for farming. For example, the availability of sunshine was needed to adopt solar energy for farming. Farmers relied on the sun to dry farm produce after harvest and power solar water pumps for crop irrigation.

"Well, you know the solar machine depends heavily on sunshine. For instance, in the rainy season if you have not had sunshine for some number of days, I don't think you will be able to use it. Even with our small solar panel we use at home sometimes in the raining season, it does not function fully". – Farmer Participant 6.

"…with what I have seen about this renewable energy, its main problem is whether there is sunshine or not…but in this our area we always get regular sunshine unless maybe in the rainy season". – Farmer Participant 16.

The cost of procuring a renewable energy technology negatively affected farmers' adoption behaviour. According to the farmers, lack of capital and high cost impeded their likelihood of adopting renewable energy technology for farming.

"…I just don't have the money to personally procure one [solar water pump] at the moment. It is always about the lack of money. That is one of our major problems as farmers. We don't make much after we harvest so how can we buy some of these new technologies unless we are supported by the government". – Farmer Participant 8.

"…I don't have that money to do that…maybe I can also personally buy the pump [solar water pump] in the future when I have the funds…but as we sit here I don't have money to buy it because I think it will be expensive and beyond my financial strength…". – Farmer Participant 6.

Given farmers perceived the high cost of renewable energy technologies and a lack of capital, logistical support was perceived to influence farmers' likelihood of adopting a renewable energy technology for farming. Logistical support was often received from non-governmental organisations.

"I do not have the financial strength to be able to afford the kind of technology we were given…as I said earlier, the one [solar water pump] we have currently, was given to us by a group of people". – Farmer Participant 21.

Overall, farmers are not averse to adopting renewable energy for farming. However, adoption depends on conditions that are perceived to control their adoption process. Farmers are most likely to adopt renewable energy technology for farming when they perceive that the broader stakeholder community provides adequate resources like capital, logistics, information, education, and training. These resources enable farmers to overcome barriers that inhibit the adoption of new technologies.

6.8.2 Non-farmer stakeholders

Three thematic areas were developed in the analysis of the stakeholder data: 1) non-farmer stakeholders' perspective on renewable energy use in agriculture, 2) Drivers and barriers to farmers' adoption of renewable energy in agriculture, and 3) the role of non-farmer stakeholders in promoting farmers' adoption of renewable energy use in agriculture. Appendix X provides a summary of thematic areas that emerged from the data.

Seven stakeholders were identified and interviewed. The stakeholders were drawn from different sectors, including research, government agencies, non-governmental organisations, and the private sector and industry. All had a focus on promoting the development of renewable energy and integration in economic sectors, including agriculture.

6.8.2.1 Non-farmer stakeholders' perspective on renewable energy use in agriculture

Fossil fuels provide the basis for energy use in Ghanaian agriculture compared to renewable energy (Energy Commission, 2019a; Karbo *et al.*, 2022). Non-farmer stakeholders believed there was a good prospect of using renewable energy in agriculture. In particular, solar energy was regarded as possible because of sunlight availability throughout the year and in different geographical locations, including rural areas where agriculture was the dominant economic activity.

"About 95% of the energy sources is the fossil fuels… solar energy is ideal, but the technology is not that widespread. Depending on the kind of value chain activity that the farmer is going to do, we normally encourage dry season farmers to use solar pumps, but they are not widespread and just a few uses it". – Non-farmer stakeholder 2 [Peasant Farmers Association].

"…we have taken time to explore the opportunities and have settled on solar. We have so far experimented or done preliminary work and trials in our farms, and we have marked several other farms that are being prepared and hopefully, by the end of the year, work on those sites will be commenced. We are also considering solar for some warehouses as I have already mentioned…to a very large extend, we would want to explore all possible means of using solar to the best in the whole agricultural value chain". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

Potential mechanisms to harness renewable energy in rural agriculture were identified. Renewable energy technologies should be tailored to suit specific characteristics of farming communities (i.e., at a smaller scale of application, which can be operated and maintained at a community level). That way, the technologies become relevant to the peculiar agricultural needs of farming communities.

"For some people like the government, they might take it that developing small-scale technologies for rural communities might not be efficient so they would call for large scale mainframes but for us, to be able to access penetration in the local communities and provide affordable technologies, we look at the small-scale technologies for communities. So, solar lanterns, at least 1 to maximum of 5kilowatt

systems, solar generators; the one with inbuilt inventors and then solar water pumping systems for farmers who are farming between 1 to 5 acres of land. We have solar driers for the farmers, to dry their crops". – Non-farmer stakeholder 4 [Institute for Sustainable Energy and Environmental Solutions].

Despite the dominant use of fossil fuels in the Ghanaian agricultural sector, stakeholders perceived there is potential for using renewable energy in agriculture. What will spread technology adoption was perceived to require the implantation of an approach that introduces farming communities' renewable energy technologies, which are relevant to their agricultural needs, farmers will likely find these technologies useful and directly address their farming needs.

6.8.2.2 Drivers and barriers to farmers' adoption of renewable energy in agriculture

Economic factors were perceived to affect renewable energy adoption in agriculture since most renewable energy technologies had an initially high cost. Therefore, farmers who could not afford this cost were less likely to adopt renewable energy technology for farming.

"The greatest [barrier] for me will be the financial or economic factor…they [farmers] do not get much support, it is capital intensive because the initial cost is high and individual farmers may not be able to afford on individual basis. So, for me the economic factor will be key". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

"…the initial cost of purchasing this renewable energy is high and some [farmers] too do not have the financial muscles to get loans and purchase it. Also, some of them also see the payback period as long for them and they want something that is quick and soon". – Non-farmer stakeholder 3 [Municipal Agriculture Department].

"…we have it [biogas systems] for farmers but the cost involved is what is deterring them from accessing the technology because most of them are small scale farmers. And as we know small scale farmers do not have enough money to acquire these types of technologies. Perhaps unless they are supported by some charitable organisations maybe like NGOs [non-governmental organisation]". – Non-farmer stakeholder 5 [DAS Biogas].

Incentives and subsidies were perceived to be enablers or facilitators which promote the adoption of renewable energy technologies among farmers. Developers and providers of renewable energy technologies could be incentivised to develop suitable payment modes for end-users like farmers, mitigating the impact of procuring renewable energy technologies at an initial high cost to farmers.

"…incentives either to the suppliers so that they can do a pay as you go services so that they can produce more because most of our rural people do not have the financial strength to purchase these technologies. This will enable them to give it to the households or the people and allow them to pay over instalment". – Non-farmer stakeholder 4 [Institute for Sustainable Energy and Environmental Solutions].

Stakeholders reported that they thought farmers perceived their peers who independently used renewable energy for farming as financially well-resourced because of the high initial cost component. As a result, such farmers were most likely discriminated against by leaders of farmer associations when external support was provided to farmers. Due to this perceived discrimination, farmers were sceptical about independently adopting renewable energy technologies.

"…once you are a smallholder farmer and you begin to adopt or introduce such technologies, people will assume that you are well-to-do and further support may not come if you are doing that as an individual. So, the social risk involved is that people will tag you as a well-to-do farmer because if you are not, you may not be able to bear the initial cost to go into it". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

Another sociocultural factor that was perceived to affect renewable energy adoption negatively was the perceived notion that renewable energy adoption fell within the decision-making domain of male farmers. This assumption, held by stakeholders, was entrenched in customary norms and values that empowered male farmers to oversee all household assets, including farms.

Also, the gender dynamics come into play, where we think that men are in a better place to adopt solar than women. Some cultural believes and customs also come into play". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

The role of traditional and opinion leaders in farming communities was identified to influence farmers' adoption of renewable energy. According to the stakeholders, traditional leaders in rural communities could approve or disapprove of a new technology based on traditional values and heritage.

"…basically, traditional leaders or opinion leaders or the community protocol should agree with the technology otherwise the people are not using it because their traditions, customs does not support it. You should also have an environment of smart working people. Behaviour comes into play and community leaders influence comes into play on the general acceptance". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

Non-farmer stakeholders also perceived demographic factors to influence the adoption of renewable energy technology for farming. These included age, gender, education, income, and access to the market.

"Whether the farming is for subsistence or commercial, you need to factor in the level of education, age, gender of the farmer which are all crucial. Again, you need to factor in the farmer's level of income, access to credit, access to market and even cost of the energy itself compared to other energy sources and also access to extension services. These and many others are all crucial aspects that can promote adoption of the technologies". – Non-farmer stakeholder 2 [Peasant Farmers Association].

The availability of resource conditions was identified as potentially influencing farmers' adoption of renewable energy. Without resources, stakeholders perceived that it was unlikely for the technologies to function.

"The first requirement is to have a high yielding water source. Even if you have a borehole, it should be able to yield a certain amount of water. Apart from that, there need to be a water collection point, it could be a poly tank that you would need which answer to the cost of the plant itself. You would need solar panels, batteries, channels through which you can irrigate the farm. In addition to that, you will need a fenced area to protect your poly tank, batteries, and other systems". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

Overall, the drivers and barriers affecting farmers' adoption of renewable energy technology were multi-faceted, supporting the notion that several factors interplay in the sequence of technology diffusion. Therefore, explaining technology adoption will require a consideration of a wide array of interrelated factors.

6.8.2.3 Role of non-farmer stakeholders in promoting farmers' adoption of renewable energy use in agriculture

The stakeholders included in the research reported that they promoted various forms of energy, in particular renewable energy. Smallholder farmers represented the primary target group to which renewable energy use in agriculture was promoted, while at the same time identified as an under-resourced group.

"The focus is on the smallholder farmers because they are the ones we work with, and they are more disadvantaged. There are some commercial farmers that are using solar but within the northern sector here, we have abundance of the sun and that's one advantage we can rely on. So, our focus is on the smallholder farmers because they do not have the resources so if we are able to build a sustainable system like the solar for them, we would be doing them a great deal of good but for commercial farmers, I believe they have more other options that they can explore". – Non-farmer stakeholder 6 [Centre for Indigenous Knowledge and Organisational Development].

Renewable energy use in agriculture was thought to gain traction and attention in Ghana and other LMIC economies. The generation of various renewable energy technologies propelled the development. Renewable energy technologies include solar dryers, water pumps, and solar coolers.

"…for agriculture we have solar water pumping and irrigation technologies, solar thermal technologies, some that we are developing ourselves and others we do for, solar coolers which we are exploring and doing more research into and then we have solar driers. Then we have the clean cookstoves of different kinds for households and institutions or agro-processing industries like fish smoking, shea butter processing, for roasting, for gari roasting, palm oil processing…". – Non-farmer stakeholder 4 [Institute for Sustainable Energy and Environmental Solutions].

Various activities aimed at integrating renewable energy into Ghanaian agriculture were identified, including research to scale up renewable energy adoption, pilot and mainstream renewable energy technology application projects, and events and fairs to showcase and publicise renewable energy technologies. Most often, pilot programmes served as demonstration platforms for farmers to obtain first-hand experience with renewable energy technologies.

"We have a project called Remotely Controlled Solar Irrigation System using a mobile device, and our main aim is to introduce technology into how we go about our

farming…this application remotely controls the system, so the farmer does not have to go to the farm every day to irrigate the crops. So, the app has been developed and tested on a 1-acre demonstration field… So, we have one on the demonstration site, thus, the 2kilowatt system…" – Non-farmer stakeholder 1 [Institute of Industrial Research].

"When it comes to promotion, it depends on the kind of programme you are running. So, one of the promotions we usually do is the Ghana Renewable Energy Fair. So, with this fair, we bring all the industry players on board then we discuss issues pertaining to the industry [Renewable energy]". – Non-farmer stakeholder 3 [Energy Commission].

National policies were perceived by non-farmer stakeholders to be instrumental in promoting renewable energy development. Although these policies primarily focused on renewable energy development in the areas of residential housing and transportation, there were strategies that could promote the application in agriculture. However, these policies often met with implementation and financing problems.

"Yes, there are a number of such policies. We have the Ghana Renewable Energy Policy which has been revised, we have the Renewable Energy Act policy, the Bio-energy policy but this is in the draft stage, Sustainable Energy forum plan that is from 2012, the Renewable Energy Master Plan that has been developed, Clean cooking strategy, thus the draft one is being developed by the Ministry of Local Government…Government policies are good but when it comes to the aspect of implementation and access to financing is what might be challenging. When it comes to programs, the policies are fast written programmes". – Non-farmer stakeholder 4 [Institute for Sustainable Energy and Environmental Solutions].

Collaborative activities between the broader stakeholder community were key in facilitating the development and application of renewable energy in Ghanaian agriculture. Stakeholder engagement with policy processes and across institutions was reported to facilitate the harmonisation of renewable energy development activities and policies. Collaborations identified included those between government institutions, research and academia, non-governmental organisations, and private sector-led industry players.

"As for this renewable energy thing, a lot of stakeholders are involved. From the government side, I can mention the Ministry of Energy and Energy Commission, the Ministry of Environment, and the Forestry Commission…I can even add the Ministry

of Local Government through to the MMDAs [Metropolitan, Municipal and District Assemblies] …there are development partners like SMB Ghana, GIZ, USAID, UNDP and other local institutions like KITE, KNUST renewable energy centre, UMaT, UNER. There are also some associations like Bio-energy Association, Clean Cooking Alliance, Association of Ghana Solar Industries, Sustainable Energy Network Ghana, and Centre for Energy, Environment and Sustainable Development…so you will come to realise there are various levels of consultations ongoing between the stakeholders". – Non-farmer stakeholder 4 [Institute for Sustainable Energy and Environmental Solutions].

Widespread renewable energy integration in agriculture was thought to be attainable given the forms and extent of contributions from the various stakeholders. At the same time, stakeholders were thought to require government input through effective policy formulation and implementation. The government's inputs are expected to catalyse an enabling environment to sustain the impact of the roles played by stakeholders.

6.9 Discussion

The research findings are discussed by comparing the perspectives of farmers and non-farmer stakeholders. The discussion focuses on potential motivations, enablers, and barriers to farmers' adoption of renewable energy in Ghanaian agriculture. The role of the broader stakeholder community in improving farmers' adoption of renewable energy in agriculture in Ghana is further discussed.

6.9.1 Motivations for farmers' adoption of renewable energy in agriculture in Ghana

Renewable energy in Ghanaian agriculture was not found to be widespread compared to the use of fossil fuels. However, all stakeholders, including farmers and non-farmer stakeholders, perceived good prospects for renewable energy use in the Ghanaian agricultural sector. There was considerable agreement between smallholder farmers and other stakeholders who regarded renewable energy, including solar and biomass, as potential energy sources for agriculture because of the abundance of sunlight and biomass resources. Both farmers and non-farmer stakeholders noted that a renewable energy technology was likely to be adopted based on three motivating factors: 1) perceived usefulness, 2) perceived ease of use, and 3) perceived compatibility. For example, a farmer most likely adopts a solar water pump because it is perceived to improve farm operational costs and increase yields and farm income (see also Masere and Worth (2022) and Dzvene *et al.* (2022)). Farmers are believed to make choices of agricultural technologies that guarantee superior benefits (Ogunlana, 2004). It is, therefore, important for researchers to demonstrate the benefits of using renewable energy technology for farming. By doing so, farmers, especially non-adopters, will tend to form positive perceptions and attitudes towards renewable energy use in agriculture.

Both farmers and non-farmer stakeholders perceived that an easy-to-operate technology could motivate farmers to adopt it. For example, the results indicate that a farmer was likely to adopt a solar water pump for irrigation if it was perceived to be easy to use (see also Nyairo *et al.* (2022)). This phenomenon indicates that renewable energy technologies should be developed with easy-to-operate features to enable farmers to easily use and obtain optimal benefits from the technologies.

According to farmers and non-farmer stakeholders, renewable energy adoption by smallholder farmers is the compatibility between the technology and the farming system used by the farmer. A farmer may be motivated to adopt biomass energy for farming because it is perceived to be compatible with their existing mixed farming agronomic practice. Farmers have been reported to adopt biological control and soil conservation technologies because of the perceived compatibility with existing farming (Sharifzadeh *et al.*, 2017; Junge *et al.*, 2009). When considering technology adoption, it is relevant to consider alignment with farmers' sociocultural values and beliefs, previously introduced practices, and what the farmers themselves perceive as a necessary need for the technology (Rogers, 2003; Adegbidi *et al.*, 2012).

6.9.2 Enablers and barriers to farmers' adoption of renewable energy in agriculture in Ghana

Both farmers and non-farmer stakeholders believe the adoption of renewable energy technologies may depend on various enablers or barriers to the adoption process, and potentially the interrelationship between these (Eidt, Pant and Hickey, 2020; Yerebakan *et al.*, 2022). Farmers and non-farmer stakeholders have identified social, economic, and technological barriers and enablers that could potentially determine the adoption of renewable energy technology in Ghanaian agriculture.

Peer influences on farmers' adoption behaviour are often initiated from interactions with family, friends, peer group members and neighbours (Tran-Nam and Tiet, 2022). Peer influence has been found to be a major influence on-farm practice and technology adoption (Tran-Nam and Tiet, 2022; Kante, Chepken and Oboko, 2018; AE *et al.*, 2017; He *et al.*, 2023; Niu *et al.*, 2022; Zhou *et al.*, 2020). A farmer may likely learn about renewable energy technology through peer influence, such as interpersonal communication, thereby acquiring information about its existence, enabling farmers to fill information gaps and minimise or dispel uncertainty regarding renewable energy technology (AE *et al.*, 2017).

The gender dimensions embedded in smallholder agriculture were also identified in relation to agricultural decision-making, in particular assuming that this is entrusted to male household members. (Bonabana-Wabbi, 2002; Mwangi and Kariuki, 2015; Mignouna *et al.*, 2011; Fisher and Carr, 2015). Creating novel approaches to ensure that women have equal voices in decision-making and can engage equally in policy processes is required. Possibly, achieving this may require policymakers to focus on empowering female farmers with the ability to 1) make choices in relation to agricultural production, 2) control over resources and assets including land, 3) generate alternative income streams, 4) undertake leadership participation and inclusion, and 5) determine time for farm work and household responsibilities as enshrined in the Women's Empowerment in Agriculture Index (WEAI) (Haug *et al.*, 2021; Kabeer, 1999; Alkire *et al.*, 2013; Sell and Minot, 2018).

Farmers and non-farmer stakeholders believe agriculture extension agents can influence farmers' adoption behaviour (Makate and Makate, 2019). Extension agents have been reported to have a considerable influence on farming practices and the adoption of technology (Langyintuo and Mekuria, 2008; Akudugu, Guo and Dadzie, 2012). This implies that extension agents can be the intermediaries between farmers and suppliers of renewable energy technologies, as extension agents can effectively introduce and disseminate information on renewable energy technology due to their frequent contact with farmers and understanding of the farming environment (Sserunkuuma, 2005; AE *et al.*, 2017).

Stakeholders considered traditional leaders another external interaction likely to influence farmers' adoption behaviour. Traditional leaders are custodians of cultural traditions in rural farming communities, ensuring new agricultural technologies conform to customary norms and values (Yengoh, Frederick and Svensson, 2009; Tanko, Muhammed and Ismaila, 2023). The influence of traditional authority on farmers' adoption behaviour suggests that all stakeholders, including those within the policy community, need to form collaborative partnerships with traditional leaders when introducing new technologies.

In relation to economic factors, farmers and non-farmer stakeholders believe the (perceived) high cost of renewable energy technology is likely to influence a farmer's adoption behaviour. The perceived cost of technology introduction has been found to be an influential factor (AE *et al.*, 2017; Kinyangi, 2014; Hartshorne and Ajjan, 2009; Zolait, 2014; Agostini, Colauzzi and Amaducci, 2021; Kumar *et al.*, 2023; Elahi, Khalid and Zhang, 2022).

While high technology costs can act as a barrier to farmers' adoption of renewable energy technology, incentives and subsidies can act as policy enablers or levers to mitigate this. Introducing incentives and subsidies can substantially reduce the final cost of renewable energy technologies for farmers, thereby becoming more affordable(Banks, Salter and Chesshire, 2007; Rahman *et al.*, 2022; Khan, 2020; Bangalore, Hochman and Zilberman, 2016). To ensure incentives and subsidies benefit farmers' adoption of renewable energy technologies, robust policy mechanisms in the form of tax reduction or exemption and financing schemes are required (Karbo *et al.*, 2022; Kumar *et al.*, 2021). This can enable farmers to reallocate financial resources to other vital sectors of the household (Olwande, Sikei and Mathenge, 2009; Lavison, 2013).

Perceived availability of spare parts, market accessibility, and technology durability were also found to influence sustainable energy adoption (see also Ghimire and Huang (2016) and Olwande, Sikei and Mathenge (2009)). This means that a market perceived to be far by farmers and entails a high travel cost due to long geographic distances can be a disincentive to farmers to likely adopt (AE *et al.*, 2017).

6.9.3 Improving farmers' adoption of renewable energy in agriculture in Ghana – The role of the broader stakeholder community

The contributions of the broader stakeholder community in promoting the adoption of agricultural technologies are important (Testa *et al.*, 2022; Mutoko, Shisanya and Hein, 2014). Stakeholders who have an interest in technology adoption may also act to promote adoption (Smitha and Devi, 2018; Vincent and Balasubramani, 2021), including within sub-Saharan Africa (Otieno *et al.*, 2021). Members of the broader stakeholder community can act as a bridge linking farmers to adopt agricultural technologies (Schut *et al.*, 2014; Westermann *et al.*, 2018). For example, through delivering education and training for farmers and providing credit, financing schemes, and logistic support, farmers may develop the capacity to adopt renewable energy technology for farming (see also Flor *et al.* (2020)).

Coherent policy framework(s) that can lead to developing and applying renewable energy technology in farming is required. Policies represent an instrument in relation to agricultural technology adoption (Hellin *et al.*, 2020; Jayne *et al.*, 2018; Kumar *et al.*, 2021; Makate and Makate, 2019). Although policies supporting renewable energy development exist in Ghana, stakeholders note the presence of implementation gaps, particularly in relation to policy financing. There is also (see also Karbo *et al.* (2022)) indicating the lack of a central policy on renewable energy integration in Ghana's agricultural sector. Therefore, an agricultural sector-led sustainable energy policy that encompasses policy levers, including subsidies and incentives, requires attention from Ghanaian policymakers.

Stakeholders consider institutional collaboration a useful mechanism that can be relied on to support the adoption of renewable energy for farming (Podestá *et al.*, 2013). Typically, stakeholder collaborations entail government agencies, development or donor partners, non-governmental organisations, farmers, researchers, and academia. Institutional collaborations foster co-production and stakeholder engagement whereby stakeholders jointly deliver services and products to facilitate farmers' adoption of renewable energy technology. For example, the research found existing collaborations among stakeholders that contributed to the adoption of renewable energy technology in farming. Correspondingly, previous research found that institutional collaborations significantly accounted for farmers' adoption of agricultural technologies (Yamoah *et al.*, 2020; Adekunle and Fatunbi, 2012; Wang *et al.*, 2020; Hermans *et al.*, 2017; Testa *et al.*, 2022; Mutoko, Shisanya and Hein, 2014). The above development implies that strategic collaborations can contribute immensely to ensuring farmers receive appropriate support regarding technology adoption.

The stakeholder research findings illuminate primary assumptions in relation to stakeholder and institutional theories. Stakeholder theory describes how groups or members are interconnected by an interest in creating value around a mutual goal (Freeman *et al.*, 2010). Following the research findings, the stakeholders have a joint interest regarding sustainable energy adoption in farming, which is achieved through value creation through the organisation of training, pilot demonstration, logistic support, policy initiatives and institutional collaborations. Institutional theory focuses on the extent to which social structures, including norms, traditions, and practices, are established and adopted as standard social behaviour (Janssen and Nonnenmann, 2017). By this definition, agriculture is a social institution encapsulating norms and practices and social and organisational players. These players include farmers and non-farmer stakeholders (i.e., researchers, policymakers, non-governmental organisations, and development and donor partners). Among these social and organisational players, an interconnected mutual interest leads to the co-production of activities to promote sustainable energy application in agriculture. Observable norms and practices under the social structure of smallholder agriculture suggest less inclusivity of female farmers in the decision-making process. Drawing from institutional theory, it showcases the role of social structures and organisational players in adopting renewable energy in Ghanaian agriculture.

6.10 Conclusion

Renewable energy is not widely adopted for farming. Nevertheless, there was a good prospect for its application in Ghanaian agriculture. Farmer and non-farmer stakeholders agreed that various factors influenced farmers' likelihood to adopt renewable energy for farming, many of which were psychological or economic. These included perceived usefulness, ease of use, and compatibility with existing farming systems. Social, economic, and technological factors represented enablers and barriers to adopting renewable energy technology.

A broader stakeholder constituency contributed to and influenced farmers' adoption behaviour. Policies and institutional collaborations contributed to the roles played by stakeholders regarding renewable energy promotion and adoption for farming. Notable policy gaps, for example, were in relation to subsidies and inadequate finance regimes. It was concluded that further research into effective policy development and implementation is needed, which entails coproduction and engagement across all interested stakeholder groups, including the farmers.

Some of these results are reflected in the primary assumptions underpinning the Decomposed Theory of Planned Behaviour, which stipulates psychological factors (i.e., attitude, subjective norms, and perceived behavioural control) can predict adoption behaviour. This will be considered further in the empirical survey work presented in the next chapter.

6.11 Summary

Various psychological factors were identified that affected farmers' adoption of renewable energy technologies. These psychological factors, when deconstructed, were found to be moderated by farmer beliefs, including 1) Attitude-(perceived usefulness, perceived ease of use, and perceived compatibility), 2) Subjective norms-(peer and superior influences), and 3) Perceived behavioural control – (self-efficacy, technology facilitating conditions, and resource facilitating conditions). Economic factors (potentially described as “rational” economic decision-making) were also reported to be important.

Chapter 7. Psychological Determinants of Farmers' Adoption of Renewable Energy Technologies in Ghanaian Agriculture

7.1 Introduction

This chapter describes the development, implementation, and analysis of a quantitative survey on a range of factors (derived from qualitative research and systematic review) predicting farmers' adoption of renewable energy technologies for agriculture. A survey of smallholder farmers was conducted in Lawra Municipality in Northern Ghana due to the dependence on farming as the main source of livelihood. A research model (the Decomposed Theory of Planned Behaviour) was adapted and tested using the survey data with the application of structural equation modelling. The Decomposed Theory of Planned Behaviour was identified as an appropriate theoretical approach based on a systematic review of theoretical approaches to farmer technology behaviours in lower-to-middle-income countries (LMICs). Therefore, the systematic review in Chapter 5 informed the theoretical approach underpinning this research.

7.2 Background

The contributing role of agriculture in global development is important as agricultural production provides food for local populations and raw materials for national industries and exports (Meijerink and Roza, 2007; Praburaj, Design and Nadu, 2018; Mehrara and Baghbanpour, 2016; Alston and Pardey, 2014; Diao, Hazell and Thurlow, 2010). In many LMICs, the agricultural sector employs the majority of the workforce (Feder and Savastano, 2017; Gollin, 2014). However, the conditions under which farmers perform agricultural activities are often associated with challenges, including pests and diseases, low levels of mechanisation, and changing climatic conditions such as unpredictable rainfall patterns and drought (Gollin, 2014; Mendelsohn, 2009).

Innovative agricultural technologies may enable farmers to overcome agricultural production barriers and provide an increase in yields and farm profits (Rehman *et al.*, 2016; Boehlje and Langemeier, 2021; Zolkin, Matvienko and Shavanov, 2021). In the Lawra Municipality of Ghana, farmers are encouraged by government and interested stakeholder groups to adopt innovative agricultural technologies, including renewable energy technology, to improve their farming productivity sustainably. At present, there is evidence that renewable energy technology adoption in Ghana for farming is low, and factors which may accelerate farmers' adoption behaviours in relation to these technologies require investigation (Karbo *et al.*, 2022; Asiamah *et al.*, 2022).

Previous research has identified factors which may predict farmers' adoption behaviours regarding new technologies (e.g., see (Kabwe, Bigsby and Cullen, 2009; Obiero *et al.*, 2019; Mogaka *et al.*, 2014; Putra, Czekaj and Lund, 2019a; Nyamwena-Mukonza, 2012; Mapemba, Grevulo and Mulagha, 2013; Mukherji *et al.*, 2017; Mwakaje, 2008). These have been reviewed in chapter 4. Understanding how these factors influence farmers' technology adoption behaviours can help researchers, policymakers, and other non-farmer stakeholders develop interventions to increase farmers' technology adoption (Borges *et al.*, 2014). The research presented in this chapter aims to assess some potential factors influencing farmers' intention to adopt renewable energy technology. Employing quantitative research methodology, the research is designed using a predictive research model (the Decomposed Theory of Planned Behaviour – DTPB) to test potential predictors of farmers' sustainable energy adoption behaviour. The DTPB was identified as a suitable theoretical approach that can predict farmers' adoption behaviour, in the systematic literature review presented in chapter 4. The DTPB was used due to the decomposition of the belief structure which allows researchers to investigate specific factors predicting adoption behaviour (i.e., attitude encompassing perceived usefulness, perceived use, compatibility; subjective norms comprising peer and external influences; and perceived behavioural control entailing self-efficacy, resource and technology facilitating conditions) (Taylor and Todd, 1995b; Ramayah *et al.*, 2009; Nyasulu and Dominic Chawinga, 2019).

Lawra Municipality was selected for the research. Agriculture is the major economic activity in this municipality employing about 80 percent of the working population (Lawra Municipal Assembly, 2018). Agriculture in this area is predominantly undertaken in smallholdings, mainly to provide food for household consumption. Crops cultivated include maize, millet, groundnuts, soya bean and cowpea. In addition, livestock primarily reared include goats, pigs, sheep, poultry, and cattle. Notable challenges of agriculture in Lawra include depleting soil fertility, erratic rainfall pattern, pests and diseases, limited access to credit, and inadequate access to innovative technology, extension services, and markets. This poses a threat to farmers only source of livelihood and food security (Lawra Municipal Assembly, 2018).

Sustainable energy technology can support agronomic practices in Lawra in relation to land preparation activities using biomass energy inputs such as organic fertilisers to improve soil fertility and solar water pump to irrigate crops (Ayamga, Kemausuor and Addo, 2015; Stock *et al.*, 2023). Crop cultivation in Lawra is mainly rain-fed. Therefore, solar water pumps can be useful for irrigation, especially in the dry season when there is no rain. In this context, governments and interested stakeholder groups have introduced sustainable energy options, including solar and biomass, to farmers for adoption into their agricultural practices. It is expected that when farmers use sustainable energy options, agronomic practices will transition from laborious manual methods to mechanised farming, enabling farmers to expand farming acreages, production yields, and household income (Sims and Kienzle, 2017; Aryal, Thapa and Simtowe, 2021).

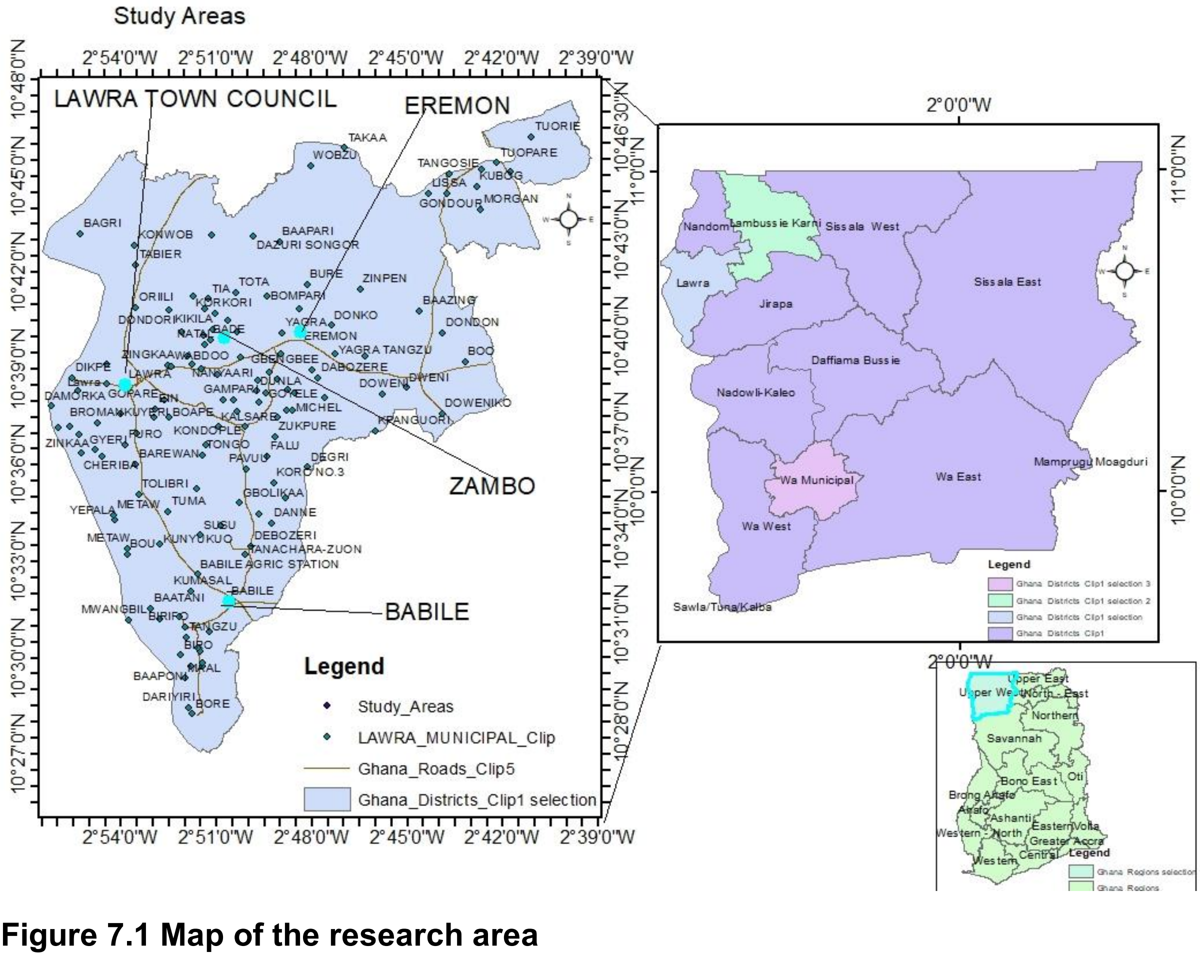


Figure 7.1 Map of the research area

Source: Author’s construct (2023).

7.3 Methodology

The survey (presented in Appendix D) was adapted from the Decomposed Theory of Planned Behaviour. DTPB was developed by Taylor and Todd (1995a) as an extension of the Theory of Planned Behaviour (TPB). The theory assumes that a behavioural intention will likely lead to an actual adoption behaviour and that interacting psychological constructs (attitude, subjective norms, and perceived behavioural control) predict behavioural intention (Alomary and Woollard, 2015; Shao *et al.*, 2022). The DTPB unifies constructs from the Technology Acceptance Model (TAM), Theory of Planned Behaviour (TPB) and Diffusion of Innovations Theory. The DTPB uses constructs of perceived ease of use and perceived usefulness from the Technology Acceptance Model (Davis, 1989); the constructs of attitude, subjective norms, and perceived behavioural control from the Theory of Planned Behaviour (Ajzen, 1991); and compatibility from the Diffusion of Innovation Theory (Rogers, 2003).

The Decomposed Theory of Planned Behaviour deconstructs the belief constructs proposed by the Theory of Planned Behaviour (see Figure 7.2). The TPB has been criticised on the basis of its assumption that attitudes can predict behaviours, which in turn are predicted by subjective norms and perceived behavioural control (Taylor and Todd, 1995a). The DTPB addresses this criticism by decomposing the attitude, subjective norms, and perceived behavioural control constructs. Specifically, attitude is the sentiment developed about a technology which is deconstructed into “ease of use”, “perceived usefulness”, and “compatibility”. Subjective norms are the social pressures that can affect an adoption behaviour emanating from peer and external influences, including family members, friends, chiefs, agricultural extension agents, and institutions. Perceived behavioural control is the perceived ability to perform an action and is decomposed into self-efficacy, resource facilitating conditions, and technology facilitating conditions, including time, money, markets, and technology expertise. The decomposition of the belief structure has been reported to improve the understanding of how specific factors interact to predict adoption intent and behaviour, including in relation to technology adoption by farmers (Nyasulu and Dominic Chawinga, 2019; Taylor and Todd, 1995a)

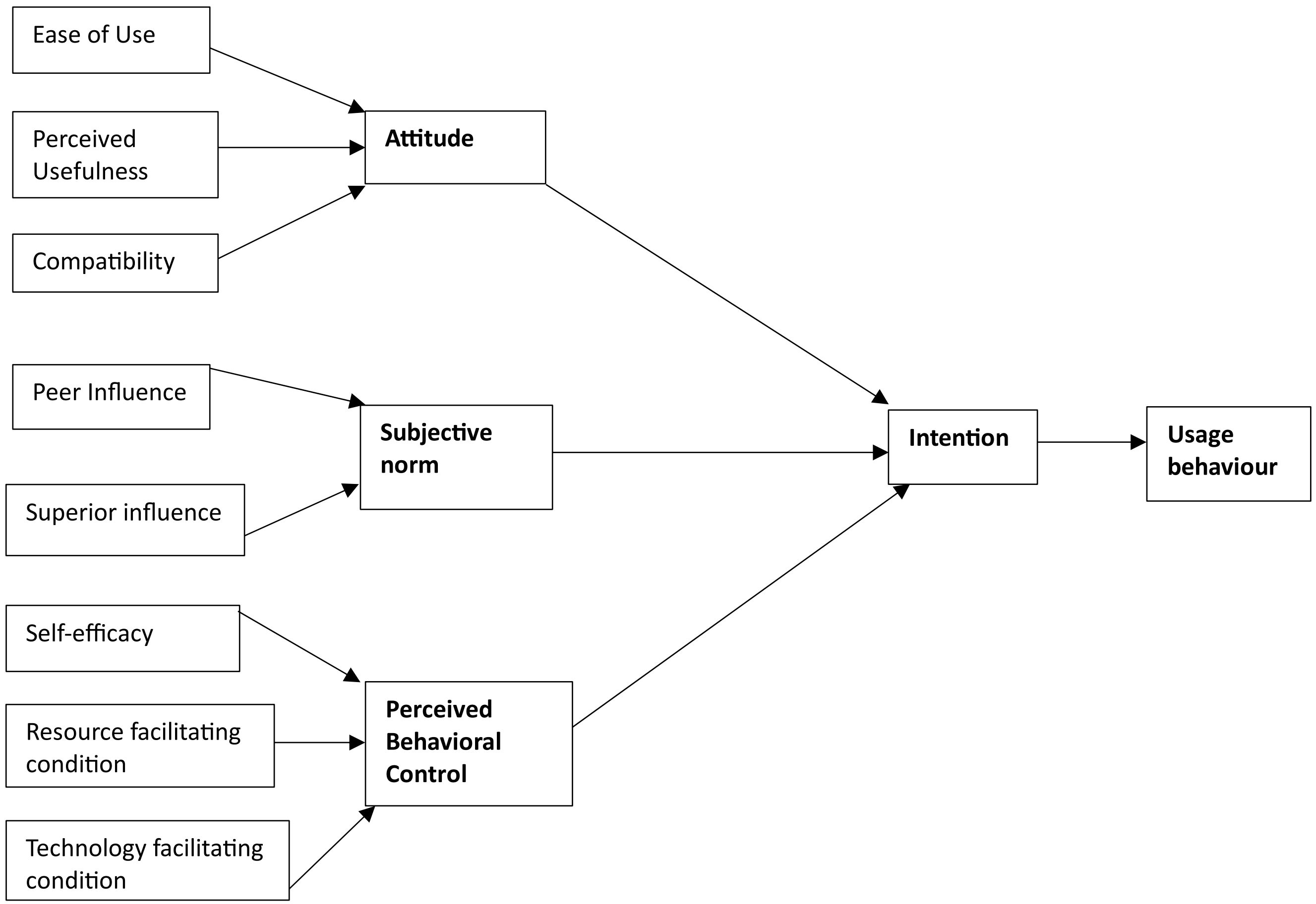


Figure 7.2 Decomposed Theory of Planned Behaviour

Source: Taylor and Todd (1995a).

7.3.1 Definition of constructs and hypotheses

The Decomposed Theory of Planned Behaviour is founded on three primary constructs which are assumed to predict an adoption intention. They are attitude (A), subjective norms (SN), and perceived behavioural control (PBC). According to Fishbein and Ajzen (1977), attitude as a construct refers to the sentiments (positive or negative) an individual develops regarding performing a particular behaviour. Subjective norms are the social pressures that an individual perceives, and that can influence an individual's intention to adopt or reject technology. The perceived behavioural control construct refers to the perceived ease or difficulty in performing an adoption behaviour regarding a technology (see Figure 7.3).

The following hypotheses are proposed:

H1: Positive attitude will positively affect a farmer's intention to adopt a renewable energy technology for farming.

H2: Positive perceived Subjective Norms will positively affect a farmer's intention to adopt a renewable energy technology for farming.

H3: High perceived Behavioural Control will positively affect a farmer's intention to adopt a renewable energy technology for farming.

The three primary constructs, attitude, subjective norms, and perceived behavioural control are decomposed into sub-constructs. Three sub-constructs contribute to the Attitude: Ease of Use, Perceived Usefulness, and Compatibility. Ease of use signifies how a new technology is convenient to understand and operate. Perceived usefulness is the expectation that the new technology improves the outcomes of a task or activity. Compatibility depicts the suitability of the new technology in view of an existing technology or practice. Therefore, it is assumed that a farmer is more likely to adopt a new technology for farming if its application is easy to understand and operate. Likewise, a farmer is more likely to adopt a technology if its operation is at some level conforming with people's existing agronomic practices.

The DTPB's belief structure is flexible and can be modified to suit different research objectives (Shao *et al.*, 2022). An additional variable (risk) is therefore introduced from Expected Utility Theory. The Expected Utility Theory assumes that adoption behaviour is conditioned by risk, uncertainty, and the superior utility expected from the new technology, which surpasses that of the old or existing technology (Mongin, 1998). This implies that a farmer compares a new technology with an existing technology or practice and is more likely to adopt the new technology if it guarantees a higher expected utility (Borges, Foletto and Xavier, 2015; Meijer *et al.*, 2015; Schoemaker, 1982). Given these assumptions, the following hypotheses have been formulated.

H4: Greater perceived ease of use will positively affect a farmer's attitude to adopt renewable energy technology for farming.

H5: Greater perceived usefulness will positively affect a farmer's attitude to adopt renewable energy technology for farming.

H6: Greater perceived compatibility will positively affect a farmer's attitude to adopt renewable energy technology for farming.

H7: Lower perceived risk will positively affect a farmer's attitude to adopt renewable energy technology for farming.

According to Fishbein and Ajzen (1977), subjective norms are the social pressures that affect an individual's intention to perform an adoption. Subjective norms can be deconstructed into two sub-constructs: peer influence and external influence. In the context of this research, farmers live in communities with family members and non-family members and are, therefore, involved in various social interactions. Peer influence occurs when colleagues or family members persuade a farmer to make a decision to adopt or not adopt a sustainable energy technology. External influence is likely to happen when a farmer is convinced by external elements such as researchers, agricultural extension professionals and other non-farmer stakeholders to adopt a new technology. The following hypotheses are formulated.

H8: Peer influence will positively increase farmer's subjective norm to adopt renewable energy technology for farming.

H9: External influence will positively increase farmer's subjective norm to adopt renewable energy technology for farming.

In the Decomposed Theory of Planned Behaviour, perceived behavioural control is comprised of three underlying sub-constructs: self-efficacy, resource facilitating conditions, and technology facilitating conditions. Self-efficacy refers to the ability of an individual to perform an action. For example, a farmer will adopt a new technology that can be operated without physical or psychological discomfort. Positively perceived resource and technology facilitating conditions stimulate an intention to adopt a new technology. For farmers, resource facilitating conditions may include sufficient time, capital, and appropriate agronomic conditions. Technology facilitating conditions may refer to the availability of spare parts for equipment, markets, and specialists who are able to repair equipment and machinery (Nyasulu and Dominic Chawinga, 2019; Taylor and Todd, 1995a). The following hypotheses have been formulated.

H10: Higher perceived self-efficacy will positively affect a farmer's perceived behavioural control to adopt renewable energy technology for farming.

H11: Greater perceived access to resource facilitating conditions will positively affect a farmer's perceived behavioural control to adopt renewable energy technology for farming.

H12: Greater perceived access to technology facilitating conditions will positively affect a farmer's perceived behavioural control to adopt renewable energy technology for farming.

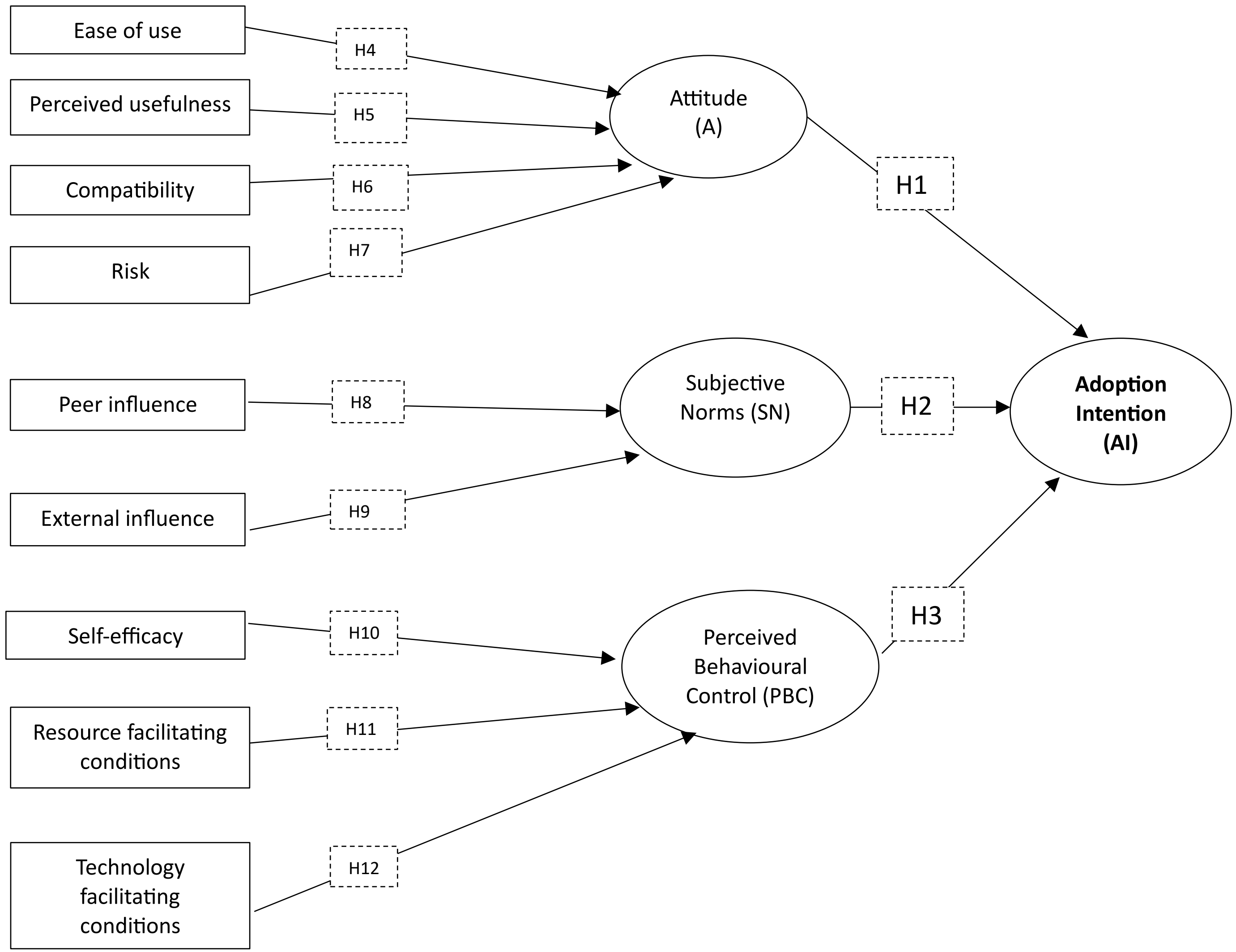


Fig 7.3 Summary of constructs predicting farmers' behavioural intentions to adopt sustainable energy technology

Source: Adapted and modified from Taylor and Todd (1995a).

7.4 Participants Selection and Sampling Strategy

A farmer survey was conducted to test the DTPB in relation to farmers' adoption of sustainable energy technology. A systematic sampling technique was used to select farmers to participate in the survey. Systematic sampling is a probability technique which enables the selection of a sample from a specified population at regular intervals (Singh and Singh, 1977). Farmers were identified through household sampling. Following the initial random selection of a household within the sampling frame, subsequent households were selected after every 10th interval count of households. The systematic sampling technique was used due to its simplicity and adequate representativeness of a population (Elsayir, 2014; Castillo, 2009; Opsomer, Francisco-Fernandez and Li, 2012).

Upon applying Yamene's formula to determine the sample estimation for the survey, 390 farmers constituted the sample size[21]. An additional 10 percent of the calculated sample size was included in case of potential non-responses. The overall sample size for the quantitative research was 429. A sample unit allows researchers to investigate a population (Acquah-Coleman, 2018; Zikmund *et al.*, 2013).

7.5 Survey Design

The survey used a 5-point Likert scale (i.e., strongly disagree to strongly agree) to measure variables, including attitudinal factors (perceived usefulness, perceived ease of use, perceived compatibility, and perceived risk), subjective norms (perceived peer and superior influences), and perceived behavioural control (self-efficacy, technology facilitating conditions, and resource facilitating conditions). Additionally, the survey collected demographic information about farmers' gender, farming experience, household and farm size, type of crops and livestock reared, etc. The survey had five sections: 1) Section A (General/background information), 2) Section B (Energy use in agriculture), 3) Section C (Socio-economic drivers and barriers), 4) Section D (Psychological drivers and barriers), and 5) Section E (External drivers facilitating sustainable energy adoption).

The survey was developed in English, and an online version was created using the KobToolbox application. The survey was downloaded from the platform. Survey

[21] Chapter 3 provides a detailed description of the sample estimation for the survey of the quantitative research.

participants accessed the survey using tablets, which were used to collect data when internet access was not possible. Data were later uploaded to a cloud-based server.

The survey commenced after obtaining ethical approval from the Faculty of Science, Agriculture and Engineering, Newcastle University (Ref: 32218/2023; 11/05/2023). The survey was piloted in a selected community in the study area. Prior to the pilot study, four field researchers were recruited and trained to administer the survey. The survey questions were translated from English to the local dialect (Dagaara). A virtual workshop was organised for the researchers to be trained on how to use the tablets to conduct the survey, including downloading and accessing the survey to begin an interview and how to upload a completed survey. After training the researchers, a pilot was conducted involving 10 farmers in a nearby community in the Nandom Municipality which has similar demographic characteristics as the study area. At the end of the pilot exercise, emerging concerns about some aspects of the survey questions were addressed by modifying specific questions. The following modifications were made: 1) farmer land ownership, 2) farmers' view on various energy forms contributing to climate change, and 3) various psychological facilitators of farmers potential to adopt renewable energy technology. The final version of the survey was downloaded to the tablets for the data collection phase of the research.

In the study area, permission was obtained from the Lawra Municipal Agriculture Department and the Lawra Traditional Paramountcy to conduct the research. Further permission was obtained from leaders of the various communities that were visited by the research team. This enabled the field researchers to gain access to the farmers in these local communities.

To operationalise the sampling technique (i.e., systematic sampling), the first count of a household was taken from the nearest household to the entry border of a community and after every 10th interval count. The total sampled farmers (n=429) were distributed across communities under the four administrative zones in the Municipality, thus 100 farmers each from Babile, Zambo, and Eremon and 129 farmers from Lawra Town Council were included because it had the most population among the administrative zones. The head of a selected household was the first point of contact to obtain permission before an interview was conducted with a participant farmer in line with the traditional entry protocol when visiting households in the study area. Farmer participants were targeted through the households because 80 percent of households engaged in farming. One farmer was interview per household. Therefore, household heads (represented by male farmers) dominated the participants sampled). An overview of the aims of the research and the purpose of the survey was explained to the household head to obtain consent to personally participate or allow other household members to participate in the survey. Farmers' participation in the survey was voluntary; hence, they were informed that they could withdraw from the survey at any point and have any data deleted. A total of 429 survey interviews were conducted from May to June 2023, of which 418 yielded completed data. Each interview took an average duration of 30 minutes.

7.6 Data Analysis

The data were exported from the KoboToolbox cloud-based server into an Excel format compatible with SPSS analytical software (version 29) and AMOS 29. The data were cleaned to identify and eliminate incomplete responses. Ultimately, the analysis proceeded with data from 418 farmers. Subsequently, a descriptive analysis was performed to analyse the demographic and background attributes of the farmers using SPSS 29. Structural equation modelling (SEM) was applied to test and validate the research model proposed (see Figure 7.4).

7.6.1 Structural equation modelling (SEM)

Structural equation modelling (SEM) is a statistical tool applied to assess the relationship between variables or constructs (Ullman and Bentler, 2012; Savalei and Bentler, 2006). SEM techniques allow researchers to concurrently assess complex and multiple relationships underpinning numerous variables, testing the predictivity of theoretical models using empirical data (Chin, 1998; Bollen and Noble, 2011). SEM was applied to investigate the relationship between latent (unobserved data) and observed (known data) variables (Bollen and Noble, 2011; Bollen, 1989). A confirmatory factor analysis (CFA) was initially applied to assess the validity of the constructs included in the research model (Decomposed Theory of Planned Behaviour) using empirical data from the farmer survey. CFA is a statistical method used to evaluate observed variables and how they measure unobservable latent constructs (Hoyle, 2000; Stapleton, 1997; Stevens, 1996). CFA was the preferred technique because the underlying latent variables were identified in the DTPB in Chapter 5. There was satisfactory evidence to develop research hypotheses based on the model to be tested and validated using empirical data (Byrne, 2013).

The application of SEM entails five steps which include 1) model specification to establish the hypothetical relationships between variables in the model; 2) model identification to ascertain whether the model is just-identified, under-identified or over-identified; 3) parameter estimation to enable model coefficients to be estimated subject to just-identified or over-identified models; 4) model evaluation to assess the overall goodness of fit of the model based on the recommended goodness of fit indices and criteria; and 5) model modification to fine-tune and improve the overall goodness of fit of the model (Fan *et al.*, 2016; Kline, 2023; Byrne, 2013; Grace, 2006).

7.7 Results

7.7.1 Descriptive data analysis

Socio-demographics

VARIABLES	MEAN	SD
Age (years)	48.03	9.98
Household size (number of people)	6.96	3.42
Farm size (acres)	5.22	2.16
Farmer experience (years)	16.85	10.20
Farmer income (GHS-Ghana Cedis)	764.52	597.59
Energy cost (GHS)	239.33	158.25

Table 7.1 Summary of descriptive statistics of farmers' socio-demographic characteristics

VARIABLES	CATEGORIES	FREQUENCY	PERCENTAGE (%)
Gender	Male	329	78.7
	Female	89	21.3
Education	None	267	63.9
	To Primary school	91	21.8
	To Junior high school	42	10.0
	To Senior high school	12	2.9
	To Tertiary	6	1.4

Purpose of farming	Food/household consumption	410	98.1
	Income	5	1.2
	Traditional heritage	3	.7
Farm labour source	Extended family	131	31.3
	Hired labour	116	27.8
	Household	171	40.9

Table 7.2 Summary of descriptive statistics on farmers' characteristics

Table 7.1 summarises the socio-demographics of the farmer population for the survey (n=418). Male farmers (79%) and female farmers (21%) represented the total survey population. Although females constituted majority of the population in Lawra Municipality, male farmers formed majority of the survey participants primarily because they represented as household heads and owned the land on which farming was done. This development is culturally typical of the Lawra traditional area and the larger Ghanaian society where inheritance is predominantly patrilinear giving males the advantage to inherit or own land over females. The existing socio-cultural practice can be attributed to the skewed participatory process where men dominated the research participants. To achieve a gender-inclusive participatory process, future research may expand the inclusion criteria for participants beyond the household to capture more female farmers who often are not household heads and do not own farmlands but contribute significantly to performing farm activities.

Most farmers (64%) had no formal education, with only (22%) obtaining primary school education. The average age of farmers was 48 years, and average farming experience was 17 years. On average, a farmer's household was comprised of seven members with an average farm size of 5 acres. The household contributed 41% of the farm labour source. Other sources of farm labour were extended family members (31%) and hired labour (28%). Annually, the average cost of farm energy inputs was about GHS239.00. The annual farm income of farmers was about GHS765.00. About 98% of farmers primarily cultivated land to provide food for household consumption (see Table 7.2).

VARIABLES	CATEGORIES	PERCENTAGE (%)
Land ownership	No	9.3

	Yes	90.7
Mixed farming (Crops & Livestock)	No	2.9
	Yes	97.1
Crops cultivated	Millet	10.5
	Maize	23.6
	Groundnut	23.0
	Cowpea	18.8
	Sorghum	15.7
	Vegetables	8.4
Livestock Reared	Goats	21.8
	Sheep	20.7
	Pigs	16.6
	Poultry	30.2
	Cattle	10.8
Do you produce adequate food to feed your household until the next farming season?	Highly inadequate	16.0
	Inadequate	37.8
	Neither adequate nor inadequate	29.7
	Adequate	13.6
	Highly adequate	2.9
General Forms of Energy Used (i.e., domestic and other economic activities)	Petrol	12.3
	Diesel	13.5
	Kerosene	1.8
	Fertiliser	18.3
	Wood/Charcoal	18.4
	Electricity	16.5
	Gas	0.8
	Human Resource	18.4
Energy Forms Used for Agricultural Activities		

Ploughing	Petrol	7.3
	Diesel	39.3
	Human resource	53.5
Irrigation	Petrol	27.3
	Diesel	30.2
	Fertiliser	0.6
	Human resource	41.9
Drying	Wood/Charcoal	1.4
	Human resource	98.6
Harvesting	Human resource	100

Table 7.3 Descriptive statistics of farmers' attributes

Most farmers (91%) owned the farmlands on which they worked, with the majority of farmers (97%) practising mixed farming (i.e., cultivating crops and livestock). Land ownership in Lawra Municipality is predominantly owned by individuals, families, and clans. As such, farmers have ownership of farmlands through individual means or family and clan inheritance. Similarly, this is a common development across most areas in Ghana. Crops cultivated were maize (24%), groundnut (23%), and cowpea (19%). Livestock reared were poultry (30%), goats (22%), sheep (21%), and pigs (17%). Most farmers (55%) indicated that they produced inadequate food to feed the household at the time of data collection, potentially representing a threat to food security in households where farmers rely on agriculture as a source of livelihood.

Generally, petrol, diesel, wood/charcoal, fertiliser, electricity, and human resources were reported to be primary energy forms (97%) which farmers used for domestic and other economic activities. Ploughing (54%), irrigation (42%), and drying (99%) were reported to be human resource energy forms used for agricultural activities. All farmers relied on human resources to manually harvest crops (see Table 7.3).

VARIABLES	CATEGORIES	MEAN
Fossil fuels contribute to Green House Gases (GHG) emissions	Strongly disagree	3.40
	Disagree	
	Neither agree nor disagree	
	Agree	
	Strongly agree	
	Strongly disagree	4.21

Renewable energy is a cheaper energy form compared to other energy sources	Disagree	
	Neither agree nor disagree	
	Agree	
	Strongly agree	
Renewable energy is a clean energy source compared to other energy sources	Strongly disagree	3.85
	Disagree	
	Neither agree nor disagree	
	Agree	
	Strongly agree	

Table 7.4 Summary of descriptive statistics on farmers' perception of Renewable Energy

Have you adopted solar technology?	**CATEGORIES**	**FREQUENCY**	**PERCENTAGE (%)**
	No	388	92.8
	Yes	30	7.2
Have you adopted biomass technology?	No	402	96.2
	Yes	16	3.8

Table 7.5 Farmers adopting renewable energy

Most farmers neither agreed nor disagreed that fossil fuels contributed to Green House Gases (GHG) emissions leading to climate change. Farmers agreed renewable energy was cheaper than other energy sources. Furthermore, farmers agreed renewable energy was a clean energy source compared to other energy sources (see Table 7.4). This implies that farmers have knowledge of the benefits of renewable energy in the context of agriculture. However, only a few farmers adopted solar (7%) and biomass (4%) energy technology (see Table 7.5).

7.8 Definition of Measurement Scales

The section of the survey assessed the predictive capacity of the DTPB, containing 45 items used to measure the constructs. Each construct (validated in the PCA) had at least three items in the form of a statement and scored using a Likert scale from 1 to 5 (where 1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, and 5=strongly agree). Table 7.6 summarises items and constructs measured in the research.

Constructs	Item	Sources
Ease of Use	EU1 (It will be stress-free for me to use solar technology for farming).	(Davis, 1989; Bagheri, Allahyari and Ashouri, 2016; Rezaei, Safa and Ganjkhanloo, 2020)
	EU2 (I will be comfortable operating solar technology alone).	
	EU3 (It will be stress-free for me to use biomass technology for farming).	
Perceived Usefulness	PU1 (Using solar technology will increase my yields).	(Davis, 1989; Rezaei, Safa and Ganjkhanloo, 2020)
	PU2 (Using solar technology will increase my profits).	
	PU3 (Using biomass technology will increase my yields).	
	PU4 (Using biomass technology will increase my profits).	
Compatible	CT1 (Adopting solar technology suites the type of farming I practice).	(Rogers, 2003; Sharifzadeh *et al.*, 2017)
	CT2 (Adopting solar technology is compatible with indigenous farming practices).	
	CT3 (Adopting biomass technology suites the type of farming I practice).	
Risk	RK1 (Using solar technology has no effect on my farm income).	(Musyoki *et al.*, 2022)
	RK2 (Using biomass technology has minimal or no effect on my farm yields).	
	RK3 (Using biomass technology has no effect on my farm income).	
Peer Influence	PI1 (A family member will approve the use of solar technology for farming).	(Taylor and Todd, 1995b)

	PI2 (A neighbour will approve the use of solar technology for farming).	
	PI3 (A family member will approve the use of biomass technology for farming).	
	PI4 (A neighbour will approve the use of biomass technology for farming).	
External Influence	EI1 (An agricultural extension officer will approve the use of solar technology for farming).	(Taylor and Todd, 1995b)
	EI2 (Members of a farmer cooperative/association will approve the use of solar technology for farming).	
	EI3 (An agricultural extension officer will approve the use of biomass technology for farming).	
	EI4 (Members of a farmer cooperative/association will approve the use of biomass technology for farming).	
Self-efficacy	SE1 (I think I have the personal ability required to use solar technology for farming).	(Ajzen, 1991; Sharifzadeh *et al.*, 2017)
	SE2 (I think I understand how solar technology for farming works.	
	SE3 (I think I have the personal ability required to use biomass technology for farming).	
	SE4 (I think I understand how biomass technology for farming works).	
Resource Facilitating Conditions	RFC1 Using solar energy will require ownership of plot(s) of land(s)).	(Venkatesh *et al.*, 2003)
	RFC2 Using solar energy will require adequate money/funds).	
	RFC3 (Using biomass energy will require crop/livestock residue)	

	RFC4 (Using biomass energy will require money/funds).	
Technology Facilitating Conditions	TFC1 (To use solar technology, the spare parts to mend the equipment must be available).	(Venkatesh *et al.*, 2003)
	TFC2 (To use solar technology, technical experts/equipment repairers must be available).	
	TFC3 (To use biomass technology, the spare parts to mend the equipment must be available).	
	TFC4 (To use biomass technology, technical experts/equipment repairers must be available).	
Attitude	ATT1 (Solar technology is affordable compared to other energy technologies).	(Ajzen, 1991; Fishbein and Ajzen, 1977)
	ATT2 (Biomass technology is useful to me for farming).	
	ATT3 (I will be comfortable operating solar technology alone).	
	ATT4 (Using solar technology has minimal or no effect on my farm yields).	
Subjective norm	SN1 (Other farmers similar to myself will approve the use of solar technology for farming).	(Ajzen, 1991; Fishbein and Ajzen, 1977)
	SN2 (Other farmers similar to myself will approve the use of biomass technology for farming).	
	SN3 (Leaders of a farmer Cooperative/Association will approve the use of biomass technology for farming).	
	PBC1 (To use solar technology, it must be available in the market for adoption).	

Perceived behavioural control	PBC2 (Biomass energy has a relatively lower cost.)	(Ajzen, 1991; Fishbein and Ajzen, 1977)
	PBC3 (To use biomass technology, it must be available in the market for adoption).	
Adoption Intention	AI1 (What is the likelihood that you will adopt solar energy for agriculture?)	(Taylor and Todd, 1995b)
	AI2 (What is the likelihood that you will adopt biomass energy for agriculture?)	

Table 7.6 Items used to measure constructs in the research

7.9 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was performed. The Kaiser-Meyer-Olkin (KMO) test was applied to validate sampling adequacy. Bartlet's Test of Sphericity (BTS) was used to determine that correlation matrix differed among the various components. The Varimax rotation method was used to assess the contribution and variances of the variables (Mondiana, Pramoedyo and Sumarminingsih, 2018; Leech, Barrett and Morgan, 2013; Barkus, Yavorsky and Foster, 2006; Ali *et al.*, 2018). A KMO with a value greater than 0.70 but closer to 1.0 was regarded as adequate. KMO and BTS from the data yielded significant values of .858 and 15602.7 (see Table 7.7). The total variance of variables extracted is explained using 12 components with eigenvalues greater than 1 (see Table 7.8).

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.858
Bartlett's Test of Sphericity	Approx. Chi-Square	15602.780
	df	1081
	Sig.	<.001

Table 7.7 Results of Kaiser-Meyer-Olkin (KMO) and Bartlet's Test of Sphericity (BTS) analysis

Total Variance Explained		
Component	Initial Eigenvalues	Extraction Sums of Squared Loadings

	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11.050	23.511	23.511	11.050	23.511	23.511
2	4.232	9.004	32.515	4.232	9.004	32.515
3	3.560	7.575	40.090	3.560	7.575	40.090
4	3.016	6.416	46.506	3.016	6.416	46.506
5	2.651	5.640	52.146	2.651	5.640	52.146
6	2.644	5.625	57.771	2.644	5.625	57.771
7	2.231	4.748	62.518	2.231	4.748	62.518
8	1.934	4.114	66.632	1.934	4.114	66.632
9	1.491	3.173	69.805	1.491	3.173	69.805
10	1.352	2.876	72.681	1.352	2.876	72.681
11	1.213	2.580	75.261	1.213	2.580	75.261
12	1.037	2.205	77.466	1.037	2.205	77.466

Table 7.8 Eigenvalues and cumulative variances

7.10 Constructs Reliability and Validity Analysis

Reliability and validity analysis were performed to assess the reliability of the constructs. A construct reliability analysis was performed to estimate the internal consistency of the items included in a construct. To achieve this, a composite reliability (CR) test was performed, with all the research constructs obtained values ranging from 0.807 to 0.978, exceeding the acceptable value of 0.7 or higher (Anderson and Gerbing, 1988; Chen, 2016). Therefore, internal consistency and reliability of construct items were established. Table 7.9 presents a summary of the composite reliability analysis.

Convergent validity and discriminant validity analyses were conducted (Hair Jr *et al.*, 2021; Chen, 2016). Using the average variance extracted (AVE), convergent validity was established, with all the constructs reaching the acceptable value of (>0.5) (Naqshbandi, Kaur and Ma, 2015; Fornell and Larcker, 1981) (see Table 7.9). Discriminant validity was measured using the Fornell and Larcker (1981) principle, denoting the square root of AVE to be greater than the correspondence of an individual construct against other constructs (Kline, 2023; Hair, 2009). The results suggested discriminant validity was acceptable (see Table 7.10).

Constructs	CR > 0.7	AVE > 0.5	MSV	ASV	Convergent Validity CR>AVE AVE>.5
Perceived Behavioural Control	0.927	0.810	0.420	0.186	YES
Perceived Ease of Use	0.931	0.820	0.235	0.025	YES
Perceived Usefulness	0.807	0.521	0.342	0.118	YES
Compatibility	0.867	0.623	0.334	0.082	YES
Risk	0.876	0.703	0.129	0.039	YES
Peer Influence	0.870	0.634	0.420	0.174	YES
External Influence	0.855	0.613	0.397	0.168	YES
Self-Efficacy	0.883	0.656	0.159	0.059	YES
Resource Facilitating Conditions	0.868	0.569	0.090	0.025	YES
Technology Facilitating Conditions	0.901	0.703	0.377	0.135	YES
Attitude	0.897	0.686	0.104	0.035	YES
Subjective Norms	0.886	0.722	0.335	0.109	YES
Adoption Intention	0.978	0.956	0.235	0.031	YES

Table 7.9 Reliability and convergent validity of constructs

CR=Composite Reliability; AVE=Average Variance Extracted; MSV=Maximum Shared Squared Variance; ASV=Average Shared Squared Variance.

Perceived Behavioural Control	Ease Of Use	Perceived Usefulness	Compatibility	Risk	Peer Influence	External Influence	Self-Efficacy	Resource Facilitating Conditions	Technology Facilitating Conditions	Attitude	Subjective Norms	Adoption Intention	Discriminant Validity MSV<AVE ASV<AVE
0.900													YES
-0.064	**0.905**												YES
0.524	-0.027	**0.722**											YES
0.578	0.011	0.257	**0.790**										YES
0.204	0.031	0.233	-0.008	**0.838**									YES
0.648	-0.063	0.487	0.364	0.293	**0.796**								YES
0.611	-0.115	0.417	0.392	0.359	0.630	**0.783**							YES
0.287	-0.109	0.323	0.204	-0.040	0.399	0.345	**0.810**						YES
0.196	-0.139	0.074	0.179	0.077	0.135	0.238	0.078	**0.754**					YES
0.614	-0.014	0.585	0.306	0.241	0.584	0.439	0.177	0.127	**0.839**				YES
0.323	0.098	0.173	0.214	0.165	0.267	0.245	0.100	0.052	0.190	**0.828**			YES
0.421	-0.058	0.342	0.231	0.177	0.476	0.579	0.370	0.300	0.352	0.062	**0.850**		YES
0.077	0.485	-0.118	0.168	-0.169	-0.002	-0.113	-0.088	-0.084	-0.071	0.124	-0.100	**0.978**	YES

Table 7.10 Discriminant validity analysis of constructs

Note: Bold diagonal values are the square roots of AVEs of relevant constructs in Table 7.9

7.11 Measurement Model Evaluation

Given that the research instrument satisfied reliability and validity conditions, structural equation modelling involving a two-step approach was applied to test the research model. The maximum-likelihood approach was employed to estimate the parameters of the research model (measurement model evaluation) (Hair *et al.*, 1998). The evaluation of the goodness-of-fit indices to validate the research model against the data was conducted. The validity of a measurement model can be evaluated using goodness-of-fit indicators, including the Goodness-of-Fit Index (GFI), CMIN/DF, Adjusted Goodness-of-Fit Index (AGFI), Normed Fit Index (NFI), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), Relative Fit Index (RFI), Incremental Fit Index (IFI), Tucker Lewis Index (TLI), the Parsimony Adjusted Measures Index (PNFI), and PCLOSE (Schermelleh-Engel, Moosbrugger and Müller, 2003; Byrne, 2013; Mulaik *et al.*, 1989; Jackson, Gillaspy Jr and Purc-Stephenson, 2009; Meyers, Gamst and Guarino, 2016; Henry and Stone, 1994; Marsh and Hau, 1996).

Although many goodness-of-fit indicators are generated during the measurement model, previous research suggests using three fit indices to establish an acceptable model fit (Zhou and Abdullah, 2017; Hair, 2006; Holmes-Smith, Coote and Cunningham, 2006). To establish and report on an overall goodness-fit model, the absolute fit indices and comparative fit indices were used to evaluate the fitness of the research model. According to Byrne (2013), CMIN/DF, RMSEA, CFI, IFI, and TLI are sufficient to establish the overall goodness-fit model. Table 7.11 contains the recommended values to develop an overall goodness fit.

Overall Model Fit				
Absolute fit indices		Comparative fit indices		
CMIN/DF	RMSEA	IFI	TLI	CFI
≤ 2: very good fit ≤ 5: acceptable fit	<. 05 =good fit <. 06 - .08 = reasonable fit <. 08 – 1 = mediocre fit > 1 = poor fit	>0. 90 = adequate fit >0. 95 = superior fit		

Table 7.11 Recommended values for overall model fit

Source: (Lassoued, 2014; Byrne, 2013; Meyers, Gamst and Guarino, 2016; Hair, Ringle and Sarstedt, 2011; Jöreskog and Sörbom, 1996; Hu and Bentler, 1999; Bagozzi and Yi, 1988).

Overall model fit:

The initial measurement model evaluation generated the following indices CMIN/DF=3.073, RMSEA=0.71, CFI=.869, TLI=.852, and IFI=.870. (CMIN/DF and RMSEA) which met the recommended values (CFI, TLI, and IFI) but did not satisfy the goodness-of-fit criteria; hence, an overall model fit was not obtained. The model fit was improved by deleting items and correlating error terms as specified under the model's modification indices (MIs). According to Anderson and Gerbing (1988) and Lassoued (2014), connecting or deleting indicators can improve an unacceptable model fit. Improving a poor model fit (i.e., model re-specification) is required in SEM when the goodness-of-fit model indicators do not meet the acceptable threshold (Saris, Satorra and Sörbom, 1987; Anderson and Gerbing, 1988; Bagozzi and Yi, 2012). As a result, the following items (*PU3, CT1, PI1, PI4, EI1, SE1, SE2, RFC1, RFC4, and TFC1*) were deleted from the model with the model modification indices of (>30). Consequently, an adequate and acceptable overall model fit was established CMIN/DF=2.573, RMSEA=0.61, CFI=0.932, TLI=0.918, and IFI=0.933. Table 7.12 provides a summary of the overall model fit.

Overall Model Fit				
Absolute fit indices		Comparative fit indices		
CMIN/DF	RMSEA	IFI	TLI	CFI
2.574	.061	0.933	0.918	0.932

Table 7.12 Overall model fit summary

7.12 Structural Model Evaluation (Hypotheses Testing)

Given that the measurement model was evaluated and yielded an overall good model fit, the structural model was evaluated, and the research hypotheses tested. From the hypothetical model, it is assumed that positive attitude, positive perceived subjective norms, and high perceived behavioural control directly predict a farmer’s intention to adopt renewable energy technology. It is further assumed that greater perceived ease of use, greater perceived usefulness, greater compatibility, higher risk, peer influence, external influence, higher self-efficacy, and greater perceived access to resource and technology facilitating conditions. The goodness-of-fit indices were re-evaluated to ensure the model fit the data being used for the structural model evaluation and testing of the hypothesised relationships in the model. Overall, the goodness-of-fit indices reported satisfied the recommended values: CMIN/DF=3.060, RMSEA=0.70, CFI=0.906, TLI=0.900, and IFI=0.907.

The results of the structural model evaluation showed that almost all the hypothesised relationships in the model were supported except for one of the research hypotheses that was not supported (subjective norms). For example, there were significant positive effects of compatibility (CT = .217, p-value < 0.01) and risk (RK = .144, p-value < .008) on attitude (ATT). This implied that H6 and H7 were supported. Similarly, there were significant positive effects of peer influence (PI = .132, p-value < .013) and external influence (EI = .514, p-value < 0.01) on subjective norms (SN), indicating H8 and H9 were supported. Additionally, there were significant positive effects of self-efficacy (SE = .230, p-value <0.01), resource facilitating conditions (RFC = .149, p-value < 0.01), and technology facilitating conditions (TFC = .534, p-value <0.01) on perceived behavioural control (PBC). In effect, H10, H11, H12 were supported.

Furthermore, there were positive and moderate effects of perceived ease of use (PE = .098, p-value < .056) and perceived usefulness (PU = .102, p-value < .090) on attitude (ATT); therefore, H4 and H5 were supported. Also, there was a positive and moderate effect of attitude (ATT = .100, p-value < .055) and perceived behavioural control (PBC = .096, p-value .072) on adoption intention (AI), indicating that H1 and H3 were supported. On the contrary, there was a negative but statistically significant effect of subjective norms (SN = -.146, p-value < .007) on adoption intention (AI), depicting that H2 was not supported (see Table 7.13). Figure 7.4 represents the structural regression path of the hypothesised model.

Hypothesis	**Regression Path**	**Coefficients (SRW)**	**P-value**	**Remarks**
H1: Positive attitude will positively affect a farmer’s intention to adopt a renewable	Attitude ---> Adoption Intention	.100	.055*	Supported

energy technology for farming.				
H2: Positive perceived subjective norms will positively affect a farmer's intention to adopt a renewable energy technology for farming.	Subjective Norms --->Adoption Intention	-.146	.007**	Not supported
H3: High perceived Behavioural Control will positively affect a farmer's intention to adopt a renewable energy technology for farming.	Perceived Behavioural Control ---> Adoption Intention	.096	.072*	Supported
H4: Greater perceived ease of use will positively affect a farmer's attitude to adopt renewable energy technology for farming.	Perceived ease of use ---> Attitude	.098	.056*	Supported
H5: Greater perceived usefulness will positively affect a farmer's attitude to adopt renewable energy technology for farming.	Perceived usefulness ---> Attitude	.102	.092*	Supported
H6: Greater perceived compatibility will positively affect a farmer's attitude to adopt	Compatibility ---> Attitude	.217	0.01***	Supported

renewable energy technology for farming.				
H7: Lower perceived risk will positively affect a farmer’s attitude to adopt renewable energy technology for farming.	Risk ---> Attitude	.144	.008**	Supported
H8: Peer influence will positively increase farmer’s subjective norm to adopt renewable energy technology for farming.	Peer influence ---> Subjective Norms	.132	.013**	Supported
H9: External influence will positively increase farmer’s subjective norm to adopt renewable energy technology for farming.	External influence ---> Subjective Norms	.514	0.01***	Supported
H10: Higher perceived self-efficacy will positively affect a farmer's perceived behavioural control to adopt renewable energy technology for farming.	Self-efficacy ---> Perceived Behavioural Control	.230	0.01***	Supported
H11: Greater perceived access to resource facilitating conditions will positively affect a farmer's perceived behavioural control to	Resource facilitating conditions ---> Perceived Behavioural Control	.149	0.01***	Supported

adopt renewable energy technology for farming.				
H12: Greater perceived access to technology facilitating conditions will positively affect a farmer's perceived behavioural control to adopt renewable energy technology for farming.	Technology facilitating conditions ---> Perceived Behavioural Control	.534	0.01***	Supported

Table 7.13 Results of hypotheses testing

*Standardised Regression Weight – SRW

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$ indicate statistical significance at 1%, 5%, and 10% respectively.

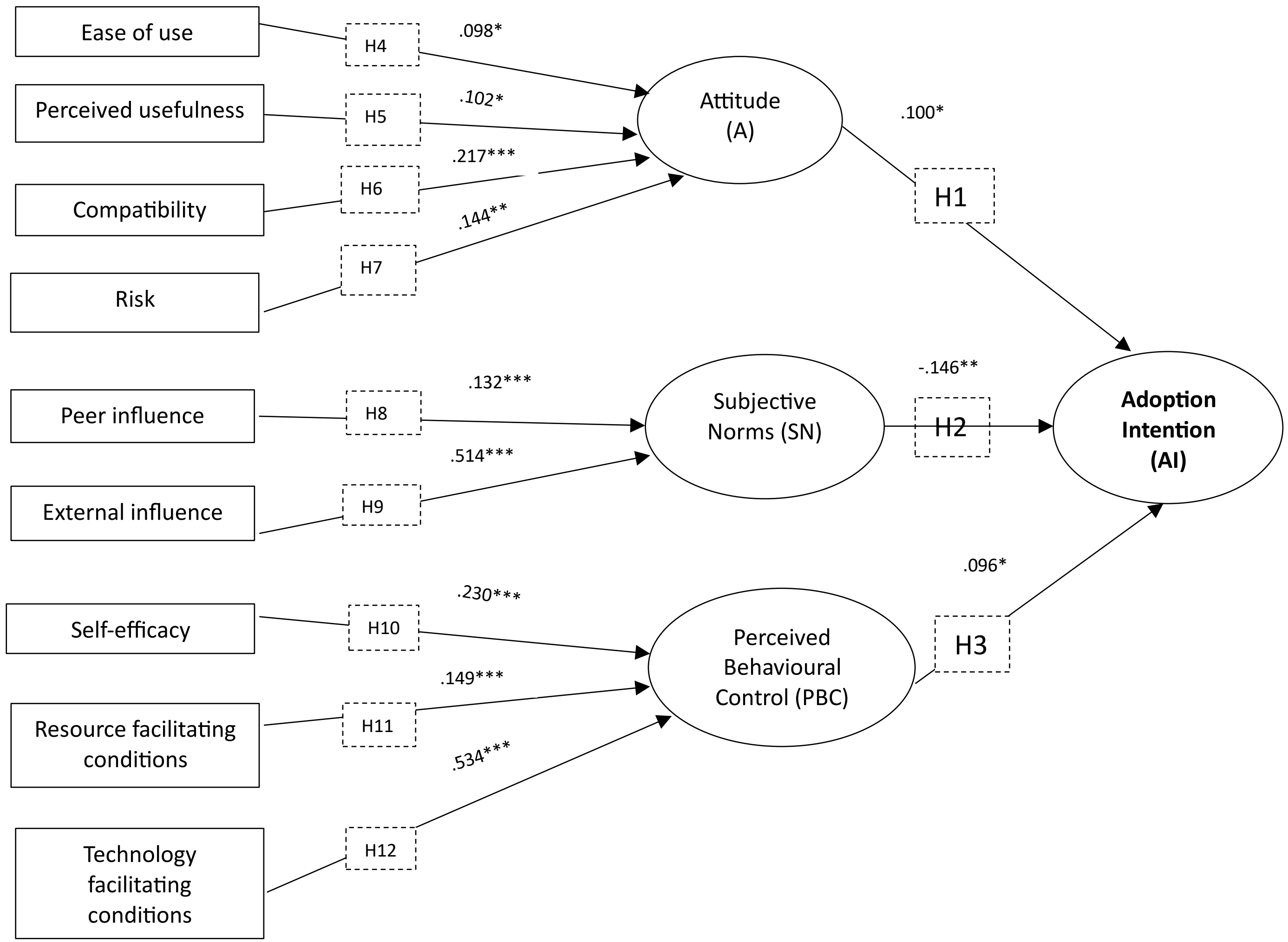


Fig 7.4 Results of structural regression path of the hypothesised model (DTPB)

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$ indicate statistical significance at 1%, 5%, and 10% respectively

7.13 Discussion

The results showed that positive attitude and high perceived behavioural control positively and moderately affected farmers' intention to adopt renewable energy technology. Likewise, farmers perceived that if they had greater access to conditions such as resources and technology that would lead to easily adopting renewable energy technology, they were more likely to develop an intention to adopt it. These results are consistent with earlier research, which found that farmers' intention to adopt new technology was significantly influenced by a growing positive attitude about the technology and a perceived sense of control to adopt a technology without difficulty (Tama *et al.*, 2021; Lalani *et al.*, 2016; Yazdanpanah *et al.*, 2014; Bagheri *et al.*, 2019; Borges *et al.*, 2014; Bruijnis *et al.*, 2013; Rezaei, Safa and Ganjkhanloo, 2020). Renewable energy technology used for farming is not widespread in Lawra Municipality. However, the results suggest that if farmers have a positive attitude towards the technology, they are more likely to develop an intention to adopt it. Therefore, developing interventions that change farmers' attitudes to be more positive will increase the adoption rate. Researchers can consider introducing renewable energy technology to farmers using innovative learning platforms, including field demonstrations and trials to witness the benefits of using the technology (Gebrezgabher *et al.*, 2015; Rezaei, Safa and Ganjkhanloo, 2020; Cheung and Vogel, 2013; Zeweld *et al.*, 2017).

The results suggested that subjective norms did not influence farmers' intention to adopt renewable energy technology, contradicting the research model. (but see (Tama *et al.*, 2021; Maleksaeidi and Keshavarz, 2019; Bagheri. *et al.*, 2019; Elahi, Khalid and Zhang, 2022). The qualitative research (chapter 6) found that farmers perceived their peers who independently used renewable energy for farming as financially well-resourced because of the high initial cost component. As a result, such farmers were most likely discriminated against by leaders of farmer associations when external support was provided to farmers. Due to this perceived discrimination, farmers were sceptical about independently adopting renewable energy technologies, a view supported by their peer group, which explains the negative relationship observed. This explanation is consistent with previous research which reported that perceived subjective norms did not positively influence individuals' adoption intention due to social factors such as cultural differences and perceived bias (Buyinza *et al.*, 2020;

Bagheri, Emami and Damalas, 2021; Laksono, Mulyo and Suryantini, 2022; Tan, Ooi and Goh, 2017).

Furthermore, greater perceived compatibility and lower perceived risk had significant positive effects on farmers' attitudes to adopt renewable energy technology. The results are coherent with findings from Dixit, Aashish and Dwivedi (2023) and Rezaei, Safa and Ganjkhanloo (2020) indicating that farmers adopt innovative technologies compatible with their contextual and pragmatic situations. Farmers in Lawra Municipality are more likely to adopt renewable energy technology that fits well with existing farming or farm characteristics. In Lawra Municipality, farmers depend primarily on agriculture as a means of livelihood; hence, they are averse to adopting technologies which pose a risk to their only source of income, and which potentially have minimal or no risk to their agricultural productivity. Greater perceived ease of use and greater perceived usefulness had positive but moderate effects on farmers' attitudes to adopt renewable energy technology. Farmers' perception in relation to how easy and useful renewable energy technology is may depend on farmers' level of experience or information acquired about the technology. Therefore, when farmers obtain sufficient information about the use and usefulness of renewable energy technology, there will be a greater intention to adopt it. Similarly, (Ulhaq *et al.*, 2022; Li *et al.*, 2021; Kardooni, Yusoff and Kari, 2016; Dixit, Aashish and Dwivedi, 2023) reported that perceived ease of use and usefulness positively impacted farmers' adoption behaviour.

A positive and significant effect of peer and external influences on farmers' subjective norms to adopt renewable energy technology was observed. This result supports the findings from the qualitative research, where farmers' adoption behaviour was positively influenced by people from both inside and outside their community. Farmers in Lawra Municipality are likely to be convinced by peers such as family members and neighbours to adopt renewable energy technology, perhaps due to knowledge or familiarity with using the technology. In addition, farmers are likely to be influenced by external factors, including the agricultural extension department/agents and farmer cooperatives, regarding the adoption of renewable energy technology. Usually, when agricultural technologies are developed, extension agents are facilitators who promote the technologies to farmers, thereby influencing farmers' adoption behaviour. Li *et al.* (2020); Wang, Jin and Mao (2019); Adesina and Chianu (2002) provide examples of previous research which reported that peer and external influences affected farmers' adoption behaviour.

Finally, the research found positive and significant effects of high self-efficacy, greater perceived access to resource facilitating conditions, and greater perceived access to technology facilitating conditions on the perceived behavioural control of farmers to adopt renewable energy. Yazdanpanah, Komendantova and Zobeidi (2022) reported that self-efficacy influenced farmers' intention to adopt new technologies. High self-efficacy implies that farmers perceive themselves to have the ability to adopt renewable energy technology without difficulty. Therefore, a higher perceived self-efficacy on the part of farmers should lead to a greater sense of perceived behavioural control to adopt renewable energy technology for farming. In addition, farmers in Lawra Municipality are more likely to develop an increasing intention to adopt renewable energy technology when they believe resources such as land and financial support are readily accessible.

Similarly, the farmers strongly indicated that they intend to adopt renewable energy when the technology and spare parts are available and accessible. This aligns with the qualitative research, which suggested that farmers adopted renewable energy technology when they perceived that the technology, spare parts, and technical expertise were available to their community. Oliveira *et al.* (2014); (Faridi, Kavoosi-Kalashami and El Bilali, 2020) reported that perceptions of facilitating conditions considerably determined farmers' behavioural intention to adopt new technologies. The significant effects of high perceived self-efficacy and greater perceived access to resource and technology facilitating conditions on farmers' adoption behaviour reported here may be attributed to various forms of support, including the provision of logistics and training activities promoted by non-farmer stakeholders, which builds the farmers' adoption capacity.

7.14 Conclusion

The theoretical model applied in this research has been validated. Thus, greater perceived compatibility, external influences, high perceived self-efficacy, greater perceived access to resource facilitating conditions, and technology facilitating conditions were the most predominant predictors that explained farmers' intention to adopt renewable energy technology for farming in Lawra Municipality. Similarly, greater perceived ease of use, greater perceived usefulness, higher perceived risk, peer influence, attitude, and high perceived behavioural control were additional factors that explained farmers’ intention to adopt renewable energy technology. In contrast to the research model, subjective norms did not affect farmers’ intention to adopt renewable energy technology.

7.15 Summary

Innovative agricultural technologies, including renewable energy, can be beneficial for farming. At present, the adoption of renewable energy technology used for farming in Lawra Municipality is low. This research investigated determinants that affected farmers’ intention to adopt renewable energy technology. Employing a farmer survey, structural equation modelling was applied to test and validate an adapted theoretical model (DTPB). Confirmatory Factor Analysis (CFA) was applied to evaluate the research model, thereby obtaining an overall fit model. Hypothetical relationships were developed based on the research model, and it emerged that, except for subjective norms, all the other constructs predicted farmers’ adoption behaviour in relation to renewable energy technology.

Chapter 8. General Discussion and Conclusion

8.1 Introduction

This chapter discusses and synthesises research findings in relation to the policy review, systematic literature review, and qualitative and quantitative research. The results from the research were triangulated using findings from qualitative and quantitative research and previously published research. Triangulation[22] was essential to validate the robustness of the research findings. The chapter discusses the theoretical contributions of the research, potential knowledge gaps and implications for future research. The findings are discussed in the context of providing evidence for policy development in Ghana's agricultural sector. The limitations of the research are discussed, and the chapter ends by drawing an overall conclusion.

8.2 Background

Agriculture is an essential economic sector in Ghana's economy despite its decreasing share of contribution to the Gross Domestic Product (GDP) in recent years (Dzanku and Udry, 2017; Diao *et al.*, 2019). The sector is predominantly occupied by smallholder farmers who depend mainly on agriculture as a source of livelihood (Akudugu, Nyamadi and Dittoh, 2016). Notably, the sector is faced with challenges including low technology adoption rate, lack of access to credit by farmers, lack of ready markets for agricultural produce, and the effects of changing climatic conditions on farming (Gollin, 2014; Kalungu and Leal Filho, 2018; Kamara *et al.*, 2019; Lipper *et al.*, 2014). These factors threaten agricultural production and food security and negatively impact farmer livelihoods (Singh and Kumari, 2023).

The adoption of innovative agricultural technologies by farmers can contribute to the sustainability of agricultural productivity and agronomic practices, increase farm income, and protect the livelihood of farmers (Singh and Kumari, 2023; Musyoki *et al.*, 2022; Kc *et al.*, 2021). In line with this, there is growing interest among non-farmer stakeholders with interests in the national economy and food security to modify agricultural production methods through the introduction and upscaling of innovative technologies for farmers (Knowler and Bradshaw, 2007; Dessart, Barreiro-Hurlé and Van Bavel, 2019; Liu, Bruins and Heberling, 2018; Mills *et al.*, 2017; Rose, Keating and Morris, 2018). The interest demonstrated by non-farmer stakeholders

[22] Triangulation is a method of evaluating the validity of research findings through verifying with data from different sources.

underscores the need for stakeholder groups needs to be put at the beginning of policy actions just as farmers' needs ought to be considered. This approach resonates with the core principle of stakeholder theory, which stipulates organisations to be holistic when prioritising the needs of other stakeholder groups (i.e., groups which can influence and groups that are influenced by policy actions) (Freeman *et al.*, 2010).

Given that many societal actors and policymakers prioritise increasing farmers' adoption of agricultural technologies to promote the sustainability of agricultural production, researchers have sought to understand the factors that affect farmers' adoption behaviour, in order to upscale the adoption of innovative technologies in the agricultural sector (O'Shea *et al.*, 2018; Moerkerken *et al.*, 2023; Rizzo *et al.*, 2023). Understanding the drivers and facilitators of, and barriers to, farmers' technology and innovation adoption behaviours can provide evidence that policies and interventions can be designed to meet farmers' technological needs adequately (Magruder, 2018; Lee, 2005), as well as provide contributions to the theoretical concepts applied in the understanding of factors (for example, psychological and economic) which influence farmers' adoption behaviour.

This research conducted a policy review to assess Ghanaian policies promoting the development and application of sustainable energy technologies in Ghanaian agriculture. In addition, a systematic review was conducted to identify an appropriate theoretical approach applied to predict farmers' adoption behaviour in relation to sustainable energy technology. The outcomes of both reviews are discussed in the context of contributions to future policy and theoretical development. The research further conducted qualitative and quantitative research to understand the predictors of farmers' adoption behaviour in relation to renewable energy technology in Ghanaian agriculture. The results from the research are analytically discussed in the context of theoretical contributions, implications for future research and evidence for policymakers in Ghana and other LMICs.

8.3 Key Findings of the Research

8.3.1 Status of renewable energy adoption in agriculture

Farmers' adoption of renewable energy technology for farming was reported to be low (Chapters 6 and 7). Generally, the adoption of new or innovative agricultural technology seems to be low or limited in many LMICs (Takahashi, Muraoka and Otsuka, 2020; Yokamo, 2020). As shown in Chapter 6, although only a few farmers have adopted renewable energy technology for farming in Ghana, evidence from the research suggested that farmers and non-farmer stakeholders considered renewable energy a sustainable energy option that could support various farm activities, including pumping water for irrigating crops, drying, and storage. Comparably, previous research has indicated that renewable energy applications in agriculture are viable in LMIC countries (Chel and Kaushik, 2011; Ali, Dash and Pradhan, 2012; Pestisha *et al.*, 2023; El Bassam, 2001).

Solar and biomass energy are sustainable energy options that are predominantly promoted for adoption in Ghanaian agriculture by non-farmer stakeholder groups. Researchers and technology-product designers (chapter 6) noted that the source of solar energy (i.e., sunlight) was available throughout the year, increasing the feasibility to deploy the technology for adoption among farmers, even in rural areas where agriculture was the dominant economic activity. The results of Chapter 6 suggested that farmers adopted energy inputs such as fertiliser derived from biomass sources because the technology matched their farming method well. In the Upper West Region of Ghana, precisely Lawra Municipality, most farmers practised mixed farming (crops and livestock) and, therefore, generated substantial crops and livestock residue, which served as raw materials for biomass energy. It is worth noting that farmers practised mixed farming as an adaptation strategy against the effects of climate change on food production (Kizito *et al.*, 2014; Sam *et al.*, 2020). In case of poor crop production yields at the end of a farming season, farmers could sell the livestock to generate income to buy food for the household until the next farming season.

Renewable energy development in Ghana has not reached its full potential (Kuamoah, 2020). However, the results of Chapter 6 suggest that to rapidly stimulate application in agriculture, there is a need for an approach that introduces sustainable energy technology that addresses farmers' specific agricultural needs rather than promoting broad-based energy technology, which may not necessarily meet the needs of different farmers. Farmers vary in the type of agriculture practised, farm size, and geographic location. On that basis, they may respond differently to adopting renewable energy technology. For example, according to the results of Chapter 6, farmers cultivating crops are more likely to adopt solar water pumps to support irrigation activities.

The deployment of renewable energy technology for farmers to adopt can consider the scale of farming. On this note, small-scale farmers may be encouraged to adopt sustainable energy technology that can be well-operated and managed at the community level. This strategy may enable farmers to benefit from adopting a particular renewable energy technology. This aligns with the results of Stringer *et al.* (2020) who reported that there is a need for distinct adaptation and sustainable development pathways for farmers, as farmers are different, so it was essential to consider a portfolio of adaptation strategies. For example, chapter 6 suggests that technology innovators in Ghana aimed to increase farmers' adoption of sustainable energy technology by designing different types of solar energy technology appropriate for smallholder and commercial farmers and by taking into account the context of rural and urban settings.

8.3.2 Determinants of renewable energy technology adoption in agriculture

The determinants of renewable energy technology adoption in Ghanaian agriculture were explored using qualitative and quantitative research. Empirical evidence indicated that psychological, social, and economic factors constituted the determinants of farmers' adoption of renewable energy technology (see Table 8.1).

Driver of issue	Key results from stakeholder chapter 6	Key results from survey chapter 7	Conclusion from combined results	Comparison with literature and reference
Attitude	N/A	Positive attitude positively affected farmers' intention to adopt renewable energy technology.	The results suggest that if farmers have a positive attitude about an innovative technology, they are more likely to develop an intention to adopt it.	(Bagheri *et al.*, 2019; Rezaei, Safa and Ganjkhanloo, 2020)
Subjective norms	N/A	Subjective norms reduced	Perceived social pressures can positively or	(Buyinza *et al.*, 2020; Laksono,

		farmers' intention to adopt renewable energy technology.	negatively influence farmers' adoption behaviour due to underlying social factors such as cultural differences and perceived bias.	Mulyo and Suryantini, 2022; Tan, Ooi and Goh, 2017)
Perceived behavioural control	N/A	High-perceived behavioural control positively affected farmers' intention to adopt renewable energy technology.	Farmers perceived to have a higher ability to perform an action through access to conditions including training, logistics, and technological resources, they develop a greater adoption intention.	(Borges *et al.*, 2014; Zeweld *et al.*, 2017; Ali *et al.*, 2020)
Perceived ease of use	Farmers perceived that the solar water pump was easier to use compared to manual irrigation using	Greater perceived ease of use positively affected farmers' attitudes to adopt renewable energy technology.	An easy-to-operate technology can motivate farmers to adopt it.	(Nyairo *et al.*, 2022)

	handheld buckets.			
Perceived usefulness	Farmers believed using a solar water pump to be cheaper than diesel- or petrol-powered pumps.	Greater perceived usefulness positively affected farmers' attitudes to adopt renewable energy technology.	Farmers adopt innovative technologies when they improve farm operational costs, increasing productivity and farm/household income.	(Masere and Worth, 2022; Dzvene *et al.*, 2022)
Perceived compatibility	Farmers perceived biomass energy to be compatible with their existing farming system.	Greater perceived compatibility positively affected farmers' attitudes to adopt renewable energy technology.	Farmers adopt innovative technology that aligns with their sociocultural values and beliefs, previously introduced practices, and what the farmers perceive as necessary for the technology.	(Junge *et al.*, 2009; Sharifzadeh *et al.*, 2017; Adegbidi *et al.*, 2012)
Risk	N/A	Lower perceived risk positively affected farmers' attitudes to adopt	Farmers are averse to adopting technologies that pose a risk to their source of income/livelihood;	(Akudugu, Guo and Dadzie, 2012; Tinh *et al.*, 2019)

		renewable energy technology.	hence, they will adopt technologies that have a minimal risk to their agricultural productivity.	
Peer influence	Through influence from family members and peers, farmers gained awareness and learnt about the benefits of using solar energy for farming.	Peer influence positively increased farmers' subjective norms to adopt renewable energy technology.	Through interpersonal communication with family members and peers, farmers acquire information about innovative technology, enabling them to fill information gaps and minimise or dispel uncertainty regarding the technology.	(AE *et al.*, 2017; He *et al.*, 2023; Niu *et al.*, 2022; Adesina and Chianu, 2002)
External influence	Farmer-based associations, the municipal agriculture department, and non-governmental organisations influenced	External influence positively increased farmers' subjective norms to adopt renewable	Extension agents and Traditional rulers can be the intermediaries between farmers and suppliers of innovative technologies, thereby	(Makate and Makate, 2019; Akudugu, Guo and Dadzie, 2012; Tanko, Muhammed and Ismaila, 2023)

	farmers' likelihood to adopt renewable energy technology for farming.	energy technology.	influencing farmers' decision to adopt new technologies.	
Self-efficacy	Farmers perceived adequate information, awareness, education, and training to be needed so that they could personally adopt a renewable energy technology for farming.	High self-efficacy positively affected the perceived behavioural control of farmers to adopt renewable energy.	Farmers perceive the adoption of new technology as voluntary or self-controllable; thus, higher perceived self-efficacy on the part of farmers would likely lead to a greater sense of perceived behavioural control to adopt it.	(Yazdanpanah, Komendantova and Zobeidi, 2022)
Technology facilitating conditions	Farmers believed greater access to and availability of renewable energy technology increased their	Greater perceived access to technology-facilitating conditions positively affected the perceived behavioural	Farmers will develop greater intentions to adopt innovative technology when there is access to spare parts, markets, and repair expertise.	(Ghimire and Huang, 2016; Faridi, Kavoosi-Kalashami and El Bilali, 2020; Oliveira *et al.*, 2014)

	likelihood of adopting the technology for farming.	control of farmers to adopt renewable energy.		
Resource facilitating conditions	Farmers believed greater access to resources, including credit, and sunshine influenced the adoption of renewable energy technology for farming.	Greater perceived access to resource-facilitating conditions positively affected the perceived behavioural control of farmers to adopt renewable energy.	Farmers will develop greater intentions to adopt innovative technology when they have access to credit, land, and time.	(Venkatesh, Thong and Xu, 2012; Nejadrezaei *et al.*, 2018)

Table 8.1 Summary of key determinants of farmers' adoption of renewable energy technology

Through the application of the Decomposed Theory of Planned Behaviour (DTPB), the quantitative research identified determinants that influenced farmers' likelihood to adopt renewable energy technology for farming. Positive attitude, greater perceived ease of use, greater perceived usefulness, greater perceived compatibility, and lower perceived risk were predictors of adopting renewable energy technology. (see (Bagheri. *et al.*, 2019; Borges *et al.*, 2014; Rezaei, Safa and Ganjkhanloo, 2020; Tama *et al.*, 2021)). Peer influence, external influence, high perceived behavioural control, higher self-efficacy, greater perceived access to resources, and technology-facilitating conditions also predicted farmers' likelihood to adopt renewable technology for farming. (see also (Adesina and Chianu, 2002; Li *et al.*, 2020; Faridi, Kavoosi-Kalashami and El Bilali, 2020; Oliveira *et al.*, 2014)).

When farmers assume that renewable energy technology can increase food production yields and income, there is a higher likelihood of adopting the technology for farming. Farmers are more likely to be “rational” when making decisions, resulting in technology adoption. I.e. when farmers are convinced by innovative technology, they perceive it can increase farm productivity and income. This is even more pronounced with smallholder farmers who rely mainly on farming to produce food for the household. Their dependence on farming to provide food means that farmers must be strategic in adopting technology to increase food production. Sustainable food production in the Upper West Region and Lawra Municipality is threatened by the effects of climate change such as extreme erratic rainfall patterns (Mohammed *et al.*, 2023). As a result, farmers are keen to adopt innovative technologies to ensure high yields to provide adequate household food.

Farmers in rural areas, including Lawra Municipality, are often conservative in terms of integrating technology which is perceived to threaten farming traditions (Amare and Darr, 2020; Meijer *et al.*, 2015; Curry *et al.*, 2021). Farmers are more inclined to adopt sustainable energy technology when it aligns with existing farming traditions. Farmers’ adoption behaviour concerning renewable energy technology may depend on a positive or negative attitude formed about the technology. To form a positive attitude about renewable energy technology, farmers require some degree of knowledge and information about that technology. Therefore, when farmers obtain sufficient information about renewable energy technology, it is likely to form a positive attitude, leading to a greater likelihood of adopting renewable energy technology for farming. This implies that researchers can consider strategies that propagate and promote sustainable energy applications in agriculture for farmers to enable them to form positive attitudes, which can lead to a likely adoption.

The likelihood of farmers adopting innovative technology may depend on their perceived ability to undertake the adoption without difficulty. As confirmed by the application of the DTPB, farmers will likely adopt renewable energy technology when it is perceived to be under their control. In the context where farmers obtain support in the form of information, finance, and training to adopt new technology, there can be a higher self-efficacy on the part of farmers, which can lead to a greater likelihood of adopting it. This means that researchers and other non-farmer stakeholders can increase farmers’ self-efficacy by conducting training and educational workshops to build farmers' capacity to adopt renewable energy technology voluntarily. Although farmers receive various trainings to facilitate the adoption of innovative technology, this can be extended to extension services, which entail routine interaction between agricultural extension agents and farmers. Obtaining adequate training about the application of renewable energy technology can augment farmers’ ability to easily adopt the technology.

Another strategy which empowers farmers' preferences for adopting renewable energy technology is the (perceived) availability of resources and technological conditions such as financial, market proximity, technology spare parts, and expertise for repair works. As noted, farmers in Lawra Municipality have low incomes and lack the financial resources required to afford innovative technology, including renewable energy technology. Moreover, there is limited or no access to credit regimes to facilitate their affordability for such technology. The results from the policy review (chapter 4) indicated a lack of a central policy regime that provides farmers access to credit and subsidies on renewable energy technology to mitigate the initial high cost of adopting the technology. Due to widespread poverty in Lawra Municipality, state funded subsidies to facilitate technology adoption and access to favourable credit facilities can increase the likelihood of adopting renewable energy technology (Balana and Oyeyemi, 2020). For example, a pay-as-you-own model may be introduced which will enable farmers to receive renewable energy technology on credit. Instead of farmers repaying the cost of the technology using cash, they may use a portion of their farm yields to offset the cost of the technology after a farming season over a fixed term duration. There is also potential for the other portion of their farm yields to be sold to the creditor if desired. This model promotes farmers’ uptake of renewable energy technology and potentially creates a ready market for agricultural produce. The unavailability of ready markets for farmers after harvest has been identified as a challenge for farmers. Therefore, when creditors provide an option to buy farmers produce, it enables farmers access a ready market to sell their produce. This model has been adopted for trials by previous research and projects aimed at promoting agricultural technology uptake among farmers (Akrofi *et al.*, 2019; Bolwig *et al.*, 2020; Ofosu and Minh, 2021; Minh, Ofosu and Dickson, 2022; Minh and Ofosu, 2022).

A policy could encourage commercial and rural banks to consider aligning credit facilities with specific sustainable energy policy goals. For example, private green financing schemes can be used by financial institutions and interested stakeholder groups to sustainably fund the development of sustainable energy projects

(Taghizadeh-Hesary and Yoshino, 2020; Rasoulinezhad and Taghizadeh-Hesary, 2022). Potentially, private green financing schemes can facilitate the scaling up sustainable energy projects beyond the pilot phase when the research or project funding cycle ends or when the government subsidy programme ends.

In Ghana, non-farmer stakeholders have ongoing initiatives aimed at empowering farmers with training, financial resources, and logistic resources to promote and increase the likelihood of farmers adopting sustainable energy technology. For example, Green People's Energy for Africa is providing farmers in rural communities in Ghana with technical and financial support to facilitate the use of solar technology in agriculture (Green People's Energy for Africa, 2023). The Centre for Indigenous Knowledge and Organisational Development (CIKOD) offers technical and logistic support to farmers in Lawra Municipality to adopt solar energy technology to support irrigation farming (CIKOD, 2023). The CSIR-Institute of Industrial Research provides research and training support to farmers in Ghana to adopt and operate automated solar water pumps for irrigation (Institute of Industrial Research, 2023). Researchers and policymakers can develop policy and technology interventions prioritising farmers' capacity-building needs.

As in other rural communities in general, farmers in Lawra Municipality are influenced by complex social relationships regarding renewable energy technology. For example, peer and external influences (i.e., family members, peer farmers, agriculture extension agents, etc) increased the likelihood of farmers' subjective norms to adopt renewable energy technology (chapter 7). Against this, subjective norms underpinned by complex social dynamics (i.e., bias) reduced farmers' likelihood of adopting renewable energy technology. Farmers in Lawra are often unable to adopt renewable energy technology on their farms when operating as individuals because their peers will perceive them to be financially resourced and resulting in the likely discrimination by leaders of farmer associations when external support is provided to farmers (chapter 6). This highlights the complex effect of the social environment on farmers' technology adoption behaviours. While it may appear that research has tended to focus on economic factors affecting farmers' adoption behaviour, the results from chapters 6 and 7 suggest that future research may consider further social and psychological factors that may influence farmers' decision-making in relation to technology adoption. Enhancing our understanding of social barriers can enable policy and technology interventions to address hidden social complexities and lead to successful adoption by farmers.

8.3.3 Research evidence and policy implications for renewable energy technology adoption in Ghana's agricultural sector

Policies may contribute to facilitating farmers' adoption of agricultural technologies (Devi, Solomon and Jayasree, 2015). In the context of this research, contributions to policy by non-farmer stakeholders influencing farmers' adoption of renewable energy technology were examined. Although the policy review in Chapter 4 indicated that there was no central policy focus to influence farmers' adoption of renewable energy technology, there were other policies which addressed challenges associated with climate change, environment, and energy as part of their policy targets addressed the need to promote renewable energy use in agriculture (see (Karbo *et al.*, 2022)).

Policies, including those within the agricultural sector, could provide achievable targets in relation to developing and facilitating the adoption of sustainable energy technology by farmers and other actors in the agricultural value chain. Sustainable energy technology innovators and product designers should consider the individual characteristics of farmers when developing renewable energy technology. This consideration can result in the development of wide-ranging sustainable energy technology to align the farming needs of different farmers. In Chapter 7, the research results indicated that greater perceived compatibility significantly predicted farmers' intention to adopt renewable energy technology. When renewable energy technology is developed based on farming attributes perceived as important by farmers, the technologies may appeal more to farmers, leading to a positive attitude about the technology and an increasing intention to adopt it.

Policy levers, including tax incentives and subsidies, can constitute an essential component of policies that can augment sustainable energy development and potential widespread technology adoption among farmers (Dorward *et al.*, 2008; Garrone *et al.*, 2019). Policy interventions that incentivise local-based innovators and product designers with special tax exemptions for imported parts and materials to build sustainable energy technologies can lead to the development of affordable renewable energy technology for agricultural use (Garrone *et al.*, 2019). This is important because in Ghana, especially in the Upper West Region, there is a high rate of poverty in farming communities, thereby affecting farmers' financial capabilities to adopt agricultural technologies. Increasing farmers' access to renewable energy technology markets through the application of policy interventions (such as decentralised or local manufacturing) can potentially enable renewable energy technology to be more accessible for adoption. The results of Chapter 6 indicate policy gaps in relation to limited access to markets to adopt renewable energy technology for agricultural use. In Chapter 7, the results indicated that greater access to technology spare parts and expertise increased farmers' intention to adopt renewable energy technology for farming. Therefore, a policy regime that includes subsidies, tax exemption, and access to markets can address these policy gaps, stimulating the use of renewable energy technology in agriculture.

Psychological factors predicted farmers' adoption behaviour in relation to renewable energy technology in Lawra (chapters 6 and 7). These predictors include positive attitude, high perceived behavioural control, greater perceived ease of use, greater perceived usefulness, greater perceived compatibility, higher perceived risk, peer and external influences, higher self-efficacy, greater perceived access to resources, and technology facilitating conditions. This implies that policymakers can consider farmers' psychological characteristics when formulating policies and interventions to promote the adoption of renewable energy technology. Such policies and interventions that align with farmers' psychological peculiarities can enhance farmers' perception of sustainable energy technology and consequently increase the likelihood of their adopting it. Agricultural policy development should not be informed only by economic factors but must also address psychological factors.

In relation to policy implementation, education and awareness creation can facilitate the promotion of farmers' adoption of renewable energy technology. This approach can use field demonstration or farmer field schools[23], identified in this research as efficient ways to introduce farmers to renewable energy technology (chapter 6). Farmer field schools can provide farmers with sufficient knowledge and information about using sustainable energy technology in agriculture. By acquiring information, farmers can form positive attitudes and higher self-efficacy about renewable energy technology, increasing their intention to adopt it. Agricultural extension agents can provide farmers with information about using renewable energy technology in agriculture. The results from chapters 6 and 7 indicated that external influences, including agricultural extension agents, significantly influenced farmers' likelihood of adopting renewable energy technology in Lawra. Agricultural extension agents and

[23] Farmer field school is an approach used by non-farmer stakeholders including governments and non-governmental organisations to introduce innovative agronomic practices to farmers.

farmers interact routinely and provide farmers with advice on good agronomic practices. Extension agents encourage farmers to adopt innovative agricultural technologies which are beneficial to their production. Given the essential role played by agricultural extension agents to positively influence farmers' adoption behaviour, the government should recruit and deploy more agricultural extension agents who can rely on their routine interaction with farmers to promote the adoption of renewable energy technology.

The agricultural sector involves many collaborative stakeholders, including farmers and non-farmer stakeholders (Eidt, Pant and Hickey, 2020). Non-farmer stakeholders, including researchers, government, and non-governmental organisations, play distinct but critical roles that may promote technology adoption among farmers. As a result, institutional collaborations between non-farmer stakeholders have been recognised to influence farmers' likelihood to adopt renewable energy technology for farming. (see (Wang *et al.*, 2020; Hermans *et al.*, 2017)). Common areas for institutional collaborations include research activities, technology or product designing, training, and sensitisation workshops for farmers to create education and awareness about renewable energy technology. Given the lack of a central policy promoting sustainable energy technology in Ghanaian agriculture, strategic institutional collaborations can lead to policy coproduction, which can provide farmers with the requisite policy support to effectively adopt renewable energy technology (Testa *et al.*, 2022; Yamoah *et al.*, 2020). This approach implies the need to develop an agricultural sector-led policy on sustainable energy, which identifies clear pathways for implementation by the various stakeholder groups. An effective implementation plan can lead to collective policy ownership by the stakeholder groups and guarantee widespread acceptance and adoption, including farmers (Yami *et al.*, 2019).

In the context of the research results (chapter 6), the concept of Innovation Platforms (IP) can be relevant to enhance effective collaborations among stakeholder groups to promote the transfer of sustainable energy technology for farmers' adoption. The underlying principle of Innovation Platforms enables broad-based stakeholder engagements to develop solutions aligned to a common interest area (Adekunle and Fatunbi, 2014). Therefore, farmers, agricultural value chain actors, and non-farmer stakeholders may work together to establish cogent options for sustainable energy technology application in farming communities, augmenting existing technology transfer channels such as researchers and agricultural extension agents.

8.4 Theoretical Contributions from the Research

The Decomposed Theory of Planned Behaviour (DTPB) assumes that a behaviour can be predicted by three core predictors: attitude, subjective norm, and perceived behavioural conditions. Underlying these factors is a set of belief factors that are assumed to influence the three main predictors of adoption behaviour. These are perceived ease of use, perceived usefulness, and compatibility for attitude; peer and external influences for subjective norm; and self-efficacy, resource-facilitating conditions, and technology-facilitating conditions for perceived behavioural control (Taylor and Todd, 1995a; Nguyen and Drakou, 2021). The DTPB has been widely applied by researchers to understand farmers' adoption behaviour due to its robust explanatory feature, which can be attributed to the decomposed belief structure (Nyasulu and Dominic Chawinga, 2019; Shao *et al.*, 2022). The Reasoned Action Approach (RAA), like the Decomposed Theory of Planned Behaviour, is an extension of the Theory of Planned Behaviour and may equally be used to explain an adoption behaviour. Nevertheless, the deconstruction of the belief structure under DTPB enables the investigation of specific factors predicting farmers' intention to adopt renewable energy technologies. The decomposed belief structure will allow for testing relationships between variables in the belief structure (Ramayah *et al.*, 2009; Taylor and Todd, 1995a).

This research extended the application of the DTPB to predict farmers' adoption behaviour in relation to renewable energy technology. In doing so, the research advances the discourse of understanding farmers' technology adoption behaviour. Chapter 5 contributes to the growing literature of research applying the DTPB to understand farmers' adoption behaviour in lower-to-middle-income countries, demonstrating that the DTPB can be a powerful theoretical approach that future research can apply to predict and explain farmers' technology adoption behaviours.

The DTPB is a model extension which integrates constructs from the Technology Acceptance Model, the Theory of Planned Behaviour, and the Diffusion of Innovation Theory (Taylor and Todd, 1995a). A risk variable from Expected Utility Theory was added to the model. Perceived lower risk was a significant predictor of farmers' adoption behaviour. To date, to my knowledge, no research has applied the DTPB with risk as an additional variable to predict farmers' intention to adopt renewable energy technology in Ghanaian agriculture. Future research may need to consider contemporary variables or factors that can be integrated into the DTPB to explain farmers' adoption behaviour.

The application of the DTPB by earlier research regarding farmers' adoption behaviour has generated varied results. The DTPB assumes that subjective norm influences an adoption behaviour, which could be positive or negative. The results from Chapter 7 showed that subjective norms reduced farmers' intention to adopt renewable energy technology. While subjective norms have also been reported to increase the adoption intention of farmers (Tama *et al.*, 2021; Elahi, Khalid and Zhang, 2022; Maleksaeidi and Keshavarz, 2019), the results from Chapter 6 suggest a deeper understanding of the social environment which generates social pressures that potentially affects farmers' adoption behaviour. This research contributes evidence upon which researchers may conduct further research to enhance our understanding of the effect of subjective norms on farmers' adoption behaviour. Essentially, conducting further research in that regard may strengthen the predictive capability of the DTPB in understanding farmers' adoption behaviour.

8.5 Limitations of the Research

The research was focused on understanding determinants that affected farmers' intention to adopt renewable energy technology for farming. As a result, in-depth interviews with farmers as well as a farmer survey were conducted using Lawra Municipality as the research area. Lawra Municipality is among the 11 Municipalities found in the Upper West Region and 261 Municipalities in Ghana. Using one Municipality out of 261 total Municipalities in Ghana may mean that the results are not generalisable, especially given that socio-economic context influences technology adoption in farming communities in Ghana. Future research could expand the case study area to include other farming municipalities of Ghana as farmers' adoption behaviour could vary due to potential factors such as differences in agroecological zones, type of agricultural production, and differences in cultural and traditional values. This can enhance the generalisation of research findings and increase relevance to policy development.

Another limitation of this research was its focus on investigating farmers' intention to adopt renewable energy technology rather than the actual execution of the adoption behaviour. At the time of writing, renewable energy technology for farming is not widespread in Lawra Municipality (i.e., only 10% of farmers adopted solar and biomass energy technology). Future research might investigate how behavioural intention relates to the technology's actual adoption.

Furthermore, various forms of renewable energy, including solar, biomass, hydro, and wind, can support agricultural activities. This research limited the focus of renewable energy technology to solar and biomass technologies because these prominent forms of renewable energy are being promoted to Ghanaian farmers for application within the agricultural sector.

8.6 Research Gaps and Future Research

In Chapter 6, the number of stakeholders interviewed (n=7) was rather low, given that 27 non-farmer stakeholder institutions were initially contacted regarding potential interviewees. Thus, many institutions were not represented in the interviewee sample. Due to the low stakeholder response rate, it was impossible to conduct a formal Social Network Analysis (SNA) to examine the relationship between actors (stakeholders) and the level of influence between these within a network. The inclusion of more non-farmer stakeholders to understand better the contributing role of non-farmer stakeholders in facilitating farmers' adoption of renewable energy technology would enable a social network analysis to be conducted, providing an opportunity for understanding the relative influence of different institutions in relation to policy development and implementation, and to create opportunities for engagement in policy-making processes for those institutional stakeholder who are currently marginalised within the policy process.

Future research to test policy recommendations using the Policy Delphi approach (De Loë *et al.*, 2016). This method involves conducting a series of data collection exercises to obtain information from various stakeholder groups with expert knowledge in sustainable energy development to identify pragmatic measures to promote renewable energy technology adoption by farmers in agriculture.

There is also a need to test increased stakeholder involvement in policy development. To develop sustainable energy policies, this may be achieved through collaborative participation among stakeholders, including farmers, government, researchers, industry, development, and donor partners. This process can lead to policy co-production, ensuring policy coherence, inclusivity, mutual learning, and shared decision-making concerning sustainable energy technology and policy options (Ryan, 2012; Wyborn *et al.*, 2019).

It is worth noting that for future research, it is worth considering assessing other forms of renewable energy that can be used to support agricultural activities, as well as their advantages and disadvantages. Overall, and in the Ghanaian context, for example, a potential criticism of some forms of biomass exploitation relates to the release of particulates into the atmosphere, which may have negative environmental and human health benefits.

Finally, future research should consider extending the theory of change approach to evaluate strategies to ensure farmers increasingly adopt sustainable energy technology. Researchers may assess diverse strategies and identify ideal implementation activities that can stimulate change in relation to increasing farmers' adoption of sustainable energy technology. Under a theory of change approach, researchers may be able to refine and develop plausible planning, implementation, and evaluation measures (Connell and Kubisch, 1998) that can facilitate rapid sustainable energy technology adoption by farmers.

8.7 Conclusion

The research presented in this thesis aimed to investigate the determinants affecting farmers' intention to adopt renewable energy technology. A policy review (chapter 4) indicated no central Ghanaian policy to promote renewable energy technology adoption in Ghanaian agriculture. However, energy, environment, and climate change policies were identified with the potential to promote sustainable energy use in agriculture. These included the National Energy Policy, National Bioenergy Policy, National Climate Change Policy, National Environment Policy, Strategic National Energy Plan I, Ghana Renewable Energy Master Plan, Sustainable Energy for All and Investing for Food and Jobs Policy. These policies promoted solar energy and the conversion of agricultural waste to energy that can potentially support farm-based activities. A systematic review (chapter 5) was conducted to identify an appropriate theoretical approach to be applied to predict determinants of farmer adoption of renewable energy technology. The results of the systematic review suggested that the Decomposed Theory of Planned Behaviour was most relevant to understanding farmers' adoption behaviour, and this was the theoretical approach applied in the farmer survey research.

In the empirical research, qualitative research was conducted to examine factors influencing farmers' adoption intention and the contributing role of non-farmer stakeholders in influencing the adoption of renewable energy in Ghanaian agriculture. The research assessed determinants of farmers' adoption of renewable energy technology in agriculture from the farmers' perspective and compared with the views of other non-farmer stakeholders, including government agencies, non-governmental organisations, research and academic institutions, and private enterprises. In-depth interviews with farmers (n=36) were conducted to investigate the potential factors affecting farmers' likelihood of adopting renewable energy technologies in their agronomic practices. The results confirmed that various factors determined farmers' adoption of renewable energy for farming, many of which were underpinned by psychological or economic factors. These included perceived usefulness, ease of use, and compatibility with existing farming systems. Social, economic, and technological factors also represented enablers and barriers to adopting renewable energy technology for farming. The contributing role played by the broader stakeholder community in facilitating farmers' technology adoption was investigated by conducting in-depth interviews with non-farmer stakeholders (n=7). The research found that a broader stakeholder constituency contributed to and influenced farmers' adoption behaviours. Policies and institutional collaborations contributed to the roles played by stakeholders regarding renewable energy promotion and adoption in farming practices. Notable policy gaps, for example, were identified in relation to subsidies and inadequate policy in relation to subsidies and financial support. Further research into effective policy development and implementation was identified as a research gap which entails coproduction and engagement across all interested stakeholder groups, including the farmers themselves.

A farmer survey was conducted based on the outcomes of the systematic review and qualitative research. Farmers were recruited (n=418) to assess psychological, economic, and other factors determining farmers' adoption of renewable energy technology for agriculture. Employing structural equation modelling, confirmatory factor analysis was applied to test and validate the research model (DTPB). A test of hypothetical relationships developed from the research model established that positive attitude and high perceived behavioural control predicted farmers' intention to adopt renewable energy technology. Also, greater perceived ease of use, greater perceived usefulness, greater perceived compatibility, high perceived risk, peer influence, external influence, higher self-efficacy, greater perceived access to resources, and technology facilitating conditions predicted farmers' adoption intention in relation to renewable energy technology. Only subjective norm was found not to predict farmers' likelihood to adopt renewable energy technology.

The research contributes to extending the application of the DTPB in farmer technology adoption research in the context of Ghana and lower-to-middle-income countries by extension. Moreover, it contributes to the existing literature and discourse on farmer technology adoption research and the potential expansion of the DTPB by integrating contemporary variables, including risk, and the generation of evidence for future research to better understand the effect of subjective norms on adoption behaviour. The research supports Ghanaian agricultural policy development by providing evidence for governments and policymakers to develop policies and interventions that align with the psychological attributes of farmers. The evidence from this research suggests that the government should establish policy regimes, including tax and credit subsidies and green financing frameworks, which may increase farmers' support in facilitating the adoption of renewable energy technology. To promote and scale-up farmers' adoption of renewable energy technology for farming, a pay-as-you-own business model may be implemented to facilitate farmers ability to obtain renewable energy technology on credit and use a portion of their farm yields to offset the cost of the technology over a period. This approach may significantly eliminate financial constraints inhibiting farmers' affordability in relation to the cost of renewable energy technology.

References

Abaka, J., Olokede, O., Ibraheem, T., Salman, H. and Fabiyi, O. (2017) 'Renewable Energy and Agriculture: A Partnership for Sustainable Development'.

Abas, N., Kalair, A. and Khan, N. (2015) 'Review of fossil fuels and future energy technologies', *Futures,* 69, pp. 31-49.

Abdul-Majid, M., Zahari, S. A., Othman, N. and Nadzri, S. (2024) 'Influence of technology adoption on farmers' well-being: Systematic literature review and bibliometric analysis', *Heliyon*.

Abebaw, D. and Haile, M. G. (2013) 'The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia', *Food Policy,* 38(1), pp. 82-91.

Abend, G. (2008) 'The meaning of 'theory'', *Sociological theory,* 26(2), pp. 173-199.

Acheampong, P. P., Owusu, V. and Nurah, G. (2018) 'How does Farmer Preference matter in Crop variety Adoption ? The case of Improved Cassava varieties' Adoption in Ghana', *Open Agriculture,* 3(1), pp. 466-477.

Acquah-Coleman, R. (2018) *Psychological Determinants of Farmers' Intention to Adopt Improved Agricultural Innovations: A Study among Smallholder Farmers in the Gushegu District of Northern Ghana.* University of Ghana.

Adams, N., Little, T. D. and Ryan, R. M. (2017) 'Self-determination theory', *Development of self-determination through the life-course*, pp. 47-54.

Adams, S. and Nsiah, C. (2019) 'Reducing carbon dioxide emissions; Does renewable energy matter?', *Science of the Total Environment,* 693, pp. 133288.

Addison, M., Ohene-Yankyera, K., Acheampong, P. P. and Wongnaa, C. A. (2022) 'The impact of uptake of selected agricultural technologies on rice farmers' income distribution in Ghana', *Agriculture & Food Security,* 11(1), pp. 1-16.

Addo, A., Bessah, E. and Amponsah, S. (2014) 'Uncertainty of food security in Ghana by biofuel (jatropha curcas) production as an adaptation and mitigation capacity to climate change', *Ethiopian Journal of Environmental Studies and Management,* 7(1), pp. 790-800.

Adegbidi, A., Mensah, R., Vidogbena, F. and Agossou, D. (2012) 'Determinants of ICT use by rice farmers in Benin: from the perception of ICT characteristics to the adoption of the technology', *Journal of Research in International Business and Management,* 2(11), pp. 273-284.

Adekunle, A. and Fatunbi, A. (2014) 'A new theory of change in African agriculture', *Middle-East Journal of Scientific Research,* 21(7), pp. 1083-1096.

Adekunle, A. and Fatunbi, A. O. (2012) 'Approaches for setting-up multi-stakeholder platforms for agricultural research and development', *World Applied Sciences Journal,* 16(7), pp. 981-988.

Adekunle, A., Osazuwa, P. and Raghavan, V. (2016) 'Socio-economic determinants of agricultural mechanisation in Africa: A research note based on cassava cultivation mechanisation', *Technological Forecasting and Social Change,* 112, pp. 313-319.

Adenle, A. A., Morris, E. J. and Parayil, G. (2013) 'Status of development, regulation and adoption of GM agriculture in Africa: Views and positions of stakeholder groups', *Food Policy,* 43, pp. 159-166.

Adesina, A. A. and Chianu, J. (2002) 'Determinants of farmers' adoption and adaptation of alley farming technology in Nigeria', *Agroforestry systems,* 55, pp. 99-112.

AE, O., Ajayi, O., Oluwalana, E. and Ogunmola, O. (2017) 'What does literature say about the determinants of adoption of agricultural technologies by smallholders farmers', *Agri Res Tech: Open Access J,* 6(555676), pp. 10.19080.

Afful-Dadzie, E., Lartey, S. O. and Clottey, D. N. K. (2022) 'Agricultural information systems acceptance and continuance in rural communities: A consumption values perspective', *Technology in Society,* 68.

Afrane, G. (2012) 'Examining the potential for liquid biofuels production and usage in Ghana', *Energy Policy,* 40, pp. 444-451.

Agostini, A., Colauzzi, M. and Amaducci, S. (2021) 'Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment', *Applied Energy,* 281, pp. 116102.

Agyekum, E. B. (2021) 'Techno-economic comparative analysis of solar photovoltaic power systems with and without storage systems in three different climatic regions, Ghana', *Sustainable Energy Technologies and Assessments,* 43, pp. 100906.

Ahmad, T. and Zhang, D. (2020) 'A critical review of comparative global historical energy consumption and future demand: The story told so far', *Energy Reports,* 6, pp. 1973-1991.

Ainembabazi, J. H. and Mugisha, J. (2014) 'The role of farming experience on the adoption of agricultural technologies: Evidence from smallholder farmers in Uganda', *Journal of Development Studies,* 50(5), pp. 666-679.

Ajibade, P. (2018) 'Technology acceptance model limitations and criticisms: Exploring the practical applications and use in technology-related studies, mixed-method, and qualitative researches', *Library Philosophy and Practice,* 9.

Ajzen, I. (1991) 'The theory of planned behavior', *Organizational Behavior and Human Decision Processes,* 50(2), pp. 179-211.

Akello, R., Turinawe, A., Wauters, P. and Naziri, D. (2022) 'Factors Influencing the Choice of Storage Technologies by Smallholder Potato Farmers in Eastern and Southwestern Uganda', *Agriculture-Basel,* 12(2).

Akrofi, N., Sarpong, D., Somuah, H. and Osei-Owusu, Y. (2019) 'Paying for privately installed irrigation services in Northern Ghana: The case of the smallholder Bhungroo Irrigation Technology', *Agricultural water management,* 216, pp. 284-293.

Akudugu, M. A., Guo, E. and Dadzie, S. K. (2012) 'Adoption of modern agricultural production technologies by farm households in Ghana: What factors influence their decisions'.

Akudugu, M. A., Nyamadi, B. V. and Dittoh, S. (2016) 'Transforming smallholder agriculture in Africa through irrigation: an assessment of irrigation impact pathways in Ghana'.

Ali, M., Man, N., Farrah, M. M. and Omar, S. Z. (2020) 'Factors influencing behavioral intention of farmers to use ICTs for agricultural risk management in Malaysia', *Pakistan Journal of Agricultural Research,* 33(2), pp. 295.

Ali, M., Raza, S. A., Qazi, W. and Puah, C.-H. (2018) 'Assessing e-learning system in higher education institutes: Evidence from structural equation modelling', *Interactive Technology and Smart Education,* 15(1), pp. 59-78.

Ali, S., Dash, N. and Pradhan, A. (2012) 'Role of renewable energy on agriculture', *International Journal of Engineering Sciences & Emerging Technologies,* 4(1), pp. 51-57.

Aliaga, M. and Gunderson, B. (1999) *Interactive statistics.* Prentice Hall.

Aliber, M. and Hall, R. (2012) 'Support for smallholder farmers in South Africa: Challenges of scale and strategy', *Development Southern Africa,* 29(4), pp. 548-562.

Alkire, S., Meinzen-Dick, R., Peterman, A., Quisumbing, A., Seymour, G. and Vaz, A. (2013) 'The women's empowerment in agriculture index', *World development,* 52, pp. 71-91.

Alomary, A. and Woollard, J. (2015) 'How is technology accepted by users? A review of technology acceptance models and theories'.

Alston, J. M. and Pardey, P. G. (2014) 'Agriculture in the global economy', *Journal of Economic Perspectives,* 28(1), pp. 121-146.
Alvesson, M. and Sandberg, J. (2018) 'Metaphorizing the research process', *The Sage Handbook of Qualitative Business and Management Research Methods,* 2, pp. 486-505.
Amankwah, E. (2011) 'Integration of biogas technology into farming system of the three northern regions of Ghana', *Journal of economics and sustainable development,* 2(4), pp. 2222-1700.
Amankwah, E. (2015) 'Solar Energy: A Potential Source of Energy for Agricultural and Rural Development in Ghana', *Journal of Agriculture and Ecology Research International*, pp. 131-140.
Amare, D. and Darr, D. (2020) 'Agroforestry adoption as a systems concept: A review', *Forest Policy and Economics,* 120, pp. 102299.
Amenta, E. and Ramsey, K. M. (2010) 'Institutional theory', *Handbook of politics: State and society in global perspective*, pp. 15-39.
Ameyaw, L. K., Ettl, G. J., Leissle, K. and Anim-Kwapong, G. J. (2018) 'Cocoa and climate change: Insights from smallholder cocoa producers in Ghana regarding challenges in implementing climate change mitigation strategies', *Forests,* 9(12), pp. 742.
Amigun, B., Musango, J. K. and Stafford, W. (2011) 'Biofuels and sustainability in Africa', *Renewable and sustainable energy reviews,* 15(2), pp. 1360-1372.
An, B. X., Preston, T. R. and Dolberg, F. (1997) 'The introduction of low-cost polyethylene tube biodigesters on small scale farms in Vietnam', *Livestock Research for Rural Development,* 9(2), pp. 27-35.
Anang, B. T. and Zakariah, A. (2022) 'Socioeconomic drivers of inoculant technology and chemical fertilizer utilization among soybean farmers in the Tolon District of Ghana', *Heliyon,* 8(6).
Anderson, J. C. and Gerbing, D. W. (1988) 'Structural equation modeling in practice: A review and recommended two-step approach', *Psychological bulletin,* 103(3), pp. 411.
Andrews, S. (2006) 'The evolution of teachers' language awareness', *Language Awareness,* 15(1), pp. 1-19.
Anum, R., Ankrah, D. A. and Anaglo, J. N. (2022) 'Influence of demographic characteristics and social network on peri-urban smallholder farmers adaptation

strategies-evidence from southern Ghana', *Cogent Food & Agriculture,* 8(1), pp. 2130969.

Appel, F., Ostermeyer-Wiethaup, A. and Balmann, A. (2016) 'Effects of the German Renewable Energy Act on structural change in agriculture–The case of biogas', *Utilities Policy,* 41, pp. 172-182.

Apuke, O. D. (2017) 'Quantitative research methods: A synopsis approach', *Kuwait Chapter of Arabian Journal of Business and Management Review,* 33(5471), pp. 1-8.

Aroonsrimorakot, S. and and Laiphrakpam, M. (2019) 'Application of solar energy technology in agricultural farming for sustainable development: A review article', *International Journal of Agricultural Technology,* Vol. 15(5)(ISSN 2630-0192 (Online)), pp. 685-692.

Aroonsrimorakot, S. and Laiphrakpam, M. (2019) 'Application of solar energy technology in agricultural farming for sustainable development: A review article', *International Journal of Agricultural Technology,* Vol. 15(5)(ISSN 2630-0192 (Online)), pp. 685-692.

Arranz-Piera, P., Bellot, O., Gavaldà, O., Kemausuor, F. and Velo, E. (2016) 'Trigeneration based on biomass-specific field case: agricultural residues from smallholder farms in ghana', *Energy Procedia,* 93, pp. 146-153.

Aryal, J. P., Thapa, G. and Simtowe, F. (2021) 'Mechanisation of small-scale farms in South Asia: Empirical evidence derived from farm households survey', *Technology in Society,* 65, pp. 101591.

Asiamah, T., Tettey, G., Boyetey, D. and Djimajor, R. 'Examining Awareness and Usage of Renewable Energy Technologies in Non-electrified Farming Communities in the Eastern Region of Ghana'. *Applied Research Conference in Africa*: Springer, 14-27.

Asibey, M. O., Yeboah, V. and Adabor, E. K. (2018) 'Palm biomass waste as supplementary source of electricity generation in Ghana: Case of the Juaben Oil Mills', *Energy & Environment,* 29(2), pp. 165-183.

Atangana, E. (2022) 'With the Continuing Increase in Sub-Saharan African Countries, Will Sustainable Development of Goal 1 Ever Be Achieved by 2030?', *Sustainability,* 14(16), pp. 10304.

Atepor, L. (2020) 'Development of Cocoa Pod Husk Fueled Dryer for Rural Cocoa Farmers', *Int. J. Agric. Innov. Res,* 9(2), pp. 132-138.

Atuguba, R. A. and Tuokuu, F. X. D. (2020) 'Ghana's renewable energy agenda: Legislative drafting in search of policy paralysis', *Energy Research & Social Science,* 64, pp. 101453.
Awafo, E. A. and Owusu, P. A. (2022) 'Energy and water mapping of the cocoa value chain in Ghana', *Sustainable Production and Consumption,* 29, pp. 341-356.
Awotide, B. A., Karimov, A. A. and Diagne, A. (2016) 'Agricultural technology adoption, commercialization and smallholder rice farmers' welfare in rural Nigeria', *Agricultural and Food Economics,* 4(1), pp. 3.
Awuni, J. A., Azumah, S. B. and Donkoh, S. A. (2018) 'Drivers of adoption intensity of improved agricultural technologies among rice farmers: evidence from northern Ghana', *Review of Agricultural and Applied Economics (RAAE),* 21(1340-2018-5180), pp. 48-57.
Ayamga, E. A., Kemausuor, F. and Addo, A. (2015) 'Technical analysis of crop residue biomass energy in an agricultural region of Ghana', *Resources, Conservation and Recycling,* 96, pp. 51-60.
Bagheri, A., Allahyari, M. and Ashouri, D. (2016) 'Interpretation on biological control adoption of the rice stem borer, Chilo suppressalis (Walker) in North Part of Iran: application for Technology Acceptance Model (TAM)', *Egyptian Journal of Biological Pest Control,* 26(1).
Bagheri, A., Bondori, A., Allahyari, M. S. and Damalas, C. A. (2019) 'Modeling farmers' intention to use pesticides: An expanded version of the theory of planned behavior', *Journal of environmental management,* 248, pp. 109291.
Bagheri, A., Bondori, A., Allahyari, M. S. and Surujlal, J. (2021) 'Use of biologic inputs among cereal farmers: application of technology acceptance model', *Environment, Development and Sustainability,* 23(4), pp. 5165-5181.
Bagheri, A., Emami, N. and Damalas, C. A. (2021) 'Farmers' behavior towards safe pesticide handling: An analysis with the theory of planned behavior', *Science of the total Environment,* 751, pp. 141709.
Bagheri, A. and Teymouri, A. (2022) 'Farmers' intended and actual adoption of soil and water conservation practices', *Agricultural Water Management,* 259.
Bagheri., Bondori, A., Allahyari, M. S. and Damalas, C. A. (2019) 'Modeling farmers' intention to use pesticides: An expanded version of the theory of planned behavior', *Journal of Environmental Management,* 248.

Bagozzi, R. P. (1981) 'Attitudes, intentions, and behavior: A test of some key hypotheses', *Journal of personality and social psychology,* 41(4), pp. 607.

Bagozzi, R. P. and Yi, Y. (1988) 'On the evaluation of structural equation models', *Journal of the academy of marketing science,* 16, pp. 74-94.

Bagozzi, R. P. and Yi, Y. (2012) 'Specification, evaluation, and interpretation of structural equation models', *Journal of the academy of marketing science,* 40, pp. 8-34.

Baiyegunhi, L., Akinbosoye, F. and Bello, L. (2022) 'Welfare impact of improved maize varieties adoption and crop diversification practices among smallholder maize farmers in Ogun State, Nigeria', *Heliyon,* 8(5), pp. e09338.

Baiyegunhi, L. J. S. (2015) 'Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa', *Water SA,* 41(1), pp. 33-39.

Bala, I. and El-jajah, W. G. (2019) 'Relationship between promotion and classroom teachers' job satisfaction in Senior Secondary Schools in Taraba State, Nigeria'.

Balana, B. and Oyeyemi, M. (2020) *Credit constraints and agricultural technology adoption: Evidence from Nigeria.* Intl Food Policy Res Inst.

Baldwin, E., Carley, S. and Nicholson-Crotty, S. (2019) 'Why do countries emulate each others' policies? A global study of renewable energy policy diffusion', *World Development,* 120, pp. 29-45.

Bangalore, M., Hochman, G. and Zilberman, D. (2016) 'Policy incentives and adoption of agricultural anaerobic digestion: A survey of Europe and the United States', *Renewable Energy,* 97, pp. 559-571.

Banks, C., Salter, A. and Chesshire, M. (2007) 'Potential of anaerobic digestion for mitigation of greenhouse gas emissions and production of renewable energy from agriculture: barriers and incentives to widespread adoption in Europe', *Water science and technology,* 55(10), pp. 165-173.

Bantilan, M. C. S. and Padmaja, R. (2008) 'Empowerment through social capital build-up: Gender dimensions in technology uptake', *Experimental Agriculture,* 44(1), pp. 61-80.

Bardi, U., El Asmar, T. and Lavacchi, A. (2013) 'Turning electricity into food: the role of renewable energy in the future of agriculture', *Journal of cleaner production,* 53, pp. 224-231.

Barkus, E., Yavorsky, C. and Foster, J. (2006) 'Understanding and Using Advanced Statistics', *Faculty of Health & Behavioural Sciences-Papers*, pp. 393.

Bartolini, F. and Viaggi, D. (2012) 'An analysis of policy scenario effects on the adoption of energy production on the farm: A case study in Emilia–Romagna (Italy)', *Energy policy,* 51, pp. 454-464.

Bashir, M., Afzal, M. T. and Azeem, M. (2008) 'Reliability and validity of qualitative and operational research paradigm', *Pakistan journal of statistics and operation research*, pp. 35-45.

Baye, R. S., Ahenkan, A. and Darkwah, S. (2021) 'Renewable energy output in sub Saharan Africa', *Renewable Energy,* 174, pp. 705-714.

Bayitse, R., Tornyie, F. and Bjerre, A.-B. (2017) 'Cassava cultivation, processing and potential uses in Ghana', *Handbook on Cassava. Nova Science Publishers, Inc*, pp. 313-333.

Bayrakcı, A. G. and Koçar, G. (2012) 'Utilization of renewable energies in Turkey's agriculture', *Renewable and Sustainable Energy Reviews,* 16(1), pp. 618-633.

Bediako, J. A. (2008) 'Agricultural technology adoption successes and failures in Ghana and Kenya', *Increasing the productivity and sustainability of rainfed cropping systems of poor smallholder farmers*, pp. 293.

Behera, B. S., Behera, R. A. and Behera, A. C. (2015) 'Solar energy applications for agriculture in India', *International Journal of Energy, Sustainability and Environmental Engineering,* 1(3), pp. 107-110.

Bell, M., Cloy, J. and Rees, R. (2014) 'The true extent of agriculture's contribution to national greenhouse gas emissions', *Environmental Science & Policy,* 39, pp. 1-12.

Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J. P. and Smith, P. (2013) 'Livestock greenhouse gas emissions and mitigation potential in Europe', *Global change biology,* 19(1), pp. 3-18.

Ben Jebli, M. and Ben Youssef, S. (2017) 'Renewable energy consumption and agriculture: evidence for cointegration and Granger causality for Tunisian economy', *International Journal of Sustainable Development & World Ecology,* 24(2), pp. 149-158.

Bessah, E. and Addo, A. (2013) 'Energy reforms as adaptation and mitigation measures to climate change: A case of Ghana', *International Journal of Development and Sustainability,* 2(2), pp. 1052-1066.

Best (2014) 'Growing Power: Exploring energy needs in smallholder agriculture', *International Institute for Environment and Development (IIED) Discussion Paper. London, UK: IIED*.

Beza, E., Reidsma, P., Poortvliet, P. M., Belay, M. M., Bijen, B. S. and Kooistra, L. (2018) 'Exploring farmers' intentions to adopt mobile Short Message Service (SMS) for citizen science in agriculture', *Computers and Electronics in Agriculture,* 151, pp. 295-310.

Bhatta, D., Paudel, K. P. and Liu, K. (2022) 'Factors influencing water conservation practices adoptions by Nepali farmers', *Environment, Development and Sustainability*, pp. 1-23.

Bhattacharyya, T., Wani, S. P. and Tiwary, P. (2021) 'Empowerment of stakeholders for scaling-up: digital technologies for agricultural extension', *Scaling-up Solutions for Farmers: Technology, Partnerships and Convergence*, pp. 121-147.

Bhuyan, S., Laxman, T., Saikanth, D. and Badekhan, A. (2023) 'Advanced Farming Technologies for Pollution Reduction and Increased Crop Productivity', *Advanced Farming Technology; Scripown Publications: New Delhi, India*, pp. 194-214.

Biddle, C. and Schafft, K. (2015) 'Axiology and anomaly in the practice of mixed methods research: A Kuhnian analysis Axiology and Anomaly in the', *Journal of Mixed Methods Research,* 9(4), pp. 320-334.

Bishop-Sambrook, C. (2005) *Contribution of farm power to smallholder livelihoods in sub-Saharan Africa.* Food and Agriculture Organization of the United Nations.

Blandford, D. and Hassapoyannes, K. (2018) 'The role of agriculture in global GHG mitigation'.

Block, H. D. and Marschak, J. (1959) 'Random orderings and stochastic theories of response'.

Bloomfield, J. and Fisher, M. J. (2019) 'Quantitative research design', *Journal of the Australasian Rehabilitation Nurses Association,* 22(2), pp. 27-30.

Boahene, K., Snijders, T. A. B. and Folmer, H. (1999) 'An Integrated Socioeconomic Analysis of Innovation Adoption: The Case of Hybrid Cocoa in Ghana', *Journal of Policy Modeling,* 21(2), pp. 167-184.

Boehlje, M. and Langemeier, M. (2021) 'Importance of New Technologies for Crop Farming', *farmdoc daily,* 11(32).

Bollen, K. A. (1989) *Structural equations with latent variables.* John Wiley & Sons.

Bollen, K. A. and Noble, M. D. (2011) 'Structural equation models and the quantification of behavior', *Proceedings of the National Academy of Sciences,* 108(supplement_3), pp. 15639-15646.

Bolwig, S., Baidoo, I., Danso, E. O., Rosati, F., Ninson, D., Hornum, S. T. and Sarpong, D. B. (2020) 'Designing a sustainable business model for automated solar-PV drip irrigation for smallholders in Ghana'.

Bonabana-Wabbi, J. (2002) *Assessing factors affecting adoption of agricultural technologies: The case of Integrated Pest Management (IPM) in Kumi District, Eastern Uganda.* Virginia Tech.

Borges, J. A. R., Foletto, L. and Xavier, V. T. (2015) 'An interdisciplinary framework to study farmers decisions on adoption of innovation: Insights from Expected Utility Theory and Theory of Planned Behavior', *African Journal of Agricultural Research,* 10(29), pp. 2814-2825.

Borges, J. A. R., Lansink, A. G. O., Ribeiro, C. M. and Lutke, V. (2014) 'Understanding farmers' intention to adopt improved natural grassland using the theory of planned behavior', *Livestock Science,* 169, pp. 163-174.

Branch, N., Okere, P. and Nwagwu, L. (2021) 'Economic insecurity: threat to Nigeria in actualizing quality higher education in global economy', *International Journal of Innovative Education Research,* 9(3), pp. 91-102.

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

Briner, R. B. and Rousseau, D. M. (2011) 'Evidence-based I–O psychology: Not there yet', *Industrial and Organizational Psychology,* 4(1), pp. 3-22.

Brink, H. I. (1993) 'Validity and reliability in qualitative research', *Curationis,* 16(2), pp. 35-38.

Brugha, R. and Varvasovszky, Z. (2000) 'Stakeholder analysis: a review', *Health policy and planning,* 15(3), pp. 239-246.

Bruijnis, M., Hogeveen, H., Garforth, C. and Stassen, E. (2013) 'Dairy farmers' attitudes and intentions towards improving dairy cow foot health', *Livestock Science,* 155(1), pp. 103-113.

Bryman, A. (2003) *Quantity and quality in social research.* Routledge.

Bryman, A. (2008) 'The end of the paradigm wars', *The SAGE handbook of social research methods*, pp. 13-25.

Bukchin, S. and Kerret, D. (2020) 'Character strengths and sustainable technology adoption by smallholder farmers', *Heliyon,* 6(8).
Bunn, C., Läderach, P., Quaye, A., Muilerman, S., Noponen, M. R. and Lundy, M. (2019) 'Recommendation domains to scale out climate change adaptation in cocoa production in Ghana', *Climate Services,* 16, pp. 100123.
Buyinza, J., Nuberg, I. K., Muthuri, C. W. and Denton, M. D. (2020) 'Psychological factors influencing farmers' intention to adopt agroforestry: a structural equation modeling approach', *Journal of Sustainable Forestry,* 39(8), pp. 854-865.
Byrne, B. M. (2013) *Structural equation modeling with Mplus: Basic concepts, applications, and programming.* routledge.
Cafer, A. M. and Rikoon, J. S. (2018) 'Adoption of new technologies by smallholder farmers: the contributions of extension, research institutes, cooperatives, and access to cash for improving tef production in Ethiopia', *Agriculture and Human Values,* 35(3), pp. 685-699.
Carter, M., Laajaj, R. and Yang, D. (2021) 'Subsidies and the African Green Revolution: Direct Effects and Social Network Spillovers of Randomized Input Subsidies in Mozambique†', *American Economic Journal: Applied Economics,* 13(2), pp. 206-229.
Cascetta, E. and Cascetta, E. (2001) 'Random Utility Theory', *Transportation Systems Engineering: Theory and Methods*, pp. 95-173.
Castillo, J. J. (2009) 'Systematic sampling', *Retrieved March,* 6, pp. 2013.
Chandio, A. A. and Jiang, Y. S. (2018) 'Factors influencing the adoption of improved wheat varieties by rural households in Sindh, Pakistan', *Aims Agriculture and Food,* 3(3), pp. 216-228.
Chel, A. and Kaushik, G. (2011) 'Renewable energy for sustainable agriculture', *Agronomy for Sustainable Development,* 31(1), pp. 91-118.
Chen, M.-F. (2016) 'Extending the theory of planned behavior model to explain people's energy savings and carbon reduction behavioral intentions to mitigate climate change in Taiwan–moral obligation matters', *Journal of Cleaner Production,* 112, pp. 1746-1753.
Cheteni, P., Mushunje, A. and Taruvinga, A. (2014) 'Barriers and incentives to potential adoption of biofuels crops by smallholder farmers in the Eastern Cape Province, South Africa'.

Cheung, R. and Vogel, D. (2013) 'Predicting user acceptance of collaborative technologies: An extension of the technology acceptance model for e-learning', *Computers & education,* 63, pp. 160-175.

Chidiebere-Mark, N. M., Onyeneke, R. U., Uhuegbulem, I. J., Ankrah, D. A., Onyeneke, L. U., Anukam, B. N. and Chijioke-Okere, M. O. (2022) 'Agricultural production, renewable energy consumption, foreign direct investment, and carbon emissions: New evidence from Africa', *Atmosphere,* 13(12), pp. 1981.

Chikaire, J., Nnadi, F., Nwakwasi, R., Anyoha, N., Aja, O., Onoh, P. and Nwachukwu, C. (2010) 'Solar energy applications for agriculture', *Journal of Agricultural and Veterinary Sciences,* 2, pp. 58-62.

Chima, C. D. (2015) 'Socio-Economic Determinants of Modern Agricultural Technology Adoption in Multiple Food Crops and Its Impact on Productivity and Food Availability at the Farm-Level: A Case Study from South-Eastern Nigeria'.

Chin, W. W. 1998. Commentary: Issues and opinion on structural equation modeling. JSTOR.

Chinnici, G., D'Amico, M. and Pecorino, B. (2015) 'Assessment and prospects of renewable energy in Italy', *Calitatea,* 16(S1), pp. 126.

Chinseu, E., Dougill, A. and Stringer, L. (2019) 'Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi', *Land Degradation and Development,* 30(5), pp. 533-543.

Chinseu, E. L., Dougill, A. J. and Stringer, L. C. (2022) 'Strengthening Conservation Agriculture innovation systems in sub-Saharan Africa: Lessons from a stakeholder analysis', *International Journal of Agricultural Sustainability,* 20(1), pp. 17-30.

Choudhary, S., Yamini, N. R., Yadav, S. K., Kamboj, M. and Sharma, A. (2018) 'A review: Pesticide residue: Cause of many animal health problems', *Journal of Entomology and Zoology Studies,* 6(3), pp. 330-333.

CIKOD (2023) 'The Centre for Indigenous Knowledge and Organisational Development'.

Clark, B., Stewart, G. B., Panzone, L. A., Kyriazakis, I. and Frewer, L. J. (2016) 'A Systematic Review of Public Attitudes, Perceptions and Behaviours Towards Production Diseases Associated with Farm Animal Welfare', *Journal of Agricultural & Environmental Ethics,* 29(3), pp. 455-478.

Cleland, J. A. (2017) 'The qualitative orientation in medical education research', *Korean journal of medical education,* 29(2), pp. 61.

Clement, O., Akinyele, O., Oladimeji, S. and Oladipo, O. (2018) *Renewable Energy Usage for Agricultural Practices: A review.*
Cochran, W. G. (1977) *Sampling techniques.* john wiley & sons.
Coleman, P. (2022) 'Validity and reliability within qualitative research for the caring sciences', *International Journal of Caring Sciences,* 14(3), pp. 2041-2045.
Connell, J. P. and Kubisch, A. C. (1998) 'Applying a theory of change approach to the evaluation of comprehensive community initiatives: progress, prospects, and problems', *New approaches to evaluating community initiatives,* 2(15-44), pp. 1-16.
Contillo, G. and Tiongco, M. 'Determinants of Adoption of the Rice Crop Manager System among Farmers in Pangasinan, Philippines'.
Country STAT Ghana (2021) 'Food and Agriculture Data Network, Republic of Ghana'.
Creswell, J. W. and Creswell, J. D. (2017) *Research design: Qualitative, quantitative, and mixed methods approaches.* Sage publications.
Creswell, J. W., Klassen, A. C., Plano Clark, V. L. and Smith, K. C. (2011) 'Best practices for mixed methods research in the health sciences', *Bethesda (Maryland): National Institutes of Health,* 2013, pp. 541-545.
Croker, R. A. (2009) 'An introduction to qualitative research', *Qualitative research in applied linguistics: A practical introduction*, pp. 3-24.
Curry, G. N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Peter, E. and Nailina, R. (2021) 'Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world', *Journal of Rural Studies,* 88, pp. 422-431.
Curwen, P. (1976) 'Utility Maximisation', *The Theory of the Firm*: Springer, pp. 127-134.
Dadzie, S. K. N., Ndebugri, J., Inkoom, E. W. and Akuamoah-Boateng, S. (2022) 'Social networking and risk attitudes nexus: implication for technology adoption among smallholder cassava farmers in Ghana', *Agriculture and Food Security,* 11(1).
Daniel, U., Pasch, K.-H. and Nayina, G. (2014) 'Biogas in Ghana: sub-sector analysis of potential and framework conditions', *GIZ, Berlin, Germany*.
Danso-Abbeam, G., Bosiako, J. A., Ehiakpor, D. S. and Mabe, F. N. (2018) 'Adoption of improved maize variety among farm households in the northern region of Ghana', *Cogent Economics & Finance,* 5(1).

Danso-Abbeam, G., Dagunga, G. and Ehiakpor, D. S. (2019) 'Adoption of Zai technology for soil fertility management: evidence from Upper East region, Ghana', *Journal of Economic Structures,* 8(1).

Davis, F. D. (1989) 'Perceived usefulness, perceived ease of use, and user acceptance of information technology', *MIS quarterly*, pp. 319-340.

de Gialdino, I. V. 'Ontological and epistemological foundations of qualitative research'. *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*.

De Loë, R. C., Melnychuk, N., Murray, D. and Plummer, R. (2016) 'Advancing the state of policy Delphi practice: a systematic review evaluating methodological evolution, innovation, and opportunities', *Technological Forecasting and Social Change,* 104, pp. 78-88.

Deci, E. L. and Ryan, R. M. (2004) *Handbook of self-determination research.* University Rochester Press.

Denzin, N. (2005) 'lincoln, y.(2003). Introduction: The Discipline and Practice of Qualitative Research', *N. Denzin & y. lincoln (eds.) The Landscape of Qualitative Research. Theories and Issues*, pp. 1-45.

Despotović, J., Rodić, V. and Caracciolo, F. (2019) 'Factors affecting farmers' adoption of integrated pest management in Serbia: An application of the theory of planned behavior', *Journal of Cleaner Production,* 228, pp. 1196-1205.

Dessart, F. J., Barreiro-Hurlé, J. and Van Bavel, R. (2019) 'Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review', *European Review of Agricultural Economics,* 46(3), pp. 417-471.

Devi, P. I., Solomon, S. S. and Jayasree, M. (2015) 'Green technologies for sustainable agriculture: Policy options towards farmer adoption', *Indian Journal of Agricultural Economics,* 69(902-2016-68343), pp. 414-425.

Diao, X., Hazell, P., Kolavalli, S. and Resnick, D. (2019) *Ghana's economic and agricultural transformation: Past performance and future prospects.* Oxford University Press.

Diao, X., Hazell, P. and Thurlow, J. (2010) 'The role of agriculture in African development', *World development,* 38(10), pp. 1375-1383.

Dibra, M. (2015) 'Rogers theory on diffusion of innovation-the most appropriate theoretical model in the study of factors influencing the integration of sustainability in tourism businesses', *Procedia-Social and Behavioral Sciences,* 195, pp. 1453-1462.

Dinh, T., Cameron, D. and Nguyen, X. (2015) 'Rural livelihood adoption framework: A conceptual and analytical framework for studying adoption of new activities by small farmers', *International Journal of Agricultural Management,* 4(4), pp. 163-172.

Dissanayake, C., Jayathilake, W., Wickramasuriya, H., Dissanayake, U., Kopiyawattage, K. and Wasala, W. (2022) 'Theories and Models of Technology Adoption in Agricultural Sector', *Human Behavior and Emerging Technologies,* 2022.

Dixit, K., Aashish, K. and Dwivedi, A. K. (2023) 'Antecedents of smart farming adoption to mitigate the digital divide–extended innovation diffusion model', *Technology in Society,* 75, pp. 102348.

Donkoh, S. A., Azumah, S. B. and Awuni, J. A. (2019) 'Adoption of improved agricultural technologies among rice farmers in Ghana: A multivariate probit approach', *Ghana Journal of Development Studies,* 16(1), pp. 46-67.

Donkor, E., Owusu, V., Owusu-Sekyere, E. and Ogundeji, A. A. (2018) 'The Adoption of Farm Innovations among Rice Producers in Northern Ghana: Implications for Sustainable Rice Supply', *Agriculture-Basel,* 8(8).

Dorward, A., Chirwa, E., Boughton, D., Crawford, E., Jayne, T., Slater, R., Kelly, V. and Tsoka, M. (2008) 'Towards 'smart'subsidies in agriculture? Lessons in recent experience in Malawi', *Natural resources perspectives,* (116).

Doss, C. R. (2006) 'Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement', *Agricultural economics,* 34(3), pp. 207-219.

Duah, M. T. (2014) *Development of a parabolic solar dryer for efficient solar energy use in the rural areas in Ghana.*

Duku, M. H., Gu, S. and Hagan, E. B. (2011) 'A comprehensive review of biomass resources and biofuels potential in Ghana', *Renewable and sustainable energy reviews,* 15(1), pp. 404-415.

Dzanku, F. M. and Udry, C. (2017) 'Flickering decades of agriculture and agricultural policy', *The Economy of Ghana Sixty Years After Independence*, pp. 157-175.

Dzvene, A. R., Tesfuhuney, W., Walker, S., Fourie, A., Botha, C. and Ceronio, G. (2022) 'Farmers' knowledge, attitudes, and perceptions for the adoption of in-field rainwater harvesting (IRWH) technique in Thaba Nchu, South Africa', *African Journal of Science, Technology, Innovation and Development,* 14(6), pp. 1458-1475.

Ehiakpor, D. S., Danso-Abbeam, G. and Mubashiru, Y. (2021) 'Adoption of interrelated sustainable agricultural practices among smallholder farmers in Ghana', *Land use policy,* 101, pp. 105142.

Eidt, C. M., Pant, L. P. and Hickey, G. M. (2020) 'Platform, participation, and power: How dominant and minority stakeholders shape agricultural innovation', *Sustainability,* 12(2), pp. 461.

El Bassam, N. (2001) 'Renewable energy for rural communities', *Renewable Energy,* 24(3-4), pp. 401-408.

Elahi, E., Khalid, Z. and Zhang, Z. (2022) 'Understanding farmers' intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture', *Applied Energy,* 309, pp. 118459.

Eliazer Nelson, A. R. L., Ravichandran, K. and Antony, U. (2019) 'The impact of the Green Revolution on indigenous crops of India', *Journal of Ethnic Foods,* 6(1), pp. 1-10.

Elings, A., Saavedra, Y. and Nkansah, G. O. (2015) *Strategies to support the greenhouse horticulture sector in Ghana*: Wageningen UR.

Elsayir, H. A. (2014) 'Comparison of precision of systematic sampling with some other probability samplings', *American Journal of Theoretical and Applied Statistics,* 3(4), pp. 111-116.

Elum, Z., Modise, D. and Nhamo, G. (2017) 'Climate change mitigation: the potential of agriculture as a renewable energy source in Nigeria', *Environmental Science and Pollution Research,* 24(4), pp. 3260-3273.

Energy Commission, G. (2019) 'Ghana Renewable Energy Master Plan'.

Energy Commission, G. (2019a) 'Strategic National Energy Plan II'.

Energy Commission, G. (2020) 'National Energy Statistics 2000-2020. Strategic Planning and Policy Directorate.'.

Energypedia (2018) *Solar Pumps for Irrigation- The Success of EnDev Approach in Ghana*. Available at: https://energypedia.info/wiki/Solar_Pumps_for_Irrigation-_The_Success_of_EnDev_Approach_in_Ghana (Accessed: 18th May 2020).

Essegbey, G. O. and MacCarthy, D. S. (2020) 'Situational analysis study for the agriculture sector in Ghana'.

Etikan, I., Musa, S. A. and Alkassim, R. S. (2016) 'Comparison of convenience sampling and purposive sampling', *American journal of theoretical and applied statistics,* 5(1), pp. 1-4.

Evenson, R. E. and Gollin, D. (2003) 'Assessing the impact of the Green Revolution, 1960 to 2000', *science*.

Eweoya, I., Okuboyejo, S. R., Odetunmibi, O. A. and Odusote, B. O. (2021) 'An empirical investigation of acceptance, adoption and the use of E-agriculture in Nigeria', *Heliyon,* 7(7), pp. e07588.

Fachverband, B. (2011) 'Biogas segment statistics 2011', *Freising, Germany: Fachverband Biogas. Available online at: http://www. biogas. org/edcom/webfvb. nsf/id/DE_Branchenzahlen (verified 23 May 2012)*.

Fadeyi, O. A., Ariyawardana, A. and Aziz, A. A. (2022) 'Factors influencing technology adoption among smallholder farmers: a systematic review in Africa'.

Falchetta, G., Adeleke, A., Awais, M., Byers, E., Copinschi, P., Duby, S., Hughes, A., Ireland, G., Riahi, K. and Rukera-Tabaro, S. (2022) 'A renewable energy-centred research agenda for planning and financing Nexus development objectives in rural sub-Saharan Africa', *Energy Strategy Reviews,* 43, pp. 100922.

Fami, H., Javad, G., Rahil, M., Rashidi, P., Saeede, N. and Mirzaei, A. (2010) 'Renewable Energy Use in Smallholder Farming Systems: A Case Study in Tafresh Township of Iran', *Sustainability,* 2.

Fan, Y., Chen, J., Shirkey, G., John, R., Wu, S. R., Park, H. and Shao, C. (2016) 'Applications of structural equation modeling (SEM) in ecological studies: an updated review', *Ecological Processes,* 5(1), pp. 19.

Faridi, A. A., Kavoosi-Kalashami, M. and El Bilali, H. (2020) 'Attitude components affecting adoption of soil and water conservation measures by paddy farmers in Rasht County, Northern Iran', *Land use policy,* 99, pp. 104885.

Feder, G., Just, R. E. and Zilberman, D. (1985) 'Adoption of agricultural innovations in developing countries: A survey', *Economic development and cultural change,* 33(2), pp. 255-298.

Feder, G. and Savastano, S. (2017) 'Modern agricultural technology adoption in sub-Saharan Africa: A four-country analysis', *Agriculture and Rural Development in a Globalizing World*: Routledge, pp. 11-25.

Fischer, G., Wittich, S., Malima, G., Sikumba, G., Lukuyu, B., Ngunga, D. and Rugalabam, J. (2018) 'Gender and mechanization: Exploring the sustainability of mechanized forage chopping in Tanzania', *Journal of Rural Studies,* 64, pp. 112-122.

Fishbein, M. and Ajzen, I. (1977) 'Belief, attitude, intention, and behavior: An introduction to theory and research', *Philosophy and Rhetoric,* 10(2).

Fisher, M. and Carr, E. R. (2015) 'The influence of gendered roles and responsibilities on the adoption of technologies that mitigate drought risk: The case of drought-tolerant maize seed in eastern Uganda', *Global Environmental Change,* 35, pp. 82-92.

Flett, R., Alpass, F., Humphries, S., Massey, C., Morriss, S. and Long, N. (2004) 'The technology acceptance model and use of technology in New Zealand dairy farming', *Agricultural Systems,* 80(2), pp. 199-211.

Flor, R. J., Maat, H., Hadi, B. A. R., Then, R., Kraus, E. and Chhay, K. (2020) 'How do stakeholder interactions in Cambodian rice farming villages contribute to a pesticide lock-in?', *Crop Protection,* 135, pp. 104799.

Fornell, C. and Larcker, D. F. (1981) 'Evaluating structural equation models with unobservable variables and measurement error', *Journal of marketing research,* 18(1), pp. 39-50.

Frantál, B. and Prousek, A. (2016) 'It's not right, but we do it. Exploring why and how Czech farmers become renewable energy producers', *Biomass and Bioenergy,* 87, pp. 26-34.

Freeman, R. E. (2010) *Strategic management: A stakeholder approach.* Cambridge university press.

Freeman, R. E., Harrison, J. S., Wicks, A. C., Parmar, B. L. and De Colle, S. (2010) 'Stakeholder theory: The state of the art'.

Frewer, L. J., Fischer, A., Brennan, M., Bánáti, D., Lion, R., Meertens, R. M., Rowe, G., Siegrist, M., Verbeke, W. and Vereijken, C. M. (2016) 'Risk/benefit communication about food—a systematic review of the literature', *Critical reviews in food science and nutrition,* 56(10), pp. 1728-1745.

Fusch, P. I. and Ness, L. R. (2015) 'Are we there yet? Data saturation in qualitative research', *The qualitative report,* 20(9), pp. 1408.

Garrone, M., Emmers, D., Lee, H., Olper, A. and Swinnen, J. (2019) 'Subsidies and agricultural productivity in the EU', *Agricultural Economics,* 50(6), pp. 803-817.

Gbodji, K. K., Quarmine, W. and Minh, T. T. (2023) 'Effective demand for climate-smart adaptation: A case of solar technologies for cocoa irrigation in Ghana', *Sustainable Environment,* 9(1), pp. 2258472.

Gebre, G. G., Isoda, H., Rahut, D. B., Amekawa, Y. and Nomura, H. (2019) 'Gender differences in the adoption of agricultural technology: The case of improved maize varieties in southern Ethiopia', *Women's Studies International Forum,* 76.

Gebrezgabher, S. A., Meuwissen, M. P., Kruseman, G., Lakner, D. and Lansink, A. G. O. (2015) 'Factors influencing adoption of manure separation technology in the Netherlands', *Journal of environmental management,* 150, pp. 1-8.

Ghana Statistical Service (2020) '2017/18 Ghana Census of Agriculture, National Report.'.

Ghimire, R. and Huang, W.-C. (2016) 'Adoption pattern and welfare impact of agricultural technology: empirical evidence from rice farmers in Nepal', *Journal of South Asian Development,* 11(1), pp. 113-137.

Glogowska, M. (2015) 'Paradigms, pragmatism and possibilities: mixed-methods research in speech and language therapy', *International journal of language & communication disorders*, pp. 1-10.

Glover, D., Sumberg, J. and Andersson, J. A. (2016) 'The adoption problem; or why we still understand so little about technological change in African agriculture', *Outlook on Agriculture,* 45(1), pp. 3-6.

Goertzen, M. J. (2017) 'Introduction to quantitative research and data', *Library Technology Reports,* 53(4), pp. 12-18.

Golafshani, N. (2003) 'Understanding reliability and validity in qualitative research', *The qualitative report,* 8(4), pp. 597-607.

Gollin, D. (2014) 'Smallholder agriculture in Africa: An overview and implications for policy IIED Working Paper IIED', *London [Google Scholar]*.

Gorjian, S., Fakhraei, O., Gorjian, A., Sharafkhani, A. and Aziznejad, A. (2022) 'Sustainable Food and Agriculture: Employment of Renewable Energy Technologies', *Current Robotics Reports,* 3(3), pp. 153-163.

Goswami, K., Choudhury, H. K. and Saikia, J. (2012) 'Factors influencing farmers' adoption of slash and burn agriculture in North East India', *Forest policy and economics,* 15, pp. 146-151.

Grace, J. B. (2006) *Structural equation modeling and natural systems.* Cambridge University Press.

Green People’s Energy for Africa (2023).

Griliches, Z. (1957) 'Hybrid corn: An exploration in the economics of technological change', *Econometrica, Journal of the Econometric Society*, pp. 501-522.

GSSa (2014) '2010 Population and Housing Census. District Analytical Report', *Prestea/Huni Valley District*.

Gutman, J. (1982) 'A means-end chain model based on consumer categorization processes', *Journal of marketing,* 46(2), pp. 60-72.
Guyatt, G., Oxman, A. D., Akl, E. A., Kunz, R., Vist, G., Brozek, J., Norris, S., Falck-Ytter, Y., Glasziou, P. and DeBeer, H. (2011) 'GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables', *Journal of clinical epidemiology,* 64(4), pp. 383-394.
Gwara, S., Wale, E. and Odindo, A. (2022) 'Behavioral intentions of rural farmers to recycle human excreta in agriculture', *Scientific reports,* 12(1), pp. 1-13.
Gyamfi, S., Modjinou, M. and Djordjevic, S. (2015) 'Improving electricity supply security in Ghana—The potential of renewable energy', *Renewable and sustainable energy reviews,* 43, pp. 1035-1045.
Hair, J. F. (2006) 'Marketing research within a changing information environment', *(No Title)*.
Hair, J. F. (2009) 'Multivariate data analysis'.
Hair, J. F., Anderson, R., Tatham, R. and Black, W. (1998) 'Multivariate data analysis prentice hall', *Upper Saddle River, NJ,* 730.
Hair, J. F., Ringle, C. M. and Sarstedt, M. (2011) 'PLS-SEM: Indeed a silver bullet', *Journal of Marketing theory and Practice,* 19(2), pp. 139-152.
Hair Jr, J., Hair Jr, J. F., Hult, G. T. M., Ringle, C. M. and Sarstedt, M. (2021) *A primer on partial least squares structural equation modeling (PLS-SEM).* Sage publications.
Hall, R. (2013) 'Mixed methods: In search of a paradigm', *Conducting research in a changing and challenging world*, pp. 71-78.
Hammersley, M. (2000) 'The relevance of qualitative research', *Oxford review of education,* 26(3-4), pp. 393-405.
Hartshorne, R. and Ajjan, H. (2009) 'Examining student decisions to adopt Web 2.0 technologies: theory and empirical tests', *Journal of computing in higher education,* 21, pp. 183-198.
Harvey, M. and Pilgrim, S. (2011) 'The new competition for land: Food, energy, and climate change', *Food policy,* 36, pp. S40-S51.
Harwood, J. (2020) 'Could the adverse consequences of the green revolution have been foreseen? How experts responded to unwelcome evidence', *Agroecology and Sustainable Food Systems,* 44(4), pp. 509-535.

Hathcoat, J. D. and Meixner, C. (2017) 'Pragmatism, factor analysis, and the conditional incompatibility thesis in mixed methods research', *Journal of Mixed Methods Research,* 11(4), pp. 433-449.

Haug, R., Mwaseba, D. L., Njarui, D., Moeletsi, M., Magalasi, M., Mutimura, M., Hundessa, F. and Aamodt, J. T. (2021) 'Feminization of african agriculture and the meaning of decision-making for empowerment and sustainability', *Sustainability,* 13(16), pp. 8993.

He, J., Zhou, W., Qing, C. and Xu, D. (2023) 'Learning from parents and friends: The influence of intergenerational effect and peer effect on farmers' straw return', *Journal of Cleaner Production,* 393, pp. 136143.

Hellin, J., Balié, J., Fisher, E., Blundo-Canto, G., Meah, N., Kohli, A. and Connor, M. (2020) 'Sustainable agriculture for health and prosperity: stakeholders' roles, legitimacy and modus operandi', *Development in Practice,* 30(7), pp. 965-971.

Hellmann, F. and Verburg, P. H. (2011) 'Spatially explicit modelling of biofuel crops in Europe', *Biomass and Bioenergy,* 35(6), pp. 2411-2424.

Henry, J. W. and Stone, R. W. (1994) 'A structural equation model of end-user satisfaction with a computer-based medical information system', *Information Resources Management Journal (IRMJ),* 7(3), pp. 21-33.

Hermans, F., Sartas, M., Van Schagen, B., van Asten, P. and Schut, M. (2017) 'Social network analysis of multi-stakeholder platforms in agricultural research for development: Opportunities and constraints for innovation and scaling', *PloS one,* 12(2), pp. e0169634.

Hess, S., Daly, A. and Batley, R. (2018) 'Revisiting consistency with random utility maximisation: theory and implications for practical work', *Theory and Decision,* 84, pp. 181-204.

Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J. and Welch, V. A. (2019) *Cochrane handbook for systematic reviews of interventions.* John Wiley & Sons.

Hillmer, U. (2009) 'Existing theories considering technology adoption', *Technology Acceptance in mechatronics*: Springer, pp. 9-28.

Hitaj, C., and Shellye Suttles (2016) 'Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass', *Economic Research Service*.

Hogset, H. (2005) *Social networks and technology adoption*.

Holmes-Smith, P., Coote, L. and Cunningham, E. (2006) 'Structural equation modeling: From the fundamentals to advanced topics', *Melbourne: Sreams*.
Hoyle, R. H. (2000) 'Confirmatory factor analysis', *Handbook of applied multivariate statistics and mathematical modeling*: Elsevier, pp. 465-497.
Hu, L. t. and Bentler, P. M. (1999) 'Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives', *Structural equation modeling: a multidisciplinary journal,* 6(1), pp. 1-55.
Huffman, W. E. (2020) 'Human capital and adoption of innovations: policy implications', *Applied Economic Perspectives and Policy,* 42(1), pp. 92-99.
Huyer, S. 2016. Closing the gender gap in agriculture. SAGE Publications Sage India: New Delhi, India.
Iddrisu, I. and Bhattacharyya, S. C. (2015) 'Ghana′ s bioenergy policy: Is 20% biofuel integration achievable by 2030?', *Renewable and Sustainable Energy Reviews,* 43, pp. 32-39.
Institute of Industrial Research (2023) 'The CSIR-Institute of Industrial Research'.
Islam, A., Ushchev, P., Zenou, Y. and Zhang, X. (2018) 'The value of information in technology adoption: Theory and evidence from bangladesh'.
ISSER (2014) *The State of the Ghanaian Economy in 2014*.
Ivankova, N. V. and Creswell, J. W. (2009) 'Mixed methods', *Qualitative research in applied linguistics: A practical introduction,* 23, pp. 135-161.
Jackson, D. L., Gillaspy Jr, J. A. and Purc-Stephenson, R. (2009) 'Reporting practices in confirmatory factor analysis: an overview and some recommendations', *Psychological methods,* 14(1), pp. 6.
Jama, B. and Pizarro, G. (2008) 'Agriculture in Africa: Strategies to improve and sustain smallholder production systems', *Annals of the New York Academy of Sciences,* 1136(1), pp. 218-232.
Jambo, I. J., Groot, J. C. J., Descheemaeker, K., Bekunda, M. and Tittonell, P. (2019) 'Motivations for the use of sustainable intensification practices among smallholder farmers in Tanzania and Malawi', *Njas-Wageningen Journal of Life Sciences,* 89.
James, R. F., Janine, A. F. and Brian, D. L. (2006) 'Renewable Energy in Agriculture: Back to the Future?', *Choices,* 21(1), pp. 27-31.
Janssen, B. and Nonnenmann, M. W. (2017) 'New institutional theory and a culture of safety in agriculture', *Journal of agromedicine,* 22(1), pp. 47-55.

Jara-Rojas, R., Canales, R., Gil, J. M., Engler, A., Bravo-Ureta, B. and Bopp, C. (2020) 'Technology Adoption and Extension Strategies in Mediterranean Agriculture: The Case of Family Farms in Chile', *Agronomy-Basel,* 10(5).

Jayne, T. S., Mason, N. M., Burke, W. J. and Ariga, J. (2018) 'Taking stock of Africa's second-generation agricultural input subsidy programs', *Food Policy,* 75, pp. 1-14.

Jebli, M. B. and Youssef, S. B. (2017) 'The role of renewable energy and agriculture in reducing CO2 emissions: Evidence for North Africa countries', *Ecological indicators,* 74, pp. 295-301.

Jha, S., Kaechele, H. and Sieber, S. (2019) 'Factors influencing the adoption of water conservation technologies by smallholder farmer households in Tanzania', *Water (Switzerland),* 11(12).

Jick, T. D. (1979) 'Mixing qualitative and quantitative methods: Triangulation in action', *Administrative science quarterly,* 24(4), pp. 602-611.

Jin, S., Li, W., Cao, Y., Jones, G., Chen, J., Li, Z., Chang, Q., Yang, G. and Frewer, L. J. (2022) 'Identifying barriers to sustainable apple production: A stakeholder perspective', *Journal of Environmental Management,* 302, pp. 114082.

Jin, T. and Kim, J. (2018) 'What is better for mitigating carbon emissions–Renewable energy or nuclear energy? A panel data analysis', *Renewable and Sustainable Energy Reviews,* 91, pp. 464-471.

John, D. A. and Babu, G. R. (2021) 'Lessons from the aftermaths of green revolution on food system and health', *Frontiers in sustainable food systems,* 5, pp. 644559.

Johnson, R. B. and Christensen, L. (2019) *Educational research: Quantitative, qualitative, and mixed approaches.* Sage publications.

Jöreskog, K. G. and Sörbom, D. (1996) *LISREL 8: User's reference guide.* Scientific Software International.

Junge, B., Deji, O., Abaidoo, R., Chikoye, D. and Stahr, K. (2009) 'Farmers' adoption of soil conservation technologies: A case study from Osun state, Nigeria', *Journal of agricultural education and Extension,* 15(3), pp. 257-274.

Kabeer, N. (1999) 'Resources, agency, achievements: Reflections on the measurement of women's empowerment', *Development and change,* 30(3), pp. 435-464.

Kabwe, G., Bigsby, H. R. and Cullen, R. (2009) 'Factors influencing adoption of agroforestry among smallholder farmers in Zambia'.

Kalinda, T. (2019) 'An Assessment of the Challenges affecting Smallholder Farmers in Adopting Biogas Technology in Zambia'.

Kalogirou, S. A. (2004) 'Solar thermal collectors and applications', *Progress in energy and combustion science,* 30(3), pp. 231-295.

Kalungu, J. W. and Leal Filho, W. (2018) 'Adoption of appropriate technologies among smallholder farmers in Kenya', *Climate and Development,* 10(1), pp. 84-96.

Kamara, A., Conteh, A., Rhodes, E. R. and Cooke, R. A. (2019) 'The relevance of smallholder farming to African agricultural growth and development', *African Journal of Food, Agriculture, Nutrition and Development,* 19(1), pp. 14043-14065.

Kamwamba-Mtethiwa, J., Wiyo, K., Knox, J. and Weatherhead, K. (2021) 'Diffusion of small-scale pumped irrigation technologies and their association with farmer-led irrigation development in Malawi', *Water International,* 46(3), pp. 397-416.

Kansanga, M., Andersen, P., Kpienbaareh, D., Mason-Renton, S., Atuoye, K., Sano, Y., Antabe, R. and Luginaah, I. (2019) 'Traditional agriculture in transition: examining the impacts of agricultural modernization on smallholder farming in Ghana under the new Green Revolution', *International Journal of Sustainable Development & World Ecology,* 26(1), pp. 11-24.

Kante, M., Chepken, C. and Oboko, R. (2018) 'Effects of farmers’ peer influence on the use of ICT-based farm input information in developing countries: a case in Sikasso, Mali', *Journal of Digital Media & Interaction,* 1(1), pp. 99-116.

Karbo, R., Frewer, L., Areal, F. and Yu, E. (2022) 'Using renewable energy to meet the energy needs of smallholder farmers: Are there policies to promote adoption in Ghana?', *Ghana Journal of Agricultural Science,* 57(1), pp. 15–29-15–29.

Karbo, R. T.-v., Frewer, L. J., Areal, F., Jones, G. and Nurudeen, S. (2023) 'A Systematic Review of the Efficacy of Theories Used to Understand Farmers’ Technology Adoption Behaviour in Lower-to-Middle-Income Countries', *Development Studies Research*.

Kardooni, R., Yusoff, S. B. and Kari, F. B. (2016) 'Renewable energy technology acceptance in Peninsular Malaysia', *Energy policy,* 88, pp. 1-10.

Kawarazuka, N. (2018) 'Agricultural Mechanization: How Far Do Women Farmers Benefit?', *CGIAR Research Program on Roots, Tubers and Bananas*.

Kawarazuka, N., Prain, G., Forsythe, L., Mayanja, S., Mudege, N., Babini, C. and Polar, V. (2018) 'Gender in agricultural mechanization: Key guiding questions'.

Kc, D., Jamarkattel, D., Maraseni, T., Nandwani, D. and Karki, P. (2021) 'The Effects of tunnel technology on crop productivity and livelihood of smallholder farmers in Nepal', *Sustainability,* 13(14), pp. 7935.

Kemausuor, F., Kamp, A., Thomsen, S. T., Bensah, E. C. and Østergård, H. (2014) 'Assessment of biomass residue availability and bioenergy yields in Ghana', *Resources, Conservation and Recycling,* 86, pp. 28-37.

Khan, I. (2020) 'Impacts of energy decentralization viewed through the lens of the energy cultures framework: Solar home systems in the developing economies', *Renewable and Sustainable Energy Reviews,* 119, pp. 109576.

Khan, M. T. I., Ali, Q. and Ashfaq, M. (2018) 'The nexus between greenhouse gas emission, electricity production, renewable energy and agriculture in Pakistan', *Renewable Energy,* 118, pp. 437-451.

Khandker, V. and Gandhi, V. P. (2012) *Introduction of New Technologies in Agriculture: A Study of the Challenges in the Adoption of Hybrid Rice in India*.

Khoza, S., de Beer, L. T., van Niekerk, D. and Nemakonde, L. (2021) 'A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: application of the extended technology acceptance model', *Gender, Technology and Development,* 25(1), pp. 1-21.

Khush, G. S. (1999) 'Green revolution: preparing for the 21st century', *Genome,* 42(4), pp. 646-655.

King, W. R. and He, J. (2006) 'A meta-analysis of the technology acceptance model', *Information & management,* 43(6), pp. 740-755.

Kinyangi, A. A. (2014) *Factors influencing the adoption of agricultural technology among smallholder farmers in Kakamega north sub-county, Kenya.* University of Nairobi.

Kizito, F., Panyan, E., Ayantunde, A. A., Bossio, D., Karbo, N., Avornyo, F. K. and Tengan, K. (2014) 'Water balance dynamics in mixed crop-livestock systems of Northern Ghana: unraveling the interactions between farm-level and landscape fluxes in the face of climate change'.

Klerkx, L., Van Mierlo, B. and Leeuwis, C. (2012) 'Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions', *Farming Systems Research into the 21st century: The new dynamic*, pp. 457-483.

Kline, R. B. (2023) *Principles and practice of structural equation modeling.* Guilford publications.

Knowler, D. and Bradshaw, B. (2007) 'Farmers' adoption of conservation agriculture: A review and synthesis of recent research', *Food policy,* 32(1), pp. 25-48.
Kodirov, D., Muratov, K., Tursunov, O., Ugwu, E. and Durmanov, A. 'The use of renewable energy sources in integrated energy supply systems for agriculture'. *IOP Conference Series: Earth and Environmental Science*: IOP Publishing, 012007.
Kondo, K., Cacho, O., Fleming, E., Villano, R. A. and Asante, B. O. (2020) 'Dissemination strategies and the adoption of improved agricultural technologies: The case of improved cassava varieties in Ghana', *Technology in Society,* 63.
Korstjens, I. and Moser, A. (2018) 'Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing', *European Journal of General Practice,* 24(1), pp. 120-124.
Koyama, K. (2017) 'The Role and Future of Fossil Fuel', *IEEJ Energy Journal, Special Issue*, pp. 80-83.
Kuamoah, C. (2020) 'Renewable Energy Deployment in Ghana: The Hype, Hope and Reality', *Insight on Africa,* 12(1), pp. 45-64.
Kuehne, G., Llewellyn, R., Pannell, D. J., Wilkinson, R., Dolling, P., Ouzman, J. and Ewing, M. (2017) 'Predicting farmer uptake of new agricultural practices: A tool for research, extension and policy', *Agricultural Systems,* 156, pp. 115-125.
Kumar, C. M. S., Singh, S., Gupta, M. K., Nimdeo, Y. M., Raushan, R., Deorankar, A. V., Kumar, T. A., Rout, P. K., Chanotiya, C. and Pakhale, V. D. (2023) 'Solar energy: A promising renewable source for meeting energy demand in Indian agriculture applications', *Sustainable Energy Technologies and Assessments,* 55, pp. 102905.
Kumar, G., Engle, C. and Tucker, C. (2018) 'Factors driving aquaculture technology adoption', *Journal of the world aquaculture society,* 49(3), pp. 447-476.
Kumar, P. (2007) 'Green Revolution and its impact on environment', *International Journal of Research in Humanities & Soc. Sciences,* 5(3), pp. 54-57.
Kumar, S., Raut, R. D., Nayal, K., Kraus, S., Yadav, V. S. and Narkhede, B. E. (2021) 'To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP', *Journal of Cleaner Production,* 293, pp. 126023.
Kunen, E., Pandey, B., Foster, R., Holthaus, J., Shrestha, B. and Ngetich, B. 'Solar water pumping: Kenya and Nepal market acceleration'. *Solar World COngress 2015*.
Kuwornu, J. K., Egyir, I. S. and Anyinam, A. K. D. (2011) 'Design of Solar Drying Technology Equipment for Drying Food Consistent with Farmers' Willingness to Pay: Evidence from Ghana', *ISDE,* 2, pp. 1-27.

Kwade, P. C., Lugu, B. K., Lukman, S., Quist, C. E. and Chu, J. (2019) 'Farmers' attitude towards the use of genetically modified crop technology in Southern Ghana: The mediating role of risk perception', *AIMS Agriculture and Food,* 4(4), pp. 833-858.

Lai, P. (2017) 'The literature review of technology adoption models and theories for the novelty technology', *JISTEM-Journal of Information Systems and Technology Management,* 14(1), pp. 21-38.

Laksono, P., Mulyo, J. H. and Suryantini, A. (2022) 'Farmers’ willingness to adopt geographical indication practice in Indonesia: A psycho behavioral analysis', *Heliyon,* 8(8).

Lalani, B., Dorward, P., Holloway, G. and Wauters, E. (2016) 'Smallholder farmers' motivations for using Conservation Agriculture and the roles of yield, labour and soil fertility in decision making', *Agricultural Systems,* 146, pp. 80-90.

Landmann, D., Lagerkvist, C. J. and Otter, V. (2021) 'Determinants of Small-Scale Farmers' Intention to Use Smartphones for Generating Agricultural Knowledge in Developing Countries: Evidence from Rural India', *European Journal of Development Research,* 33(6), pp. 1435-1454.

Langyintuo, A. S. and Mekuria, M. (2008) 'Assessing the influence of neighborhood effects on the adoption of improved agricultural technologies in developing agriculture', *African Journal of Agricultural and Resource Economics,* 2(311-2016-5528), pp. 151-169.

Lassoued, R. (2014) *How Trust in the Food System and in Brands Builds Consumer Confidence in Credence Attributes: A Structural Equation Model.* University of Saskatchewan.

Lavison, R. (2013) *Factors influencing the adoption of organic fertilizers in vegetable production in Accra.* Msc Thesis, Accra Ghana.

Lawal, A. I. (2023) 'The Nexus between economic growth, energy consumption, agricultural output, and CO2 in Africa: Evidence from frequency domain estimates', *Energies,* 16(3), pp. 1239.

Lawler, J., Spencer, B., Olden, J., Kim, S.-H., Lowe, C., Bolton, S., Beamon, B., Thompson, L. and Voss, J. (2013) 'Mitigation and adaptation strategies to reduce climate vulnerabilities and maintain ecosystem services', *Climate Vulnerability*, pp. 315.

Lawra Municipal Assembly (2018) 'MUNICIPAL MEDIUM TERM DEVELOPMENT PLAN

2018-2021'.
Lee, D. R. (2005) 'Agricultural sustainability and technology adoption: Issues and policies for developing countries', *American journal of agricultural economics,* 87(5), pp. 1325-1334.
Leech, N., Barrett, K. and Morgan, G. A. (2013) *SPSS for intermediate statistics: Use and interpretation.* Routledge.
Lenka, S., Lenka, N., Sejian, V. and Mohanty, M. (2015) 'Contribution of agriculture sector to climate change', *Climate change impact on livestock: Adaptation and mitigation*, pp. 37-48.
Li, B., Ding, J., Wang, J., Zhang, B. and Zhang, L. (2021) 'Key factors affecting the adoption willingness, behavior, and willingness-behavior consistency of farmers regarding photovoltaic agriculture in China', *Energy Policy,* 149, pp. 112101.
Li, J., Feng, S., Luo, T. and Guan, Z. (2020) 'What drives the adoption of sustainable production technology? Evidence from the large scale farming sector in East China', *Journal of Cleaner Production,* 257, pp. 120611.
Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D. and Henry, K. (2014) 'Climate-smart agriculture for food security', *Nature climate change,* 4(12), pp. 1068-1072.
Liu, T., Bruins, R. J. and Heberling, M. T. (2018) 'Factors influencing farmers' adoption of best management practices: A review and synthesis', *Sustainability,* 10(2), pp. 432.
Liu, X., Zhang, S. and Bae, J. (2017) 'The nexus of renewable energy-agriculture-environment in BRICS', *Applied Energy,* 204, pp. 489-496.
Llewellyn, R. S. and Brown, B. (2020) 'Predicting Adoption of Innovations by Farmers: What is Different in Smallholder Agriculture?', *Applied Economic Perspectives and Policy,* 42(1), pp. 100-112.
Lowder, S. K., Skoet, J. and Raney, T. (2016) 'The number, size, and distribution of farms, smallholder farms, and family farms worldwide', *World Development,* 87, pp. 16-29.
Lubua, E. W. and Kyobe, M. E. (2019) 'The Influence of Socioeconomic Factors to the Use of Mobile Phones in the Agricultural Sector of Tanzania', *African Journal of Information Systems,* 11(4), pp. 352-366.
Lwiza, F., Mugisha, J., Walekhwa, P. N., Smith, J. and Balana, B. (2017) 'Dis-adoption of Household Biogas technologies in Central Uganda', *Energy for Sustainable Development,* 37, pp. 124-132.

Maarouf, H. (2019) 'Pragmatism as a supportive paradigm for the mixed research approach: Conceptualizing the ontological, epistemological, and axiological stances of pragmatism', *International Business Research,* 12(9), pp. 1-12.

MacVaugh, J. and Schiavone, F. (2010) 'Limits to the diffusion of innovation: A literature review and integrative model', *European journal of innovation management,* 13(2), pp. 197-221.

Magruder, J. R. (2018) 'An assessment of experimental evidence on agricultural technology adoption in developing countries', *Annual Review of Resource Economics,* 10, pp. 299-316.

Mahama, M., Derkyi, N. S. A. and Nwabue, C. M. (2020) 'Challenges of renewable energy development and deployment in Ghana: perspectives from developers', *GeoJournal*, pp. 1-15.

Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., Sultan, M. and Raza, A. (2023) 'Renewable energy as an alternative source for energy management in agriculture', *Energy Reports,* 10, pp. 344-359.

Makate, C. and Makate, M. (2019) 'Interceding role of institutional extension services on the livelihood impacts of drought tolerant maize technology adoption in Zimbabwe', *Technology in Society,* 56, pp. 126-133.

Maleksaeidi, H. and Keshavarz, M. (2019) 'What influences farmers' intentions to conserve on-farm biodiversity? An application of the theory of planned behavior in fars province, Iran', *Global Ecology and Conservation,* 20, pp. e00698.

Mallett, R., Hagen-Zanker, J., Slater, R. and Duvendack, M. (2012) 'The benefits and challenges of using systematic reviews in international development research', *Journal of development effectiveness,* 4(3), pp. 445-455.

Mango, N., Makate, C., Tamene, L., Mponela, P. and Ndengu, G. (2018) 'Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa', *Land,* 7(2), pp. 49.

Mapemba, L. D., Grevulo, J. A. and Mulagha, A. M. (2013) 'What drives adoption of biofuel (Jatropha Curcas) production in central eastern Malawi?', *Journal of Energy Technologies & Policy,* 3(10), pp. 75-92.

Marsh, H. W. and Hau, K.-T. (1996) 'Assessing goodness of fit: Is parsimony always desirable?', *The journal of experimental education,* 64(4), pp. 364-390.

Martinho, V. J. P. D. (2018) 'Interrelationships between renewable energy and agricultural economics: An overview', *Energy Strategy Reviews,* 22, pp. 396-409.

Martins, F., Felgueiras, C. and Smitková, M. (2018) 'Fossil fuel energy consumption in European countries', *Energy Procedia,* 153, pp. 107-111.

Masere, T. and Worth, S. (2022) 'Factors influencing adoption, innovation of new technology and decision-making by small-scale resource constrained farmers: The perspective of farmers in lower Gweru, Zimbabwe', *African Journal of Food, Agriculture, Nutrition and Development,* 22(3), pp. 20013-20035.

Masimba, F. and Zuva, T. 'A Model for the Adoption and Acceptance of Mobile Farming Platforms (MFPs) by Smallholder Farmers in Zimbabwe'. *Computer Science On-line Conference*: Springer, 710-725.

Massresha, S. E., Lema, T. Z., Neway, M. M. and Degu, W. A. (2021) 'Perception and determinants of agricultural technology adoption in North Shoa Zone, Amhara Regional State, Ethiopia', *Cogent Economics & Finance,* 9(1), pp. 1956774.

Maxwell, J. A. (2010) 'Validity: How might you be wrong', *Qualitative educational research: Readings in reflexive methodology and transformative practice,* (s 279), pp. 287.

Meadowcroft, J. and Rosenbloom, D. (2023) 'Governing the net-zero transition: Strategy, policy, and politics', *Proceedings of the National Academy of Sciences,* 120(47), pp. e2207727120.

Meda, Y. J. M., Egyir, I. S., Zahonogo, P., Jatoe, J. B. D. and Atewamba, C. (2018) 'Institutional factors and farmers' adoption of conventional, organic and genetically modified cotton in Burkina Faso', *International Journal of Agricultural Sustainability,* 16(1), pp. 40-53.

Mehrara, M. and Baghbanpour, J. (2016) 'The contribution of industry and agriculture exports to economic growth: the case of developing countries', *World Scientific News,* (46), pp. 100-111.

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W. and Nieuwenhuis, M. (2015) 'The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa', *International Journal of Agricultural Sustainability,* 13(1), pp. 40-54.

Meijerink, G. W. and Roza, P. (2007) *The role of agriculture in economic development.* Wageningen UR.

Melesse, B. (2018) 'A review on factors affecting adoption of agricultural new technologies in Ethiopia', *Journal of Agricultural Science and Food Research,* 9(3), pp. 1-4.

Mendelsohn, R. (2009) 'The impact of climate change on agriculture in developing countries', *Journal of Natural Resources Policy Research,* 1(1), pp. 5-19.

Mensah, T. N. O., Oyewo, A. S. and Breyer, C. (2021) 'The role of biomass in sub-Saharan Africa’s fully renewable power sector–The case of Ghana', *Renewable Energy*.

Mercurio, D. I. and Hernandez, A. A. 'Understanding User Acceptance of Information System for Sweet Potato Variety and Disease Classification: An Empirical Examination with an Extended Technology Acceptance Model'. 272-277.

MESTI (2015) 'National Climate Change Policy Action Programme for Implementation: 2015–2020'.

Meyers, L. S., Gamst, G. and Guarino, A. J. (2016) *Applied multivariate research: Design and interpretation.* Sage publications.

Mgale, Y. J. and Yunxian, Y. (2021) 'Price risk perceptions and adoption of management strategies by smallholder rice farmers in Mbeya region, Tanzania', *Cogent Food & Agriculture,* 7(1).

Mignouna, D. B., Manyong, V. M., Rusike, J., Mutabazi, K. and Senkondo, E. M. (2011) 'Determinants of adopting imazapyr-resistant maize technologies and its impact on household income in Western Kenya'.

Mihretie, A. A., Abebe, A. and Misganaw, G. S. (2022) 'Adoption of Tef (Eragrostis Tef) Production Technology Packages in Northwest Ethiopia', *Cogent Economics & Finance,* 10(1), pp. 2013587.

Miles, D. M., Logan, J. W., Arora, S. and Jenkins, J. N. (2016) 'On-farm resources and renewable energy in broiler chicken production: brinson farms case study', *International Journal of Poultry Science,* 15(2), pp. 41.

Millot, A., Krook-Riekkola, A. and Maïzi, N. (2020) 'Guiding the future energy transition to net-zero emissions: Lessons from exploring the differences between France and Sweden', *Energy Policy,* 139, pp. 111358.

Mills, J., Gaskell, P., Ingram, J., Dwyer, J., Reed, M. and Short, C. (2017) 'Engaging farmers in environmental management through a better understanding of behaviour', *Agriculture and human values,* 34, pp. 283-299.

Minh, T. T. and Ofosu, A. (2022) *Solar-based irrigation bundle profile and scaling in Ghana.* IWMI.

Minh, T. T., Ofosu, A. and Dickson, D. N. (2022) 'Demand-supply linkage pathway to scaling solar-based irrigation along irrigated vegetable value chains in Upper East Region, Ghana'.

Moerkerken, A., Blasch, J., Van Beukering, P. and Van Well, E. (2020) 'A new approach to explain farmers' adoption of climate change mitigation measures', *Climatic Change,* 159, pp. 141-161.

Moerkerken, A., Duijndam, S., Blasch, J., van Beukering, P. and van Well, E. (2023) 'Which farmers adopt solar energy? A regression analysis to explain adoption decisions over time', *Renewable Energy Focus,* 45, pp. 169-178.

MoFA (2007) *Food and Agriculture Sector Development Policy (FASDEP II)*.

Mogaka, B. O., Bett, H. K. and Ng'ang'a, S. K. (2021) 'Socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya', *Journal of Agriculture and Food Research,* 5.

Mogaka, V., Ehrensperger, A., Iiyama, M., Birtel, M., Heim, E. and Gmuender, S. (2014) 'Understanding the underlying mechanisms of recent Jatropha curcas L. adoption by smallholders in Kenya: A rural livelihood assessment in Bondo, Kibwezi, and Kwale districts', *Energy for sustainable development,* 18, pp. 9-15.

Mohajan, H. K. (2018) 'Qualitative research methodology in social sciences and related subjects', *Journal of Economic Development, Environment and People,* 7(1), pp. 23-48.

Mohammed, K., Batung, E., Saaka, S. A., Kansanga, M. M. and Luginaah, I. (2023) 'Determinants of mechanized technology adoption in smallholder agriculture: Implications for agricultural policy', *Land Use Policy,* 129, pp. 106666.

Mohammed, Y., Mokhtar, A., Bashir, N. and Saidur, R. (2013) 'An overview of agricultural biomass for decentralized rural energy in Ghana', *Renewable and Sustainable Energy Reviews,* 20, pp. 15-25.

Moher, D., Liberati, A., Tetzlaff, J. and Altman, D. G. (2009) 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement', *Journal of Clinical Epidemiology,* 62, pp. 1006e1012.

Momvandi, A., Najafabadi, M. O., Hosseini, J. F. and Lashgarara, F. (2018) 'The Identification of Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran', *Water,* 10(11).

Mondiana, Y. Q., Pramoedyo, H. and Sumarminingsih, E. (2018) 'Structural equation modeling on Likert scale data with transformation by successive interval method and with no transformation', *Int. J. Sci. Res. Publ,* 8(5), pp. 398-405.

Mongin, P. (1998) 'Expected utility theory'.

Morgan, D. L. (1998) 'Practical strategies for combining qualitative and quantitative methods: Applications to health research', *Qualitative health research,* 8(3), pp. 362-376.

Moriarty, J. (2011) 'Qualitative methods overview'.

Morse, J. M. (1991) 'Approaches to qualitative-quantitative methodological triangulation', *Nursing research,* 40(2), pp. 120-123.

Mrema, G. C., Baker, D. and Kahan, D. (2008) *Agricultural mechanization in sub-Saharan Africa: time for a new look.* FAO.

Mukherji, A., Chowdhury, D. R., Fishman, R., Lamichhane, N., Khadgi, V. and Bajracharya, S. (2017) 'Sustainable financial solutions for the adoption of solar powered irrigation pumps in Nepal's Terai'.

Mulaik, S. A., James, L. R., Van Alstine, J., Bennett, N., Lind, S. and Stilwell, C. D. (1989) 'Evaluation of goodness-of-fit indices for structural equation models', *Psychological bulletin,* 105(3), pp. 430.

Mulugo, L., Kyazze, F. B., Kibwika, P., Kikulwe, E., Omondi, A. B. and Ajambo, S. (2020) 'Unravelling technology-acceptance factors influencing farmer use of banana tissue culture planting materials in Central Uganda', *African Journal of Science Technology Innovation & Development,* 12(4), pp. 453-465.

Musungwini, S., van Zyl, I. and Kroeze, J. H. 2022. The Perceptions of Smallholder Farmers on the Use of Mobile Technology: A Naturalistic Inquiry in Zimbabwe.

Musyoki, M. E., Busienei, J. R., Gathiaka, J. K. and Karuku, G. N. (2022) 'Linking farmers' risk attitudes, livelihood diversification and adoption of climate smart agriculture technologies in the Nyando basin, South-Western Kenya', *Heliyon*, pp. e09305.

Mutoko, M. C., Shisanya, C. A. and Hein, L. (2014) 'Fostering technological transition to sustainable land management through stakeholder collaboration in the western highlands of Kenya', *Land use policy,* 41, pp. 110-120.

Mutyasira, V., Hoag, D. and Pendell, D. (2018) 'The adoption of sustainable agricultural practices by smallholder farmers in Ethiopian highlands: An integrative approach', *Cogent Food & Agriculture,* 4(1), pp. 1552439.

Muzari, W., Gatsi, W. and Muvhunzi, S. (2012) 'The impacts of technology adoption on smallholder agricultural productivity in sub-Saharan Africa: A review', *Journal of Sustainable Development,* 5(8), pp. 69.

Mwakaje, A. G. (2008) 'Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints', *Renewable and Sustainable Energy Reviews,* 12(8), pp. 2240-2252.

Mwangi, M. and Kariuki, S. (2015) 'Factors determining adoption of new agricultural technology by smallholder farmers in developing countries', *Journal of Economics and sustainable development,* 6(5).

Mwaura, G. G., Kiboi, M. N., Bett, E. K., Mugwe, J. N., Muriuki, A., Nicolay, G. and Ngetich, F. K. (2021) 'Adoption Intensity of Selected Organic-Based Soil Fertility Management Technologies in the Central Highlands of Kenya', *Frontiers in Sustainable Food Systems,* 4.

Nampijja, D. and Birevu, P. M. 'Adoption and use of mobile technologies for learning among smallholder farmer communities in Uganda'. 83-87.

Naqshbandi, M. M., Kaur, S. and Ma, P. (2015) 'What organizational culture types enable and retard open innovation?', *Quality & Quantity,* 49, pp. 2123-2144.

National Renewable Energy Action Plan, G. N. (2015) 'National Renewable Energy Action Plans (NREAPs)
(Ghana) Period [2015-2020]'.

Ndeke, A. M., Mugwe, J. N., Mogaka, H., Nyabuga, G., Kiboi, M., Ngetich, F., Mucheru-Muna, M., Sijali, I. and Mugendi, D. (2021) 'Gender-specific determinants of Zai technology use intensity for improved soil water management in the drylands of Upper Eastern Kenya', *Heliyon,* 7(6), pp. e07217.

Ndiritu, S. W., Kassie, M. and Shiferaw, B. (2014) 'Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya', *Food Policy,* 49(P1), pp. 117-127.

Nejadrezaei, N., Allahyari, M. S., Sadeghzadeh, M., Michailidis, A. and El Bilali, H. (2018) 'Factors affecting adoption of pressurized irrigation technology among olive farmers in Northern Iran', *Applied Water Science,* 8, pp. 1-9.

Netherlands Enterprise Agency (2016) 'Business Opportunities for Renewable Energy in Ghana'.

Ng'ang'a, S. K., Jalang'o, D. A. and Girvetz, E. H. (2020) 'Adoption of technologies that enhance soil carbon sequestration in East Africa. What influence farmers' decision?', *International Soil and Water Conservation Research,* 8(1), pp. 90-101.

Nguyen, N. and Drakou, E. G. (2021) 'Farmers intention to adopt sustainable agriculture hinges on climate awareness: The case of Vietnamese coffee', *Journal of cleaner production,* 303, pp. 126828.

Niu, Z., Chen, C., Gao, Y., Wang, Y., Chen, Y. and Zhao, K. (2022) 'Peer effects, attention allocation and farmers' adoption of cleaner production technology: Taking green control techniques as an example', *Journal of Cleaner Production,* 339, pp. 130700.

Nnanna, G. (2010) 'Addressing the food versus fuel debate in Ghana', *Business Day,* 8.

Noble, H. and Smith, J. (2015) 'Issues of validity and reliability in qualitative research', *Evidence-based nursing,* 18(2), pp. 34-35.

Nonvide, G. M. A. (2020) 'Identification of Factors Affecting Adoption of Improved Rice Varieties among Smallholder Farmers in the Municipality of Malanville, Benin', *Journal of Agricultural Science and Technology,* 22(2), pp. 305-316.

Nwokoye, E. S., Oyim, A., Dimnwobi, S. K. and Ekesiobi, C. S. (2019) 'Socioeconomic determinants of information and communication technology adoption among rice farmers in Ebonyi State, Nigeria', *Nigerian Journal of Economic and Social Studies,* 61(3), pp. 367-397.

Nyairo, N. M., Pfeiffer, L., Spaulding, A. and Russell, M. (2022) 'Farmers' attitudes and perceptions of adoption of agricultural innovations in Kenya: a mixed methods analysis', *Journal of Agriculture and Rural Development in the Tropics and Subtropics,* 123(1), pp. 147-160.

Nyamwena-Mukonza, C. (2012) 'Adoption of biofuels technologies by smallholder farmers in Zimbabwe', *8th PhD GLOBELICS Academy in Brazil www. redesist. ie. ufrj. br/ga2012/paper/ChipoMukonza. pdf*.

Nyasulu, C. and Dominic Chawinga, W. (2019) 'Using the decomposed theory of planned behaviour to understand university students' adoption of WhatsApp in learning', *E-Learning and Digital Media,* 16(5), pp. 413-429.

O'Shea, R., O'Donoghue, C., Ryan, M. and Breen, J. (2018) *Understanding farmers: From adoption to attitudes*.

Obeng-Darko, N. A. (2019) 'Why Ghana will not achieve its renewable energy target for electricity. Policy, legal and regulatory implications', *Energy Policy,* 128, pp. 75-83.

Obiero, K. O., Waidbacher, H., Nyawanda, B. O., Munguti, J. M., Manyala, J. O. and Kaunda-Arara, B. (2019) 'Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya', *Aquaculture International,* 27(6), pp. 1689-1707.

Obisesan, A. (2014) 'Gender differences in technology adoption and welfare impact among Nigerian farming households'.

Odeh, L. E. (2010) 'A comparative analysis of global north and global south economies'.

Ofosu, A. and Minh, T. T. (2021) 'Small-Scale Irrigation Dialogue Space: Understanding the scalability of solar-powered irrigation in Ghana: market segmentation and mapping pump suitability'.

Ogunlana, E. A. (2004) 'The technology adoption behavior of women farmers: The case of alley farming in Nigeria', *Renewable Agriculture and Food Systems,* 19(1), pp. 57-65.

Ojiako, I. A., Manyong, V. M. and Ikpi, A. E. (2007) 'Determinants of rural farmers' improved soybean adoption decisions in northern Nigeria', *Journal of Food Agriculture & Environment,* 5(2), pp. 215-223.

Okello, J., Zhou, Y., Barker, I. and Schulte-Geldermann, E. (2019) 'Motivations and Mental Models Associated with Smallholder Farmers' Adoption of Improved Agricultural Technology: Evidence from Use of Quality Seed Potato in Kenya', *European Journal of Development Research,* 31(2), pp. 271-292.

Okpukpara, B. (2010) 'Credit constraints and adoption of modern cassava production technologies in rural farming communities of Anambra State, Nigeria', *African Journal of Agricultural Research,* 5(24), pp. 3379-3386.

Oliveira, T., Faria, M., Thomas, M. A. and Popovič, A. (2014) 'Extending the understanding of mobile banking adoption: When UTAUT meets TTF and ITM', *International journal of information management,* 34(5), pp. 689-703.

Olwande, J., Sikei, G. and Mathenge, M. (2009) 'Agricultural technology adoption: A panel analysis of smallholder farmers' fertilizer use in Kenya'.

Ommani, A. R., Chizari, M., Salmanzadeh, C. and Hosaini, J. F. A. (2009) 'Predicting adoption behavior of farmers regarding on-farm sustainable water resources management (SWRM): Comparison of models', *Journal of Sustainable Agriculture,* 33(5), pp. 595-616.

Opsomer, J. D., Francisco-Fernandez, M. and Li, X. (2012) 'Model-based non-parametric variance estimation for systematic sampling', *Scandinavian Journal of Statistics,* 39(3), pp. 528-542.

Osei, G., Arthur, R., Afrane, G. and Agyemang, E. O. (2013) 'Potential feedstocks for bioethanol production as a substitute for gasoline in Ghana', *Renewable Energy,* 55, pp. 12-17.

Otchere-Appiah, G. and Hagan, E. (2014) 'Potential for electricity generation from maize residues in rural Ghana: a case study of Brong Ahafo region', *Int J Renewable Energy Technol Res,* 3(5), pp. 1-10.

Otieno, W., Ochilo, W., Migiro, L., Jenner, W. and Kuhlmann, U. (2021) 'Tools for pest and disease management by stakeholders: A case study on Plantwise'.

Owusu, P. A. and Asumadu-Sarkodie, S. (2016) 'A review of renewable energy sources, sustainability issues and climate change mitigation', *Cogent Engineering,* 3(1), pp. 1167990.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A. and Brennan, S. E. (2021) 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews', *Systematic reviews,* 10(1), pp. 1-11.

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F. and Wilkinson, R. (2006) 'Understanding and promoting adoption of conservation practices by rural landholders', *Australian journal of experimental agriculture,* 46(11), pp. 1407-1424.

Panwar, N., Kaushik, S. and Kothari, S. (2011) 'Role of renewable energy sources in environmental protection: A review', *Renewable and sustainable energy reviews,* 15(3), pp. 1513-1524.

Paris, T., Diaz, C. and Hossain, I. (2011) 'Participatory evaluation of a rice flour mill by poor rural women: lessons from Bangladesh', *Gender, Technology and Development,* 15(2), pp. 275-299.

Park, N. and Peterson, C. (2008) 'The cultivation of character strengths', *Teaching for wisdom: Cross-cultural perspectives on fostering wisdom*, pp. 59-77.

Parker, C., Scott, S. and Geddes, A. (2019) 'Snowball sampling', *SAGE research methods foundations*.

Pattanayak, S. K., Mercer, D. E., Sills, E. and Yang, J.-C. (2003) 'Taking stock of agroforestry adoption studies', *Agroforestry systems,* 57(3), pp. 173-186.

Pestisha, A., Gabnai, Z., Chalgynbayeva, A., Lengyel, P. and Bai, A. (2023) 'On-farm renewable energy systems: A systematic review', *Energies,* 16(2), pp. 862.

Peterman, A., Behrman, J. A. and Quisumbing, A. R. (2014) 'A review of empirical evidence on gender differences in nonland agricultural inputs, technology, and services in developing countries', *Gender in Agriculture: Closing the Knowledge Gap*, pp. 145-186.

Peterson, C. and Seligman, M. E. (2004) *Character strengths and virtues: A handbook and classification.* Oxford University Press.

Podestá, G. P., Natenzon, C. E., Hidalgo, C. and Toranzo, F. R. (2013) 'Interdisciplinary production of knowledge with participation of stakeholders: a case study of a collaborative project on climate variability, human decisions and agricultural ecosystems in the Argentine Pampas', *Environmental science & policy,* 26, pp. 40-48.

Popper, K. R. (1957) 'Philosophy of science: A personal report'.

Praburaj, L., Design, F. and Nadu, T. (2018) 'Role of agriculture in the economic development of a country', *Shanlax International Journal of Commerce,* 6(3), pp. 1-5.

PracticalAction (2010) *Poor people's energy outlook 2010.* Practical Action Publishing.

Putra, A., Czekaj, T. and Lund, M. 'Study of the biogas technology adoption as a livestock waste management among smallholder farmers in Indonesia'. *IOP Conference Series: Earth and Environmental Science*: IOP Publishing, 012070.

Quansah, D. A. and Adaramola, M. S. (2018) 'Ageing and degradation in solar photovoltaic modules installed in northern Ghana', *Solar Energy,* 173, pp. 834-847.

Quartey, E. (2012) 'Briquetting agricultural waste as an energy source in Ghana', *Recent Researches in Environment, Energy Planning and Pollution*, pp. 200-204.

Rahman, M. M., Khan, I., Field, D. L., Techato, K. and Alameh, K. (2022) 'Powering agriculture: Present status, future potential, and challenges of renewable energy applications', *Renewable Energy,* 188, pp. 731-749.

Rahman, M. S., Sujan, M. H. K., Sherf-Ui-Alam, M. and Kabir, M. H. (2021) 'Adoption and dis-adoption of farm mechanization in Bangladesh: Case of rice-wheat thresher', *Emirates Journal of Food and Agriculture,* 33(12), pp. 1000-1007.

Ramayah, T., Rouibah, K., Gopi, M. and Rangel, G. J. (2009) 'A decomposed theory of reasoned action to explain intention to use Internet stock trading among Malaysian investors', *Computers in Human Behavior,* 25(6), pp. 1222-1230.

Rasoulinezhad, E. and Taghizadeh-Hesary, F. (2022) 'Role of green finance in improving energy efficiency and renewable energy development', *Energy Efficiency,* 15(2), pp. 14.

Rauniyar, G. P. and Goode, F. M. (1992) 'Technology adoption on small farms', *World Development,* 20(2), pp. 275-282.

Razavi, S. (2012) 'World development report 2012: Gender equality and development—A commentary', *Development and Change,* 43(1), pp. 423-437.

Rehman, A., Jingdong, L., Khatoon, R., Hussain, I. and Iqbal, M. S. (2016) 'Modern agricultural technology adoption its importance, role and usage for the improvement of agriculture', *Life Science Journal,* 14(2), pp. 70-74.

REN21 (2017) *RENEWABLES 2017*
GLOBAL STATUS REPORT, Paris: REN21 Secretariat.

RenewableEnergyTechnologyTransferProject, C.-G.-S. (2018) *A Baseline Study of Renewable Energy Technologies*
in Ghana, Accra: UNDP, Energy Commission, Ghana and The Danish Government. Available at: http://energycom.gov.gh/rett/documents-downloads (Accessed: 18th May, 2020.).

Rezaei, R., Safa, L. and Ganjkhanloo, M. M. (2020) 'Understanding farmers' ecological conservation behavior regarding the use of integrated pest management-an application of the technology acceptance model', *Global Ecology and Conservation,* 22, pp. e00941.

Rezaei-Moghaddam, K., Vatankhah, N. and Ajili, A. (2020) 'Adoption of pro-environmental behaviors among farmers: application of Value–Belief–Norm theory', *Chemical and Biological Technologies in Agriculture,* 7(1).

Richards, M. B., Wollenberg, E. and van Vuuren, D. (2018) 'National contributions to climate change mitigation from agriculture: allocating a global target', *Climate Policy,* 18(10), pp. 1271-1285.

Ritchie, J. and Lewis, J. (2006) 'Qualitative research practice', *A guide for*.

Rizzo, G., Migliore, G., Schifani, G. and Vecchio, R. (2023) 'Key factors influencing farmers' adoption of sustainable innovations: a systematic literature review and research agenda', *Organic Agriculture*, pp. 1-28.

Rogers, E. M. (2003) *Diffusion of Innovations.* Simon and Schuster.

Rola-Rubzen, M. F., Paris, T., Hawkins, J. and Sapkota, B. (2020) 'Improving Gender Participation in Agricultural Technology Adoption in Asia: From Rhetoric to Practical Action', *Applied Economic Perspectives and Policy,* 42(1), pp. 113-125.
Rola-Rubzen, M. F., Paris, T., Hawkins, J. and Sapkota, B. (2020) 'Improving gender participation in agricultural technology adoption in Asia: from rhetoric to practical action', *Applied Economic Perspectives and Policy,* 42(1), pp. 113-125.
Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D. and Garnett, T. (2017) 'Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures', *Global Environmental Change,* 47, pp. 1-12.
Rose, D. C., Keating, C. and Morris, C. (2018) 'Understanding how to influence farmers' decision-making behaviour: a social science literature review'.
Ruzzante, S., Labarta, R. and Bilton, A. (2021) 'Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature', *World Development,* 146, pp. 105599.
Ryan, B. (2012) 'Co-production: Option or obligation?', *Australian Journal of Public Administration,* 71(3), pp. 314-324.
Ryan, B. and Gross, N. C. (1943) 'The diffusion of hybrid seed corn in two Iowa communities', *Rural sociology,* 8(1), pp. 15.
Ryzhkov, A., Bogatova, T., Maslennikov, G., Osipov, P. and Nizov, V. 'Creation of energy-efficient and environmentally friendly energy sources on fossil fuels to address global climate issues'. *Journal of Physics: Conference Series*: IOP Publishing, 012115.
Salimi, M., Pourdarbani, R. and Asgarnezhad Nouri, B. (2020) 'FACTORS AFFECTING THE ADOPTION OF AGRICULTURAL AUTOMATION USING DAVIS'S ACCEPTANCE MODEL (CASE STUDY: ARDABIL)', *Acta Technologica Agriculturae,* 23(1), pp. 30-39.
Saliou, I. O., Zannou, A., Aoudji, A. K. N. and Honlonkou, A. N. (2020) 'Drivers of Mechanization in Cotton Production in Benin, West Africa', *Agriculture-Basel,* 10(11).
Sam, K. O., Botchway, V. A., Karbo, N., Essegbey, G. O., Nutsukpo, D. K. and Zougmoré, R. B. (2020) 'Evaluating the utilisation of Climate-Smart Agriculture (CSA) technologies and practices among smallholder farmers in The Lawra, Jirapa and Nandom districts of Ghana', *Ghana Journal of Agricultural Science,* 55(2), pp. 122-144.

Saris, W. E., Satorra, A. and Sörbom, D. (1987) 'The detection and correction of specification errors in structural equation models', *Sociological methodology*, pp. 105-129.

Sarpong, D. B., Mabhaudhi, T., Minh, T. and Cofie, O. (2022) 'Sustainable financing ecosystem for cocoa irrigation in Ghana: a literature review'.

Satyavathi, C. T., Bharadwaj, C. and Brahmanand, P. (2010) 'Role of farm women in agriculture: Lessons learned', *Gender, Technology and Development,* 14(3), pp. 441-449.

Savalei, V. and Bentler, P. M. (2006) 'Structural equation modeling', *The handbook of marketing research: Uses, misuses, and future advances,* 330, pp. 36.

Schermelleh-Engel, K., Moosbrugger, H. and Müller, H. (2003) 'Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures', *Methods of psychological research online,* 8(2), pp. 23-74.

Schoemaker, P. J. (1982) 'The expected utility model: Its variants, purposes, evidence and limitations', *Journal of economic literature*, pp. 529-563.

Schoneveld, G. C., German, L. A. and Nutakor, E. (2011) 'Land-based Investments for Rural Development? A Grounded Analysis of the Local Impacts of Biofuel Feedstock Plantations in Ghana', *Ecology and Society,* 16(4).

Schut, M., van Paassen, A., Leeuwis, C. and Klerkx, L. (2014) 'Towards dynamic research configurations: A framework for reflection on the contribution of research to policy and innovation processes', *Science and public policy,* 41(2), pp. 207-218.

Schwerhoff, G. and Sy, M. (2017) 'Financing renewable energy in Africa–Key challenge of the sustainable development goals', *Renewable and Sustainable Energy Reviews,* 75, pp. 393-401.

Sebuliba, E., Isubikalu, P., Turyahabwe, N., Mwanjalolo, J. G. M., Eilu, G., Kebirungi, H., Egeru, A. and Ekwamu, A. 'Factors influencing farmer choices of use of shade trees in coffee fields around Mount Elgon, Eastern Uganda', *Small-Scale Forestry*.

Sell, M. and Minot, N. 'What factors explain women's empowerment? decision-making among small-scale farmers in Uganda'. *Women's Studies International Forum*: Elsevier, 46-55.

Senyolo, M. P., Long, T. B., Blok, V. and Omta, O. (2018) 'How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa', *Journal of Cleaner Production,* 172, pp. 3825-3840.

Sertoglu, K., Ugural, S. and Bekun, F. V. (2017) 'The contribution of agricultural sector on economic growth of Nigeria', *International Journal of Economics and Financial Issues,* 7(1), pp. 547-552.
Shah, S. S., Shah, A. A. and Khaskhell, N. (2018) 'Pragmatism research paradigm: a philosophical framework of advocating methodological pluralism in social science research', *Journal of Grassroot,* 52(1).
Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P. and Stewart, L. A. (2015) 'Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation', *Bmj,* 349.
Shao, Y., Wang, Z., Zhou, Z., Chen, H., Cui, Y. and Zhou, Z. (2022) 'Determinants affecting public intention to use micro-vertical farming: a survey investigation', *Sustainability,* 14(15), pp. 9114.
Sharifzadeh, M. S., Damalas, C. A., Abdollahzadeh, G. and Ahmadi-Gorgi, H. (2017) 'Predicting adoption of biological control among Iranian rice farmers: An application of the extended technology acceptance model (TAM2)', *Crop Protection,* 96, pp. 88-96.
Sharma, G. (2017) 'Pros and cons of different sampling techniques', *International journal of applied research,* 3(7), pp. 749-752.
Shaw, I. (2003) 'Qualitative research and outcomes in health, social work and education', *Qualitative Research,* 3(1), pp. 57-77.
Sheikh, A. T., Mugera, A., Pandit, R., Burton, M. and Davies, S. (2022) 'The adoption of laser land leveler technology and its impact on groundwater use in irrigated farmland in Punjab, Pakistan', *Land Degradation & Development*.
Sheth, J. N., Newman, B. I. and Gross, B. L. (1991) 'Why we buy what we buy: A theory of consumption values', *Journal of business research,* 22(2), pp. 159-170.
Shi, Y., Siddik, A., Masukujjaman, M., Zheng, G. W., Hamayun, M. and Ibrahim, A. M. (2022) 'The Antecedents of Willingness to Adopt and Pay for the IoT in the Agricultural Industry: An Application of the UTAUT 2 Theory', *Sustainability,* 14(11).
Sileshi, M., Kadigi, R., Mutabazi, K. and Sieber, S. (2019) 'Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia', *International Soil and Water Conservation Research,* 7(4), pp. 354-361.
Silva, A. G., Canavari, M. and Sidali, K. L. (2018) 'A Technology Acceptance Model of common bean growers' intention to adopt Integrated Production in the Brazilian Central Region', *Die Bodenkultur: Journal of Land Management, Food and Environment,* 68(3), pp. 131.

Silva, L. M. d., Bitencourt, C. C., Faccin, K. and Iakovleva, T. (2019) 'The role of stakeholders in the context of responsible innovation: A meta-synthesis', *Sustainability,* 11(6), pp. 1766.

Sims, B. and Kienzle, J. (2017) 'Sustainable agricultural mechanization for smallholders: what is it and how can we implement it?', *Agriculture,* 7(6), pp. 50.

Simtowe, F. (2006) 'Can risk-aversion towards fertilizer explain part of the non-adoption puzzle for hybrid maize? Empirical evidence from Malawi', *Journal of Applied Sciences,* 6(7), pp. 1490-1498.

Singh, D. and Singh, P. (1977) 'New systematic sampling', *Journal of Statistical Planning and Inference,* 1(2), pp. 163-177.

Singh, J. and Kumari, M. (2023) 'Socio-economic Impacts of Agricultural Technologies on Farmers' Livelihood', *National Academy Science Letters*, pp. 1-5.

Smith, P. and Gregory, P. J. (2013) 'Climate change and sustainable food production', *Proceedings of the nutrition society,* 72(1), pp. 21-28.

Smitha, S. and Devi, M. (2018) 'Linkage among stakeholders in livestock sector-a technology adoption perspective', *Agriculture Update,* 13(4), pp. 470-476.

Sodjinou, E., Glin, L. C., Nicolay, G., Tovignan, S. and Hinvi, J. (2015) 'Socioeconomic determinants of organic cotton adoption in Benin, West Africa', *Agricultural and Food Economics,* 3(1), pp. 1-22.

Sotnyk, I., Kurbatova, T., Kubatko, O., Prokopenko, O., Prause, G., Kovalenko, Y., Trypolska, G. and Pysmenna, U. (2021) 'Energy security assessment of emerging economies under global and local challenges', *Energies,* 14(18), pp. 5860.

Sraboni, E., Malapit, H. J., Quisumbing, A. R. and Ahmed, A. U. (2014) 'Women's empowerment in agriculture: What role for food security in Bangladesh?', *World development,* 61, pp. 11-52.

Sserunkuuma, D. (2005) 'The adoption and impact of improved maize and land management technologies in Uganda', *eJADE: electronic Journal of Agricultural and Development Economics,* 2(853-2016-56118), pp. 67-84.

Stapleton, C. D. (1997) 'Basic Concepts and Procedures of Confirmatory Factor Analysis'.

Stevens, J. (1996) 'Categorical data: The log linear model', *Applied multivariate statistics for the social sciences (3rd ed., pp. 518-557). Mahwah, NJ: Lawrence Erlbaum Associates*.

Stock, R., Nyantakyi-Frimpong, H., Antwi-Agyei, P. and Yeleliere, E. (2023) 'Volta photovoltaics: Ruptures in resource access as gendered injustices for solar energy in Ghana', *Energy Research & Social Science,* 103, pp. 103222.

Stringer, L. C., Fraser, E. D., Harris, D., Lyon, C., Pereira, L., Ward, C. F. and Simelton, E. (2020) 'Adaptation and development pathways for different types of farmers', *Environmental Science & Policy,* 104, pp. 174-189.

Sukamolson, S. (2007) 'Fundamentals of quantitative research', *Language Institute Chulalongkorn University,* 1(3), pp. 1-20.

Sunny, F. A., Fu, L., Rahman, M. S. and Huang, Z. (2022) 'Determinants and Impact of Solar Irrigation Facility (SIF) Adoption: A Case Study in Northern Bangladesh', *Energies,* 15(7), pp. 2460.

Sutherland, L.-A., Peter, S. and Zagata, L. (2015) 'Conceptualising multi-regime interactions: The role of the agriculture sector in renewable energy transitions', *Research Policy,* 44(8), pp. 1543-1554.

Taghizadeh-Hesary, F. and Yoshino, N. (2020) 'Sustainable solutions for green financing and investment in renewable energy projects', *Energies,* 13(4), pp. 788.

Takahashi, K., Muraoka, R. and Otsuka, K. (2020) 'Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature', *Agricultural Economics,* 51(1), pp. 31-45.

Tama, R. A. Z., Ying, L., Yu, M., Hoque, M. M., Adnan, K. M. and Sarker, S. A. (2021) 'Assessing farmers' intention towards conservation agriculture by using the Extended Theory of Planned Behavior', *Journal of Environmental Management,* 280, pp. 111654.

Tan, C.-S., Ooi, H.-Y. and Goh, Y.-N. (2017) 'A moral extension of the theory of planned behavior to predict consumers' purchase intention for energy-efficient household appliances in Malaysia', *Energy Policy,* 107, pp. 459-471.

Tanko, M. (2022) 'Nexus of risk preference, culture and religion in the adoption of improved rice varieties: Evidence from Northern Ghana', *Land Use Policy,* 115.

Tanko, M. and Ismaila, S. (2021) 'How culture and religion influence the agriculture technology gap in Northern Ghana', *World Development Perspectives,* 22, pp. 100301.

Tanko, M., Muhammed, M. A. and Ismaila, S. (2023) 'Reshapping agriculture technology adoption thinking: Malthus, Borlaug and Ghana's fail green revolution', *Heliyon*, pp. e12783.

Taylor and Todd (1995a) 'Decomposition and crossover effects in the theory of planned behavior: A study of consumer adoption intentions', *International journal of research in marketing,* 12(2), pp. 137-155.
Taylor and Todd (1995b) 'Understanding information technology usage: A test of competing models', *Information systems research,* 6(2), pp. 144-176.
Tenny, S., Brannan, G. D., Brannan, J. M. and Sharts-Hopko, N. C. (2017) 'Qualitative study'.
Testa, F., Tessitore, S., Buttol, P., Iraldo, F. and Cortesi, S. (2022) 'How to overcome barriers limiting LCA adoption? The role of a collaborative and multi-stakeholder approach', *The International Journal of Life Cycle Assessment,* 27(7), pp. 944-958.
Tetteh, E., Opareh, N., Ampadu, R. and Antwi, K. B. (2014) 'Impact of climate change: Views and perceptions of policy makers on smallholder agriculture in Ghana', *International Journal of Sciences: Basic and Applied Research,* 1(13), pp. 79-89.
Thomsen, S. T. (2014) 'Bioenergy from agricultural residues in Ghana'.
Thorogood, N. and Green, J. (2018) 'Qualitative methods for health research', *Qualitative methods for health research*, pp. 1-440.
Tinh, L., Hung, P. T. M., Dzung, D. G. and Trinh, V. H. D. (2019) 'Determinants of farmers' intention of applying new technology in production: The case of vietgap standard adoption in Vietnam', *Asian Journal of Agriculture and Rural Development,* 9(2), pp. 164-178.
Tolassa, T. B. and Jara, G. O. (2022) 'Factors affecting improved seed and soil conservation technology adoptions in Bore District', *Economic Research-Ekonomska Istraživanja*, pp. 1-12.
Tongco, M. D. C. (2007) 'Purposive sampling as a tool for informant selection'.
Tongwane, M. I. and Moeletsi, M. E. (2018) 'A review of greenhouse gas emissions from the agriculture sector in Africa', *Agricultural systems,* 166, pp. 124-134.
Tran-Nam, Q. and Tiet, T. (2022) 'The role of peer influence and norms in organic farming adoption: Accounting for farmers' heterogeneity', *Journal of Environmental Management,* 320, pp. 115909.
Tubiello, F. N., Salvatore, M., Rossi, S., Ferrara, A., Fitton, N. and Smith, P. (2013) 'The FAOSTAT database of greenhouse gas emissions from agriculture', *Environmental Research Letters,* 8(1), pp. 015009.
Tuckett, A. G. (2005) 'Applying thematic analysis theory to practice: A researcher's experience', *Contemporary nurse,* 19(1-2), pp. 75-87.

Uaiene, R. N., Arndt, C. and Masters, W. (2009) 'Determinants of agricultural technology adoption in Mozambique', *Discussion papers,* 67.
Ugochukwu, A. and Phillips, P. (2018) 'Technology Adoption by Agricultural Producers: A Review of the Literature', pp. 361-377.
Ulhaq, I., Pham, N. T. A., Le, V., Pham, H.-C. and Le, T. C. (2022) 'Factors influencing intention to adopt ICT among intensive shrimp farmers', *Aquaculture,* 547, pp. 737407.
Ullman, J. B. and Bentler, P. M. (2012) 'Structural equation modeling', *Handbook of Psychology, Second Edition,* 2.
UNDP (2018) 'Solar-Powered Irrigation: A Boost for Farming Productivity'. Available at: https://www.gh.undp.org/content/ghana/en/home/presscenter/articles/2018/solar_power_irrigation.html (Accessed: 18th May, 2020.).
United Nations (2015) 'United Nations transforming our world: the 2030 agenda for sustainable development', *Division for Sustainable Development Goals: New York, NY, USA*.
Valizadeh, N., Rezaei-Moghaddam, K. and Hayati, D. (2020) 'Analyzing Iranian farmers' behavioral intention towards acceptance of drip irrigation using extended technology acceptance model', *Journal of Agricultural Science and Technology,* 22(5), pp. 1177-1190.
Van der Knaap, L. M., Leeuw, F. L., Bogaerts, S. and Nijssen, L. T. (2008) 'Combining Campbell standards and the realist evaluation approach: the best of two worlds?', *American journal of evaluation,* 29(1), pp. 48-57.
Van Hulst, F. J. and Posthumus, H. (2016) 'Understanding (non-) adoption of conservation agriculture in Kenya using the reasoned action approach', *Land Use Policy,* 56, pp. 303-314.
van Vliet, J. A., Slingerland, M. A., Waarts, Y. R. and Giller, K. E. (2021) 'A living income for cocoa producers in Côte d'Ivoire and Ghana?', *Frontiers in Sustainable Food Systems,* 5, pp. 732831.
Venkatesh, V., Morris, M. G., Davis, G. B. and Davis, F. D. (2003) 'User acceptance of information technology: Toward a unified view', *MIS quarterly*, pp. 425-478.
Venkatesh, V., Thong, J. Y. and Xu, X. (2012) 'Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology', *MIS quarterly*, pp. 157-178.

Vincent, A. and Balasubramani, N. (2021) 'Climate-smart agriculture (CSA) and extension advisory service (EAS) stakeholders' prioritisation: a case study of Anantapur district, Andhra Pradesh, India', *Journal of Water and Climate change,* 12(8), pp. 3915-3931.

Vrolijk, F. (2013) 'The local impacts of land grabbing for biofuel feedstock plantations in Ghana', *Van Hall Larenstein University of Applied Sciences, Tropenbos International, August2013 Velp, Netherland. 61p Accessed June,* 21.

Wacker, J. G. (1998) 'A definition of theory: research guidelines for different theory-building research methods in operations management', *Journal of operations management,* 16(4), pp. 361-385.

Wahyudi, J. (2017) 'The Determinant Factors of Biogas Technology Adoption in Cattle Farming: Evidences from Pati, Indonesia', *International Journal of Renewable Energy Development,* 6(3).

Wang, W., Wang, J., Liu, K. and Wu, Y. J. (2020) 'Overcoming barriers to agriculture green technology diffusion through stakeholders in China: A social network analysis', *International journal of environmental research and public health,* 17(19), pp. 6976.

Wang, Y.-n., Jin, L. and Mao, H. (2019) 'Farmer cooperatives' intention to adopt agricultural information technology—Mediating effects of attitude', *Information Systems Frontiers,* 21, pp. 565-580.

Watson, R. (2015) 'Quantitative research', *Nursing standard,* 29(31).

Wesseh Jr, P. K. and Lin, B. (2017) 'Is renewable energy a model for powering Eastern African countries transition to industrialization and urbanization?', *Renewable and Sustainable Energy Reviews,* 75, pp. 909-917.

Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L. and Campbell, B. (2018) 'Scaling up agricultural interventions: Case studies of climate-smart agriculture', *Agricultural Systems,* 165, pp. 283-293.

Weyori, A. E., Amare, M., Garming, H. and Waibel, H. (2018) 'Agricultural innovation systems and farm technology adoption: findings from a study of the Ghanaian plantain sector', *Journal of Agricultural Education & Extension,* 24(1), pp. 65-87.

Wu, Y. and Liu, S. (2012) 'Impacts of biofuels production alternatives on water quantity and quality in the Iowa River Basin', *Biomass and Bioenergy,* 36, pp. 182-191.

Wyborn, C., Datta, A., Montana, J., Ryan, M., Leith, P., Chaffin, B., Miller, C. and Van Kerkhoff, L. (2019) 'Co-producing sustainability: reordering the governance of science, policy, and practice', *Annual Review of Environment and Resources,* 44, pp. 319-346.

Yamane, Y. (1967) 'Mathematical formulae for sample size determination', *J. Mathemetics,* 1, pp. 1-29.
Yami, M., van Asten, P., Hauser, M., Schut, M. and Pali, P. (2019) 'Participation without negotiating: Influence of stakeholder power imbalances and engagement models on agricultural policy development in Uganda', *Rural Sociology,* 84(2), pp. 390-415.
Yamoah, F. A., Kaba, J. S., Amankwah-Amoah, J. and Acquaye, A. (2020) 'Stakeholder collaboration in climate-smart agricultural production innovations: Insights from the cocoa industry in Ghana', *Environmental Management,* 66, pp. 600-613.
Yankey, V., Hofer, A. and Kraft, D. (2011) 'Country Chapter: Ghana', *Renewable Energies in West Africa. Regional reports on potential and markets,* 17.
Yazdanpanah, M., Hayati, D., Hochrainer-Stigler, S. and Zamani, G. H. (2014) 'Understanding farmers' intention and behavior regarding water conservation in the Middle-East and North Africa: A case study in Iran', *Journal of environmental management,* 135, pp. 63-72.
Yazdanpanah, M., Komendantova, N. and Zobeidi, T. (2022) 'Explaining intention to apply renewable energy in agriculture: the case of broiler farms in Southwest Iran', *International Journal of Green Energy,* 19(8), pp. 836-846.
Yengoh, G., Frederick, A. and Svensson, M. G. (2009) 'Technology adoption in small-scale agriculture: the case of Cameroon and Ghana'.
Yerebakan, M. O., Chen, Y., Tatsch, C. A., Gu, Y. and Hu, B. 'Factors that Affect Acceptance of Agricultural Related Robotic or Wearable Technology by Agricultural Stakeholders: A Pilot Survey'. *2022 IEEE 3rd International Conference on Human-Machine Systems (ICHMS)*: IEEE, 1-6.
Yigezu, Y. A., Mugera, A., El-Shater, T., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y. and Loss, S. (2018) 'Enhancing adoption of agricultural technologies requiring high initial investment among smallholders', *Technological Forecasting and Social Change,* 134, pp. 199-206.
Yin, R. K. (2009) *Case study research: Design and methods.* sage.
Yogarajan, L., Masukujjaman, M., Ali, M. H., Khalid, N., Osman, L. H. and Alam, S. S. (2023) 'Exploring the hype of blockchain adoption in agri-food supply chain: a systematic literature review', *Agriculture,* 13(6), pp. 1173.
Yokamo, S. (2020) 'Adoption of improved agricultural technologies in developing countries: literature review', *Int. J. Food Sci. Agric,* 4(2), pp. 183-190.

Yvonne Feilzer, M. (2010) 'Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm', *Journal of mixed methods research,* 4(1), pp. 6-16.

Zakaria, A., Alhassan, S. I., Kuwornu, J. K., Azumah, S. B. and Derkyi, M. A. (2020) 'Factors influencing the adoption of climate-smart agricultural technologies among rice farmers in northern Ghana', *Earth Systems and Environment,* 4, pp. 257-271.

Zerssa, G., Feyssa, D., Kim, D.-G. and Eichler-Löbermann, B. (2021) 'Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture', *Agriculture,* 11(3), pp. 192.

Zeweld, W., Van Huylenbroeck, G., Tesfay, G. and Speelman, S. (2017) 'Smallholder farmers' behavioural intentions towards sustainable agricultural practices', *Journal of environmental management,* 187, pp. 71-81.

Zhou, D. Y. and Abdullah (2017) 'The acceptance of solar water pump technology among rural farmers of northern Pakistan: A structural equation model', *Cogent Food & Agriculture,* 3(1).

Zhou, L., Zhang, F., Zhou, S. and Turvey, C. G. (2020) 'The peer effect of training on farmers' pesticides application: a spatial econometric approach', *China Agricultural Economic Review,* 12(3), pp. 481-505.

Zikmund, W. G., Babin, B. J., Carr, J. C. and Griffin, M. (2013) *Business research methods.* Cengage learning.

Zolait, A. H. S. (2014) 'The nature and components of perceived behavioural control as an element of theory of planned behaviour', *Behaviour & Information Technology,* 33(1), pp. 65-85.

Zolkin, A., Matvienko, E. and Shavanov, M. 'Innovative technologies in agricultural crops breeding and seed farming'. *IOP Conference Series: Earth and Environmental Science*: IOP Publishing, 022092.

Appendix A. Summary of extracted data from articles for the systematic review

Theory	Overview of Theory	Theoretical Approach and Study Application	Classification	Advantage(s)	Disadvantage(s)	Full Reference
Theory of Planned Behaviour (TPB) – (Ajzen, 1991)	The TPB suggests that a person's behaviour can be predicted by the intentions, attitude (beliefs about an attitude object, in this case, an agricultural technology), subjective norms (beliefs about others' attitude towards an object) and perceived behavioural control (beliefs about one's ability to perform a behaviour).	1. The TPB was applied to explain farmers' intended and actual adoption behaviour of soil and water conservation practices in Heris County in East Azerbaijan Province, Iran (Bagheri and Teymouri, 2022).	User Acceptance Theory	1. The TPB is an extension of the Theory of Reasoned Action, recognizing perceived behavioural control as an equally important factor in predicting behaviour. 2. The TPB provides an in-depth analysis of decisions and behaviour.	1. It is limited to measuring the individual's intention to execute a behaviour, not the actual behaviour. 2. Questionnaires can be time-consuming when strictly applied and leave little or no time for exploring other factors. Generally, the questionnaire is limited to a specific technology, making the results ungeneralizable in a broader context. 3. It lacks consideration for other explanatory factors like	Bagheri, A., & Teymouri, A. (2022). Farmers' intended and actual adoption of soil and water conservation practices. *Agricultural Water Management, 259*. doi:10.1016/j.agwat.2021.107244 Tinh, L., Hung, P. T. M., Dzung, D. G., & Trinh, V. H. D. (2019). Determinants of farmers' intention of applying new technology in production: The case of vietgap standard adoption in Vietnam. *Asian Journal of Agriculture and Rural Development, 9*(2), 164-178. Gwara, S., Wale, E., & Odindo, A. (2022). Behavioral intentions of rural farmers to recycle human excreta in agriculture. *Scientific reports, 12*(1), 1-13.

		2. The TPB was combined with EUT to investigate the influencing factors on the intention of farmers to adopt agricultural VIETGAP technology in Vietnam (Tinh *et al.*, 2019). 3. The TPB was used to explore South African rural farmers' behavioural intention to recycle human excreta in agriculture		3. It takes into consideration social pressures on the user/individual by using the social norm construct.	farmer/farm/household characteristics, farming context, and acquisition of information/learning process. 4. Monolithic and inflexible structure of belief constructs.	Landmann, D., Lagerkvist, C. J., & Otter, V. (2021). Determinants of Small-Scale Farmers' Intention to Use Smartphones for Generating Agricultural Knowledge in Developing Countries: Evidence from Rural India. *European Journal of Development Research, 33*(6), 1435-1454. doi:10.1057/s41287-020-00284-x Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532 Mutyasira, V., Hoag, D., & Pendell, D. (2018). The adoption of sustainable agricultural practices by smallholder farmers in Ethiopian highlands: An integrative approach. *Cogent Food & Agriculture, 4*(1), 1552439. Musungwini, S., van Zyl, I., & Kroeze, J. H. (2022) The Perceptions of Smallholder Farmers on the Use of Mobile Technology: A Naturalistic

		(Gwara, Wale and Odindo, 2022). 4. The TPB was combine with TAM to explore the factors influencing Indian smallholder farmers' intention to adopt smartphones to generate agricultural knowledge (Landmann, Lagerkvist and Otter, 2021). 5. The TPB was applied with TAM,				Inquiry in Zimbabwe. In*: Vol. 439 LNNS* (pp. 530-544). Bagheri, A., Bondori, A., Allahyari, M. S., & Damalas, C. A. (2019). Modeling farmers' intention to use pesticides: An expanded version of the theory of planned behavior. *Journal of environmental management, 248*. doi:10.1016/j.jenvman.2019.109291

		TRA, UTAUT, SRT, HBM and IBM to explore determinants affecting farmers' adoption of Pressurized Irrigation Systems in Iran (Momvandi *et al.*, 2018). 6. The TPB was adopted to examine the influence of psycho-social and socioeconomic factors on smallholder farmers' adoption of				

		sustainable agricultural practices in the Ethiopian Highlands (Mutyasira, Hoag and Pendell, 2018). 7. The TPB was combined with TAM and TRA to investigate smallholder farmers' perceptions of adopting mobile technology in Zimbabwe (Musungwini, van Zyl and Kroeze, 2022).				

		8. An expanded version of the TPB was applied to study farmers' intention to adopt pesticide use in Iranian agriculture (Bagheri. *et al.*, 2019).				
Utility Maximisation Theory (UMT) – Bentham and Mill (1748 -1832)	The UMT assumes that economic decisions are arrived at to attain the most positive economic outcome.	1. The UMT was combined with DOI and TRA to investigate how the risk attitudes of Ghanaian farmers are shaped by social interactions in	Decision-making Theory	1. The UMT captures 'actual' behaviour of the user/farmer using the concept of revealed preference. 2. Variables are more easily measured than psychological constructs.	1. It does not consider psychological constructs/variables in explaining/predicting an individual's behaviour.	Dadzie, S. K. N., Ndebugri, J., Inkoom, E. W., & Akuamoah-Boateng, S. (2022). Social networking and risk attitudes nexus: implication for technology adoption among smallholder cassava farmers in Ghana. *Agriculture and Food Security, 11*(1). Doi:10.1186/s40066-022-00376-3 Danso-Abbeam, G., Dagunga, G., & Ehiakpor, D. S. (2019). Adoption of Zai technology for soil fertility management: evidence from Upper East

		their information and communication networks to influence their technology adoption decision (Dadzie *et al.*, 2022). 2. The UMT was employed to identify the determinants of adopting zai technology for soil fertility management in the Upper East Region of Ghana (Danso-Abbeam,		3. The results of different studies can be compared in a broader context since the methodology in the construct is similar.		region, Ghana. *Journal of Economic Structures, 8*(1). doi:10.1186/s40008-019-0163-1 Ndeke, A. M., Mugwe, J. N., Mogaka, H., Nyabuga, G., Kiboi, M., Ngetich, F., . . . Mugendi, D. (2021). Gender-specific determinants of Zai technology use intensity for improved soil water management in the drylands of Upper Eastern Kenya. *Heliyon, 7*(6), e07217. doi:https://doi.org/10.1016/j.heliyon.2021.e07217 Baiyegunhi, L. J. S. (2015). Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa. *Water SA, 41*(1), 33-39. Chandio, A. A., & Jiang, Y. S. (2018). Factors influencing the adoption of improved wheat varieties by rural households in Sindh, Pakistan. *AIMS Agriculture and Food, 3*(3), 216-228. doi:10.3934/agrfood.2018.3.216

		Dagunga and Ehiakpor, 2019). 3. The UMT was used to evaluate gender-specific factors of choice and use intensity of the zai technology and soil water management among farmers in the drylands of Upper Eastern Kenya (Ndeke *et al.*, 2021). 4. The UMT was adopted to identify the determinants				Massresha, S. E., Lema, T. Z., Neway, M. M., & Degu, W. A. (2021). Perception and determinants of agricultural technology adoption in North Shoa Zone, Amhara Regional State, Ethiopia. *Cogent Economics & Finance, 9*(1), 1956774. Ojiako, I. A., Manyong, V. M., & Ikpi, A. E. (2007). Determinants of rural farmers' improved soybean adoption decisions in northern Nigeria. *Journal of Food Agriculture & Environment, 5*(2), 215-223. Retrieved from <Go to ISI>://WOS:000246988700046 Tolassa, T. B., & Jara, G. O. (2022). Factors affecting improved seed and soil conservation technology adoptions in Bore District. *Economic Research-Ekonomska Istraživanja*, 1-12. doi:10.1080/1331677X.2021.2021433 Awotide, B. A., Karimov, A. A., & Diagne, A. (2016). Agricultural technology adoption, commercialization and smallholder rice farmers’

		of adopting rainwater harvesting technologies for household gardening in Msinga, KwaZulu-Natal, South Africa (Baiyegunhi, 2015). 5. The UMT was employed to examine the drivers of high-yield wheat variety adoption among farmers in Sindh, Pakistan (Chandio and Jiang, 2018).				welfare in rural Nigeria. *Agricultural and Food Economics, 4*(1), 3. Mwaura, G. G., Kiboi, M. N., Bett, E. K., Mugwe, J. N., Muriuki, A., Nicolay, G., & Ngetich, F. K. (2021). Adoption Intensity of Selected Organic-Based Soil Fertility Management Technologies in the Central Highlands of Kenya. *Frontiers in Sustainable Food Systems, 4*. doi:10.3389/fsufs.2020.570190

		6. The UMT was employed to study the perception and determinants of technology adoption in the agriculture of North Shoa Zone, Amhara regional state, Ethiopia (Massresha *et al.*, 2021). 7. The UMT was adopted to explain farmers' decision to adopt improved soybean varieties in Northern				

		Nigeria (Ojiako, Manyong and Ikpi, 2007). 8. The UMT was adopted to examine drivers of improved seed and soil conservation technology adoption in the Bore District in Southern Ethiopia (Tolassa and Jara, 2022). 9. The UMT was employed to study the physical and socioeconomic factors				

		influencing the intensity adoption of improved rice varieties, the determinants of market participation and the effect on rice farmers' welfare in Nigeria (Awotide, Karimov and Diagne, 2016). 10. The UMT was used to study the specific organic-based technologies applied by farmers and				

		identify the socioeconomic factors affecting the adoption intensity of selected organic-based technologies in the Central Highlands of Kenya (Mwaura *et al.*, 2021).				
The Expected Utility Theory (EUT) – Daniel Bernoulli (1738)	The EUT posits that a person considers the risky and uncertain outlooks of new technology and will most likely adopt it if the expected utility from the new technology surpasses the old technology.	1. The EUT was adopted to understand the effects of institutional factors on farmers' adoption of conventional, organic and	Decision-making Theory	1. The theory enables a person's expected utility to be rated according to the weighting of benefit gained.	1. It does not consider psychological constructs as a predictor of a behaviour/action. 2. The theory is criticized for its unreasonable assumption in relation to the weighting of benefit gained.	Meda, Y. J. M., Egyir, I. S., Zahonogo, P., Jatoe, J. B. D., & Atewamba, C. (2018). Institutional factors and farmers' adoption of conventional, organic and genetically modified cotton in Burkina Faso. *International Journal of Agricultural Sustainability, 16*(1), 40-53. doi:10.1080/14735903.2018.1429523 Musyoki, M. E., Busienei, J. R., Gathiaka, J. K., & Karuku, G. N. (2022). Linking farmers' risk

		genetically modified cotton in Burkina Faso (Meda *et al.*, 2018). 2. The EUT was used to examine farmers' risk attitudes and household livelihood diversification influences on adopting CSA technologies in the Nyando Basin, South-Western Kenya (Musyoki *et al.*, 2022).				attitudes, livelihood diversification and adopting climate-smart agriculture technologies in the Nyando basin, South-Western Kenya. *Heliyon*, e09305. Tinh, L., Hung, P. T. M., Dzung, D. G., & Trinh, V. H. D. (2019). Determinants of farmers' intention of applying new technology in production: The case of vietgap standard adoption in Vietnam. *Asian Journal of Agriculture and Rural Development, 9*(2), 164-178. Sileshi, M., Kadigi, R., Mutabazi, K., & Sieber, S. (2019). Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. *International Soil and Water Conservation Research, 7*(4), 354-361. doi:10.1016/j.iswcr.2019.08.002 Simtowe, F. (2006). Can risk-aversion towards fertilizer explain part of the non-adoption puzzle for hybrid maize? Empirical evidence from Malawi. *Journal of Applied Sciences, 6*(7), 1490-1498.

		3. The EUT was combined with TPB to investigate the influencing factors on the intention of farmers to adopt agricultural VIETGAP technology in Vietnam (Tinh *et al.*, 2019). 4. The EUT was used to study factors determining the adoption of soil and water conservation practices by smallholder farmers in				Sodjinou, E., Glin, L. C., Nicolay, G., Tovignan, S., & Hinvi, J. (2015). Socioeconomic determinants of organic cotton adoption in Benin, West Africa. *Agricultural and Food Economics, 3*(1), 1-22. Tanko, M. (2022). Nexus of risk preference, culture and religion in the adoption of improved rice varieties: Evidence from Northern Ghana. *Land Use Policy, 115*. doi:10.1016/j.landusepol.2022.106040 Bhatta, D., Paudel, K. P., & Liu, K. (2022). Factors influencing water conservation practices adoptions by Nepali farmers. *Environment, Development and Sustainability*, 1-23. Ng'ang'a, S. K., Jalang'o, D. A., & Girvetz, E. H. (2020). Adoption of technologies that enhance soil carbon sequestration in East Africa. What influence farmers' decision? *International Soil and Water Conservation Research, 8*(1), 90-101. doi:10.1016/j.iswcr.2019.11.001

		Ethiopia (Sileshi *et al.*, 2019). 5. EUT was used to explain the association between attitude and risk towards Malawian farmers' adoption of fertilizers and hybrid maize (Simtowe, 2006). 6. The EUT was applied to examine institutional and socioeconomic factors affecting				Okpukpara, B. (2010). Credit constraints and adoption of modern cassava production technologies in rural farming communities of Anambra State, Nigeria. *African Journal of Agricultural Research, 5*(24), 3379-3386. Retrieved from <Go to ISI>://WOS:000286331800006 Mango, N., Makate, C., Tamene, L., Mponela, P., & Ndengu, G. (2018). Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa. *Land, 7*(2), 49.

		farmers' adoption of organic cotton in Benin (Sodjinou *et al.*, 2015). 7. The EUT was employed to explain the relationship between risk, religion and culture towards farmers' adoption of improved rice varieties in Northern Ghana (Tanko, 2022). 8. The EUT was used to examine				

		factors that determine water conservation practices by farmers in Nepal (Bhatta, Paudel and Liu, 2022). 9. The EUT was applied to explore determinants affecting smallholder farmers' adoption of technologies enhancing soil carbon sequestration in Kenya and Ethiopia (Ng'ang'a,				

		Jalang'o and Girvetz, 2020). 10. The EUT was used to assess credit constraints and explain factors driving the adoption of modern cassava production technologies in the Anambra State of Nigeria (Okpukpara, 2010). 11. The EUT was utilized to study the drivers for small-scale irrigation				

		farming as a climate-smart agriculture practice and the influence on household income in the Chinyanja Triangle (Mozambique, Zambia and Malawi) (Mango *et al.*, 2018).				
Diffusion of Innovations Theory (DOI) – Rogers, 1995	The theory examines the social processes which lead to a new technology/innovation adoption in different groups. Five stages are identified at which technology may be adopted. These are 1) Relative advantage	1. The DOI was combined with UMT and TRA to investigate how the risk attitudes of Ghanaian farmers are shaped by	Diffusion Theory	1. Generalizability and applicability across many disciplines. 2. It addresses technological innovations from a dual perspective to	1. Its explanatory power is sometimes limited. For instance, it does not address social determinants. 2. The theory's predictive power focuses on mass communication without considering environmental,	Dadzie, S. K. N., Ndebugri, J., Inkoom, E. W., & Akuamoah-Boateng, S. (2022). Social networking and risk attitudes nexus: implication for technology adoption among smallholder cassava farmers in Ghana. *Agriculture and Food Security, 11*(1). Doi:10.1186/s40066-022-00376-3 Mihretie, A. A., Abebe, A., & Misganaw, G. S. (2022). Adoption of Tef (Eragrostis Tef)

	[having better advantage than old technology], 2) Compatibility [new technology fits with existing cultural norms, attitudes, and beliefs], 3) Complexity [the technology is easy to understand and use], 4) Trialability [the technology that potential users can easily test], and 5) Observability [possible to see others use the technology successfully].	social interactions in the information and communication networks of farmers to influence their technology adoption decision (Dadzie *et al.*, 2022). 2. The DOI was applied to identify the determinants of adopting Tef technology packages and factors driving adoption intensity in Yilmana		enable the reduction of uncertainty about the outcomes of technology.	technological, and interpersonal factors. 3. The internal consistency can be problematic as the theory only differentiates types of adopters but fails to distinguish between different target groups within the adopters and categorizes them as unified.	Production Technology Packages in Northwest Ethiopia. *Cogent Economics & Finance, 10*(1), 2013587. Nyairo, N. M., Pfeiffer, L., Spaulding, A., & Russell, M. (2022). Farmers' attitudes and perceptions of adoption of agricultural innovations in Kenya: a mixed methods analysis. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 123*(1), 147-160. doi:10.17170/kobra-202204216055 Goswami, K., Choudhury, H. K., & Saikia, J. (2012). Factors influencing farmers' adoption of slash and burn agriculture in North East India. *Forest policy and economics, 15*, 146-151. Jha, S., Kaechele, H., & Sieber, S. (2019). Factors influencing the adoption of water conservation technologies by smallholder farmer households in Tanzania. *Water (Switzerland), 11*(12). doi:10.3390/W11122640

		Densa District, Northwest Ethiopia (Mihretie, Abebe and Misganaw, 2022). 3. The DOI was adopted and modified to study the effects of attitude and perception on smallholder farmers' adoption of agricultural innovation in Kenya (Nyairo *et al.*, 2022). 4. The DOI was used to examine the				Kwade, P. C., Lugu, B. K., Lukman, S., Quist, C. E., & Chu, J. (2019). Farmers' attitude towards the use of genetically modified crop technology in Southern Ghana: The mediating role of risk perception. *AIMS Agriculture and Food, 4*(4), 833-858. doi:10.3934/agrfood.2019.4.833 Sharifzadeh, M. S., Damalas, C. A., Abdollahzadeh, G., & Ahmadi-Gorgi, H. (2017). Predicting adoption of biological control among Iranian rice farmers: An application of the extended technology acceptance model (TAM2). *Crop protection, 96*, 88-96. Cafer, A. M., & Rikoon, J. S. (2018). Adoption of new technologies by smallholder farmers: the contributions of extension, research institutes, cooperatives, and access to cash for improving tef production in Ethiopia. *Agriculture and Human Values, 35*(3), 685-699. doi:10.1007/s10460-018-9865-5 Chinseu, E., Dougill, A., & Stringer, L. (2019). Why do smallholder farmers dis-adopt

		factors influencing farmers' adoption of slash and burn practices in Northeast India (Goswami, Choudhury and Saikia, 2012). 5. The DOI was adopted to investigate drivers affecting the adoption of water conservation technologies by smallholder farmers in Tanzania (Jha,				conservation agriculture? Insights from Malawi. *Land Degradation and Development, 30*(5), 533-543. doi:10.1002/ldr.3190 Kamwamba-Mtethiwa, J., Wiyo, K., Knox, J., & Weatherhead, K. (2021). Diffusion of small-scale pumped irrigation technologies and their association with farmer-led irrigation development in Malawi. *Water International, 46*(3), 397-416. Kondo, K., Cacho, O., Fleming, E., Villano, R. A., & Asante, B. O. (2020). Dissemination strategies and the adoption of improved agricultural technologies: The case of improved cassava varieties in Ghana. *Technology in Society, 63*. doi:10.1016/j.techsoc.2020.101408

		Kaechele and Sieber, 2019). 6. The DOI was employed to examine the influence of risk perception as a mediating tool on Ghanaian farmers' attitudes towards GMO technology (Kwade *et al.*, 2019). 7. The DOI was integrated with TAM2 to investigate the acceptance of biological control among rice farmers in				

		Iran (Sharifzadeh *et al.*, 2017). 8. The DOI was used to explore factors determining farmers' adoption of sustainable intensification practices in Ethiopia (Cafer and Rikoon, 2018). 9. The DOI was employed to explain farmers' dis-adoption of conservation agriculture in Malawi (Chinseu,				

		Dougill and Stringer, 2019). 10. The DOI was applied in a study to explain the diffusion of small-scale irrigation pumps among farmers in Malawi (Kamwamba-Mtethiwa *et al.*, 2021). 11. The DOI was used to examine the various dissemination strategies and factors determining				

		farmers' adoption of improved cassava varieties in Ghana (Kondo *et al.*, 2020).				
Technology Acceptance Model (TAM) – Davis, 1986, 1989	The TAM suggests that two main factors (perceived usefulness and perceived ease of use) together explain a person's technology adoption.	1. The TAM was used to investigate factors affecting farmers' adoption of biological inputs in Bilehsavar County of Ardabil Province, Iran (Bagheri *et al.*, 2021). 2. The TAM was used to	User Acceptance Theory	1. The TAM has proven statistically reliable in many empirical studies. 2. The TAM uses "perceived use" and "perceived ease of use" to replace the subjective norm in the TPB.	1. The theory ignores some important theoretical constructs, such as social determinants.	Bagheri, A., Bondori, A., Allahyari, M. S., & Surujlal, J. (2021). Use of biologic inputs among cereal farmers: application of technology acceptance model. *Environment, Development and Sustainability, 23*(4), 5165-5181. Doi:10.1007/s10668-020-00808-9 Contillo, G., & Tiongco, M. (2019). *Determinants of Adoption of the Rice Crop Manager System among Farmers in Pangasinan, Philippines*. Nwokoye, E. S., Oyim, A., Dimnwobi, S. K., & Ekesiobi, C. S. (2019). Socioeconomic determinants of information and communication technology adoption among rice farmers in Ebonyi State, Nigeria. *Nigerian Journal of Economic and Social Studies, 61*(3), 367-397.

		examine factors influencing farmers' adoption of Pangasinan, Philippines' rice crop management system (Contillo and Tiongco, 2019). 3. The TAM was combined with TPB to investigate the determinants of ICT adoption among rice in Ebonyi state, Nigeria (Landmann,				Landmann, D., Lagerkvist, C. J., & Otter, V. (2021). Determinants of Small-Scale Farmers' Intention to Use Smartphones for Generating Agricultural Knowledge in Developing Countries: Evidence from Rural India. *European Journal of Development Research, 33*(6), 1435-1454. doi:10.1057/s41287-020-00284-x Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532 Salimi, M., Pourdarbani, R., & Asgarnezhad Nouri, B. (2020). FACTORS AFFECTING THE ADOPTION OF AGRICULTURAL AUTOMATION USING DAVIS'S ACCEPTANCE MODEL (CASE STUDY: ARDABIL). *Acta Technologica Agriculturae, 23*(1), 30-39. doi:10.2478/ata-2020-0006

		Lagerkvist and Otter, 2021). 4. The TAM was combined with TPB, TRA, UTAUT, SRT, HBM and IBM to explore the factors influencing Indian smallholder farmers' intention to adopt smartphones to generate agricultural knowledge (Momvandi *et al.*, 2018). 5. The TAM was used to identify the				Musungwini, S., van Zyl, I., & Kroeze, J. H. (2022) The Perceptions of Smallholder Farmers on the Use of Mobile Technology: A Naturalistic Inquiry in Zimbabwe. In*: Vol. 439 LNNS* (pp. 530-544). Mercurio, D. I., & Hernandez, A. A. (2020). *Understanding User Acceptance of Information System for Sweet Potato Variety and Disease Classification: An Empirical Examination with an Extended Technology Acceptance Model*. Valizadeh, N., Rezaei-Moghaddam, K., & Hayati, D. (2020). Analyzing Iranian farmers' behavioral intention towards acceptance of drip irrigation using extended technology acceptance model. *Journal of Agricultural Science and Technology, 22*(5), 1177-1190. Zhou, D. Y., & Abdullah. (2017). The acceptance of solar water pump technology among rural farmers of northern Pakistan: A structural equation model. *Cogent Food & Agriculture, 3*(1). doi:10.1080/23311932.2017.1280882

		factors influencing the acceptance and adoption of agricultural automation machines in Ardabil, Iran (Salimi, Pourdarbani and Asgarnezhad Nouri, 2020). 6. The TAM was combined with TPB and TRA to investigate smallholder farmers' perceptions of adopting mobile technology in				

		Zimbabwe (Musungwini, van Zyl and Kroeze, 2022). 7. The TAM was used to explain conditions influencing users to accept information systems for classifying sweet potato varieties and diseases in the Philippines (Mercurio and Hernandez, 2020). 8. The TAM was integrated with The				

		Multiplicity Model to predict farmers' adoption behaviour towards sustainable water management in Iran (Ommani *et al.*, 2009). 9. The TAM was used to examine the farmers' behavioural intention to accept drip irrigation in Iran (Valizadeh, Rezaei-				

		Moghaddam and Hayati, 2020). 10. The TAM was combined with UTAUT to assess farmers' acceptance of solar water pump technology in Northern Pakistan (Zhou and Abdullah, 2017).				
Extended Technology Acceptance Model (TAM2) – Venkatesh and Davis, 2000	The TAM2 was developed to be an improved version of the original Technology Acceptance Model (TAM). TAM2 introduces two new constructs that consider social pressures	1. The TAM2 was used with UTAUT2 to explore the socioeconomic drivers of mobile phone adoption in a	User Acceptance Theory	1. The TAM2 can predict the user's actual usage behaviour. 2. It includes social imperatives as an important	1. The theory is often criticized for its unsuitability and applicability outside specific contexts.	Lubua, E. W., & Kyobe, M. E. (2019). The Influence of Socioeconomic Factors to the Use of Mobile Phones in the Agricultural Sector of Tanzania. *African Journal of Information Systems, 11*(4), 352-366. Retrieved from <Go to ISI>://WOS:000488624100006

	(subjective norms, voluntariness, and image) and cognitive instrumental processes (job relevance, output quality, results demonstrability, and perceived ease of use)	farming community in Tanzania (Lubua and Kyobe, 2019). 2. The TAM2 predicted CSA adoption among at-risk smallholder farmers in Malawi and Zambia (Khoza *et al.*, 2021). 3. The TAM2 was integrated with DOI to investigate the acceptance of biological control among rice farmers in Iran		moderator of adoption behaviour, and it includes subjective norm as a predictor of behavioural intention.		Khoza, S., de Beer, L. T., van Niekerk, D., & Nemakonde, L. (2021). A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: application of the extended technology acceptance model. *Gender, Technology and Development, 25*(1), 1-21. Sharifzadeh, M. S., Damalas, C. A., Abdollahzadeh, G., & Ahmadi-Gorgi, H. (2017). Predicting adoption of biological control among Iranian rice farmers: An application of the extended technology acceptance model (TAM2). *Crop protection, 96*, 88-96.

		(Sharifzadeh *et al.*, 2017).				
The Decomposed Theory of Planned Behaviour (DTPB) – Taylor and Todd, 1995	The theory is a modification of the TPB that breaks the main three influencing elements of behavioural intention/action (attitude, subjective norms, and perceived behavioural control) into more detailed components. In effect, attitudinal belief is disaggregated into perceived usefulness, ease of operation and compatibility, whereas control belief is disaggregated into self-efficacy and facilitating conditions.	1. The DTPB was applied to investigate smallholder farmers' intentions to adopt sustainable agriculture practices in Ethiopia (Zeweld *et al.*, 2017).	User Acceptance Theory	1. The DTPB includes a multi-dimensional belief construct. 2. The theory allows for analysis of relationship between specific variables subsumed within the belief construct.	1. The theory may be limited to measuring only the individual's intention to engage in a behaviour, not the actual behavior.	Zeweld, W., Van Huylenbroeck, G., Tesfay, G., & Speelman, S. (2017). Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of environmental management, 187*, 71-81.
The Reason Action Approach	The RAA is a modification of the theory of planned behaviour.	1. The RAA was used to explore why	User Acceptance Theory	1. The RAA attempts to provide a	1. The theory may be limited to measuring only the individual's intention	Van Hulst, F. J., & Posthumus, H. (2016). Understanding (non-) adoption of conservation

(RAA) – Fishbein and Ajzen, 2010	The RAA theorizes that a person's actual behaviour/adoption/action is predetermined by behavioral intention, which is also informed by the attitude towards the action, perceived norms regarding the action, and perceived behavioural control over the action. Perceived norms have two categories; injunctive norms (perception of what others think you should do) and descriptive norms (perception of what others practice).	Kenyan farmers choose conservation agriculture or conventional farming (Van Hulst and Posthumus, 2016).		detailed explanation of how background factors\constructs influence behavioural intention.	to engage in a behavior, not the actual behavior.	agriculture in Kenya using the reasoned action approach. *Land Use Policy, 56*, 303-314.
Theory of Reason Action (TRA) (Fishbein and Ajzen, 1977)	The TRA explains the conduct of an individual is influenced by an intention to execute that action which is, by extension,	1. The TRA was combined with DOI and UMT to investigate	User Acceptance Theory	1. The TRA provides insight on the reason for an individual's	1. The theory relies on measuring attitudes towards action, which may be an inadequate predictor of behavior.	Dadzie, S. K. N., Ndebugri, J., Inkoom, E. W., & Akuamoah-Boateng, S. (2022). Social networking and risk attitudes nexus: implication for technology adoption among smallholder cassava farmers in Ghana. *Agriculture and Food*

	influenced by the attitude towards the said action and subjective norms.	how the risk attitudes of Ghanaian farmers are shaped by social interactions in farmers' information and communication networks to influence their technology adoption decision (Dadzie *et al.*, 2022). 2. TRA was applied with TPB, TAM, UTAUT, SRT, HBM and IBM to explore		intended action or behaviour.		*Security, 11*(1). Doi:10.1186/s40066-022-00376-3 Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532 Musungwini, S., van Zyl, I., & Kroeze, J. H. (2022) The Perceptions of Smallholder Farmers on the Use of Mobile Technology: A Naturalistic Inquiry in Zimbabwe. In*: Vol. 439 LNNS* (pp. 530-544).

		determinants affecting farmers' adoption of Pressurized Irrigation Systems in Iran (Momvandi *et al.*, 2018). 3. TRA was combined with TPB and TAM to investigate the perceptions of smallholder farmers on adopting mobile technology in Zimbabwe (Musungwini,				

		van Zyl and Kroeze, 2022).				
Random Utility Theory (RUT) – (Block and Marschak, 1959)	Random Utility Theory is an aspect of Utility Theory that explains the variation in choices people make resulting from random factors.	1. RUT was employed to examine the socioeconomic variables driving soybean farmers' decision to adopt inoculant technology and chemical fertilizer in the Tolon District in Ghana (Anang and Zakariah, 2022). 2. RUT was adopted to examine the	Decision-making Theory	1. The RUT can increase accuracy when examining factors in the rationality of choice.	1. The theory assumes that people's choices or behaviors are always or highly rational.	Anang, B. T., & Zakariah, A. (2022). Socioeconomic drivers of inoculant technology and chemical fertilizer utilization among soybean farmers in the Tolon District of Ghana. *Heliyon, 8*(6). doi:10.1016/j.heliyon.2022.e09583 Baiyegunhi, L., Akinbosoye, F., & Bello, L. (2022). Welfare impact of improved maize varieties adoption and crop diversification practices among smallholder maize farmers in Ogun State, Nigeria. *Heliyon, 8*(5), e09338. Rahman, M. S., Sujan, M. H. K., Sherf-Ui-Alam, M., & Kabir, M. H. (2021). Adoption and dis-adoption of farm mechanization in Bangladesh: Case of rice-wheat thresher. *Emirates Journal of Food and Agriculture, 33*(12), 1000-1007. doi:10.9755/ejfa.2021.v33.i12.2794 Sheikh, A. T., Mugera, A., Pandit, R., Burton, M., & Davies, S. (2022). The adoption of laser land leveler technology and its impact on

		determinants of improved maize varieties adoption and crop diversification and the impact on the welfare of smallholder farmers in Ogun State, Nigeria (Baiyegunhi, Akinbosoye and Bello, 2022). 3. RUT was employed to study the driving factors affecting the adoption and dis-adoption of rice-wheat				groundwater use in irrigated farmland in Punjab, Pakistan. *Land Degradation & Development*. Akello, R., Turinawe, A., Wauters, P., & Naziri, D. (2022). Factors Influencing the Choice of Storage Technologies by Smallholder Potato Farmers in Eastern and South-western Uganda. *AGRICULTURE-BASEL, 12*(2). doi:10.3390/agriculture12020240 Danso-Abbeam, G., Bosiako, J. A., Ehiakpor, D. S., & Mabe, F. N. (2018). Adoption of improved maize variety among farm households in the northern region of Ghana. *Cogent Economics & Finance, 5*(1). doi:10.1080/23322039.2017.1416896 Nonvide, G. M. A. (2020). Identification of Factors Affecting Adoption of Improved Rice Varieties among Smallholder Farmers in the Municipality of Malanville, Benin. *Journal of Agricultural Science and Technology, 22*(2), 305-316. Retrieved from <Go to ISI>://WOS:000519295600002

		threshers in Bangladesh (Rahman *et al.*, 2021). 4. RUT was applied to examine the factors that influence the adoption of laser land leveller technology and the effect on the amount of groundwater applied to wheat crops in three irrigated agro-ecological zones in Punjab Province of				Saliou, I. O., Zannou, A., Aoudji, A. K. N., & Honlonkou, A. N. (2020). Drivers of Mechanization in Cotton Production in Benin, West Africa. *AGRICULTURE-BASEL, 10*(11). doi:10.3390/agriculture10110549 Sunny, F. A., Fu, L., Rahman, M. S., & Huang, Z. (2022). Determinants and Impact of Solar Irrigation Facility (SIF) Adoption: A Case Study in Northern Bangladesh. *Energies, 15*(7), 2460. Abebaw, D., & Haile, M. G. (2013). The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia. *Food policy, 38*(1), 82-91. doi:10.1016/j.foodpol.2012.10.003 Lwiza, F., Mugisha, J., Walekhwa, P. N., Smith, J., & Balana, B. (2017). Dis-adoption of Household Biogas technologies in Central Uganda. *Energy for Sustainable development, 37*, 124-132. doi:10.1016/j.esd.2017.01.006

		Pakistan (Sheikh *et al.*, 2022). 5. RUT was used to investigate various factors influencing the potato farmers' choice of storage facility technologies in Uganda (Akello *et al.*, 2022). 6. RUT was utilized to identify the factors affecting the adoption of improved maize varieties among farmers				Mogaka, B. O., Bett, H. K., & Ng'ang'a, S. K. (2021). Socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya. *Journal of Agriculture and Food Research, 5*. doi:10.1016/j.jafr.2021.100168

		in the Northern region of Ghana (Danso-Abbeam *et al.*, 2018). 7. RUT was anchored in a study to examine factors determining farmers' adoption of improved rice varieties in Malanville Municipality in Benin (Nonvide, 2020). 8. RUT was modelled in a study to				

		identify affecting the mechanization of cotton production in Benin (Saliou *et al.*, 2020). 9. RUT was employed in a study to explore determinants affecting farmers' adoption of solar irrigation facilities in Northern Bangladesh (Sunny *et al.*, 2022). 10. RUT was employed to examine the				

		potential of cooperative membership to increase the likelihood of adopting fertilizers, improved seeds and pesticides among farmers in Ethiopia (Abebaw and Haile, 2013). 11. RUT was used to investigate the dis-adoption of biogas technology among farming households in Uganda (Lwiza *et al.*, 2017).				

		12. RUT was used to study socioeconomic factors driving farmers' adoption of climate-smart soil practices in Western Kenya (Mogaka, Bett and Ng'ang'a, 2021).				
The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh *et al.*, 2003)	The UTAUT is a technology acceptance theory that combines other user and technology acceptance theories. The theory incorporates eight existing theories, including the Theory of Reasoned Action, the Technology Acceptance	1. The UTAUT was employed to investigate adopting and accepting E-agriculture in Nigeria (Eweoya *et al.*, 2021). 2. The UTAUT was applied	User Acceptance Theory	1. The UTAUT is a comprehensive and robust tool to explain adoption behaviour due to integrating other technology user and acceptance theories.	1. Despite the broad integration of many theories into the UTAUT, it is limited in explaining behavioural intention when applied in different adoption contexts.	Eweoya, I., Okuboyejo, S. R., Odetunmibi, O. A., & Odusote, B. O. (2021). An empirical investigation of acceptance, adoption and the use of E-agriculture in Nigeria. *Heliyon, 7*(7), e07588. doi:https://doi.org/10.1016/j.heliyon.2021.e07588 Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of Factors Affecting the Use of Pressurized

	Model, the Motivational Model, the Theory of Planned Behaviour, the combined Theory of Planned Behaviour and Technology Acceptance Model, the Model of PC Utilization, the Innovation Diffusion Theory and the Social Cognitive Theory.	with TPB, TAM, TRA, SRT, HBM and IBM to identify determinants affecting farmers' adoption of Pressurized Irrigation Systems in Iran (Momvandi *et al.*, 2018). 3. The UTAUT was used to investigate the factors affecting farmers' intention to adopt banana tissue culture derived				Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532 Mulugo, L., Kyazze, F. B., Kibwika, P., Kikulwe, E., Omondi, A. B., & Ajambo, S. (2020). Unravelling technology-acceptance factors influencing farmer use of banana tissue culture planting materials in Central Uganda. *African Journal of Science Technology Innovation & Development, 12*(4), 453-465. doi:10.1080/20421338.2019.1634900 Nampijja, D., & Birevu, P. M. (2016). *Adoption and use of mobile technologies for learning among smallholder farmer communities in Uganda*. Sebuliba, E., Isubikalu, P., Turyahabwe, N., Mwanjalolo, J. G. M., Eilu, G., Kebirungi, H., . . . Ekwamu, A. Factors influencing farmer choices of use of shade trees in coffee fields around Mount Elgon, Eastern Uganda. *Small-scale Forestry*. doi:10.1007/s11842-022-09523-x

		planting materials in Central Uganda (Mulugo *et al.*, 2020). 4. The UTAUT was employed to assess mobile learning adoption and use practices among farmers in Uganda (Nampijja and Birevu, 2016). 5. The UTAUT was used to examine farmers' decision to adopt shade trees in coffee				Zhou, D. Y., & Abdullah. (2017). The acceptance of solar water pump technology among rural farmers of northern Pakistan: A structural equation model. *Cogent Food & Agriculture, 3*(1). doi:10.1080/23311932.2017.1280882

		fields in Mount Elgon, Eastern Uganda (Sebuliba *et al.*). 6. The UTAUT was combined with TAM to assess farmers' acceptance of solar water pump technology in Northern Pakistan (Zhou and Abdullah, 2017).				
Self-Determination Theory (SDT) – Deci and Ryan (1980s)	The SDT explains factors that drive a person's motivation and personality based on three psychological elements: autonomy,	1. SDT was used to examine the motivation for sustainable intensification	Personality Theory	1. The SDT can be applied in different disciplines.	1. The theory is criticized for being overly multifaceted hence the possibility of weak predictability.	Jambo, I. J., Groot, J. C. J., Descheemaeker, K., Bekunda, M., & Tittonell, P. (2019). Motivations for the use of sustainable intensification practices among smallholder farmers in Tanzania and Malawi. *NJAS-WAGENINGEN*

	competence, and relatedness.	practices among smallholder farmers in Tanzania and Malawi (Jambo *et al.*, 2019).				*JOURNAL OF LIFE SCIENCES, 89*. doi:10.1016/j.njas.2019.100306
Institutional Theory – Meyer and Rowan (1970s)	Institutional Theory explains the factors that build a social structure, such as rules and norms, and how they develop a social structure and influence behaviour.	1. Institutional Theory was used to assess the effects of institutional factors on farmers' adoption of conventional, organic and genetically modified cotton in Burkina Faso (Meda *et al.*, 2018).	Organizational Structure Theory	1. Institutional Theory provides insights into how social structure influences behaviour, which other theories do not capture.	1. The theory has been criticized for having weak social structure elements which are unlikely to influence social behaviour significantly.	Meda, Y. J. M., Egyir, I. S., Zahonogo, P., Jatoe, J. B. D., & Atewamba, C. (2018). Institutional factors and farmers' adoption of conventional, organic and genetically modified cotton in Burkina Faso. *International Journal of Agricultural Sustainability, 16*(1), 40-53. doi:10.1080/14735903.2018.1429523

Means-end Chain Theory (MEC) - (Gutman, 1982)	The MEC is centred on the assumption that the desire for a positive outcome mostly drives a person's decision or choice to avoid a negative outcome. i.e., the values held by the individual play a key role in decision-making.	1. MEC was used to examine farmers' determinants of quality potato seed use and the mental models associated with quality seed potato use in Kenya (Okello *et al.*, 2019).	Personality Theory	1. The MEC enables an extensive examination of values and their significance in a person's ultimate decision.	1. Social determinants are not explicitly accounted for in the theory's predictive capacity.	Okello, J., Zhou, Y., Barker, I., & Schulte-Geldermann, E. (2019). Motivations and Mental Models Associated with Smallholder Farmers' Adoption of Improved Agricultural Technology: Evidence from Use of Quality Seed Potato in Kenya. *European Journal of Development Research, 31*(2), 271-292. doi:10.1057/s41287-018-0152-5
Value-Belief-Norm Theory (VBN) – Stern et al., (1999)	The VBN stipulates that an individual adopts a technology based on moral norms believed to sway the individual to act in a certain way.	1. The VBN was used to explore farmers' pro-environmental behaviours in relation to adopting clean technology	Personality Theory	1. The theory better explains the link between an individual and the environment regarding adopting environmental-	1. The theory's assumptions limit its wide application to disciplines unrelated to environmental conservation.	Rezaei-Moghaddam, K., Vatankhah, N., & Ajili, A. (2020). Adoption of pro-environmental behaviors among farmers: application of Value–Belief–Norm theory. *Chemical and Biological Technologies in Agriculture, 7*(1). doi:10.1186/s40538-019-0174-z

		associated with locally avaialble rich compost in Fars Province in the South of Iran (Rezaei-Moghaddam, Vatankhah and Ajili, 2020).		conservation practices.		
The Extended Unified Theory of Acceptance and Use of Technology (UTAUT2) – Venkatesh et al., (2012)	The Extended Unified Theory of Acceptance and Use of Technology (UTAUT2) was a comprehensive framework developed from the Unified Theory of Acceptance and Use of Technology (UTAUT). The model pays particular attention to the consumer technology use context and adds three	1. The UTAUT2 was used to identify factors affecting Bangladeshi farmers' willingness to adopt and pay for the Internet of Things applied in agricultural	User Acceptance Theory	1. The UTAUT2 considers confounding variables, including age, gender and experience, with the potential to moderate an adoption behaviour.	1. In UTAUT2, (perceived) voluntariness of actions on the part of the adopter has been ignored.	Shi, Y., Siddik, A., Masukujjaman, M., Zheng, G. W., Hamayun, M., & Ibrahim, A. M. (2022). The Antecedents of Willingness to Adopt and Pay for the IoT in the Agricultural Industry: An Application of the UTAUT 2 Theory. *Sustainability, 14*(11). doi:10.3390/su14116640 Lubua, E. W., & Kyobe, M. E. (2019). The Influence of Socioeconomic Factors to the Use of Mobile Phones in the Agricultural Sector of Tanzania. *African Journal of Information Systems, 11*(4), 352-366. Retrieved from <Go to ISI>://WOS:000488624100006

	more: hedonic motivation, price value and habit.	contexts (Shi *et al.*, 2022). 2. The UTAUT2 was combined with TAM2 to explore the socioeconomic drivers of mobile phone adoption in a farming community in Tanzania (Lubua and Kyobe, 2019). 3. The UTAUT2 was modified to develop a model for adopting and accepting mobile farming				Masimba, F., & Zuva, T. (2022). *A Model for the Adoption and Acceptance of Mobile Farming Platforms (MFPs) by Smallholder Farmers in Zimbabwe.* Paper presented at the Computer Science On-line Conference. Beza, E., Reidsma, P., Poortvliet, P. M., Belay, M. M., Bijen, B. S., & Kooistra, L. (2018). Exploring farmers' intentions to adopt mobile Short Message Service (SMS) for citizen science in agriculture. *Computers and Electronics in Agriculture, 151*, 295-310. doi:10.1016/j.compag.2018.06.015

		platforms by smallholder farmers in Zimbabwe (Masimba and Zuva, 2022). 4. An extended version of the UTAUT2 was used to investigate farmers' characteristics influence on the acceptance of mobile SMS in Ethiopia (Beza *et al.*, 2018).				
Lancaster Consumer Theory (LCT)	Lancaster Consumer Theory (LCT) was a new approach to consumer theory that assumed	1. LCT was used to assess Ghanaian farmers'	Decision-making Theory	1. The LCT focuses on the properties of technology and	1. The theory's focus may exclude the moderating effect of	Acheampong, P. P., Owusu, V., & Nurah, G. (2018). How does Farmer Preference matter in Crop variety Adoption ? The case of Improved Cassava varieties' Adoption in Ghana. *Open*

– Lancaster (1966)	goods are not the immediate objects of preference, utility, or welfare to the consumer or end-user but the associated characteristics of the goods directly relevant to the consumer or end-user.	preferences for cassava variety traits and to establish the valuation for these traits (Acheampong, Owusu and Nurah, 2018).		how these moderate an adopter's preferences.	utility from an adopters' perspective.	*Agriculture, 3*(1), 466-477. doi:10.1515/opag-2018-0052
Protection Motivation Theory (PMT) Rodgers (1975)	PMT postulates the three crucial components of fear appear to be (i) the magnitude of noxiousness of a depicted event; (ii) the probability of that event's occurrence; and (iii) the efficacy of a protective response. Each communication variable linked to these components initiates corresponding cognitive	1. PMT was used to examine the effects of price risk perception on the adoption of management strategies among smallholder rice farmers in the Mbeya region,	Personality Theory	1. The PMT emphasizes the individuals' perceptive ability about technology adoption to be adopted under the three proposed contexts (i.e., the magnitude of noxiousness of a depicted event, the probability of	1. The theory does not account for social determinants and how they moderate an adopter's behaviour.	Mgale, Y. J., & Yunxian, Y. (2021). Price risk perceptions and adoption of management strategies by smallholder rice farmers in Mbeya region, Tanzania. *Cogent Food & Agriculture, 7*(1). doi:10.1080/23311932.2021.1919370

	appraisal processes that mediate attitude change.	Tanzania (Mgale and Yunxian, 2021).		that event's occurrence, and the efficacy of a protective response).		
Social Recognition Theory (SRT) – Axel Honneth (1980s)	The SRT posits that an individual adopts a technology based on a perception of people's judgement.	1. The SRT was applied with TPB, TAM, TRA, UTAUT, HBM and IBM to explore determinants affecting farmers' adoption of Pressurized Irrigation Systems in Iran (Momvandi *et al.*, 2018).	User Acceptance Theory	1. The SRT acknowledges the moderating effect of social imperatives on an adopter's behavioural intention towards a technology.	1. The theory lacks consideration of the cognitive ability of the adopter and how that affects behavioural intention.	Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532
Health Belief Model (HBM)	The HBM states that the perception of a personal	1. The HBM was applied	Personality Theory	1. The salient beliefs of an	1. The theory has been criticized for neglecting	Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of

– US Social Psychologists (1950s)	health behaviour threat is influenced by at least three factors: general health values, interests, and health concerns; specific beliefs about vulnerability to a particular health threat; and beliefs about the consequences of the health problem.	with TPB, TAM, TRA, UTAUT, SRT and IBM to explore determinants affecting farmers' adoption of Pressurized Irrigation Systems in Iran (Momvandi *et al.*, 2018).		individual or adopter are emphasized in the HBM.	time, expense, or fear as possible moderating variables.	Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532
Integrated Behavioral Model (IBM) – Fishbein (2000)	The IBM was developed to include construct constructs from the Theory of Reasoned Action/Theory of Planned Behavior. The determinants of behavior in the IBM theory are based on the intention to	1. The IBM was applied with TPB, TAM, TRA, UTAUT, SRT and HBM to explore determinants affecting	Decision-making Theory	1. The IBM considers the moderating effect of utility on adoption behaviour. 2. There is consideration for the potential of	1. The moderating variables may be numerous/overwhelming, leading to the complexity of the theory application.	Momvandi, A., Najafabadi, M. O., Hosseini, J. F., & Lashgarara, F. (2018). The Identification of Factors Affecting the Use of Pressurized Irrigation Systems by Farmers in Iran. *Water, 10*(11). doi:10.3390/w10111532

	perform the behavior. Thus, the motivation of what benefit to gain results in an individual to behave in a particular way. This means that, without motivation, a person is unlikely to carry out a recommended behavior. In this theory, four components are assumed to be likely to affect behavior; (1) a person has a strong intention to perform it and the knowledge and skill to do so, (2) there is no severe environmental constraint preventing performance, (3) the behavior is salient to the person performing it, and (4) the person has	farmers' adoption of Pressurized Irrigation Systems in Iran (Momvandi *et al.*, 2018).		various variables likely to moderate an adoption behaviour.		

	performed the behavior previously.					
Consumptions Value Theory (CVT) by (Sheth, Newman and Gross, 1991)	The CVT explains an individual's choice to adopt a particular technology compared to other technologies. The theory attempts to explain the adopter's evaluation of the value of adopting a particular technology.	1. The CVT was used to examine rural farmers' acceptance of agricultural information systems in Ghana (Afful-Dadzie, Lartey and Clottey, 2022).	Decision-making Theory	1. The CVT can identify easy and simple variables to measure.	1. The theory focuses mainly on economic variables and may miss out non-economic variables which affect an adoption decision.	Afful-Dadzie, E., Lartey, S. O., & Clottey, D. N. K. (2022). Agricultural information systems acceptance and continuance in rural communities: A consumption values perspective. *Technology in Society, 68*. doi:10.1016/j.techsoc.2022.101934
Peterson and Seligman's Theory of Character Strength (TCS) – Peterson and Seligman (2004)	Peterson and Seligman's Theory of Character Strength theorizes that the personal character of an adopter (i.e., creativity, curiosity, bravery etc.) can predict an adoption of a technology.	1. Peterson and Seligman's TCS was used to explain the influence of farmers' variables, including character	Personality Theory	1. The TCS is a practical approach to predict an adoption behaviour as it focuses on the adopter's personality.	1. The theory may be limited in its interpretive perspective due to its strict focus on the adopter's personality without consideration for external variables.	Bukchin, S., & Kerret, D. (2020). Character strengths and sustainable technology adoption by smallholder farmers. *Heliyon, 6*(8). doi:10.1016/j.heliyon.2020.e04694

		strength, to predict the adoption of sustainable agricultural technologies in the Thies region of Senegal (Bukchin and Kerret, 2020).				
Production Function Theory (PFT) – Cobb and Douglas (1927, 1947)	The PFT assumes that an adoption behaviour is conditioned by the relationship between inputs and outputs variables required for a production process.	1. The PFT was used to explore factors influencing the number of farm innovations adopted by farmers in Ghana's Upper West and East regions	Decision-making Theory	1. Variables measured within the PFT are easy and simple to measure.	1. The theory relies mainly on economic variables to predict adoption behaviour.	Donkor, E., Owusu, V., Owusu-Sekyere, E., & Ogundeji, A. A. (2018). The Adoption of Farm Innovations among Rice Producers in Northern Ghana: Implications for Sustainable Rice Supply. *AGRICULTURE-BASEL, 8*(8). doi:10.3390/agriculture8080121

		(Donkor *et al.*, 2018).				
The Multiplicity Model (MM) – Bergson (1960s)	The MM is an integrative model that integrates the farm structure and diffusion theories to explain the influence on an individual's adoption behaviour. Variables are distinguished by the adopters' characteristics and economic factors.	1. The Multiplicity Model was integrated with TAM to predict farmers' adoption behaviour towards sustainable water management in Iran.	Organizational Structure Theory	1. The MM is a stronger predictor of adoption behaviour than the farm structure and diffusion theories used independently.	1. The theory does not consider social imperatives as likely determinants of adoption behaviour.	Ommani, A. R., Chizari, M., Salmanzadeh, C., & Hosaini, J. F. A. (2009). Predicting adoption behavior of farmers regarding on-farm sustainable water resources management (SWRM): Comparison of models. *Journal of Sustainable Agriculture, 33*(5), 595-616. doi:10.1080/10440040902997827

Appendix B. Critical appraisal of articles reviewed

				Was there a clear statement of the aims of the	Was the research design appropriate to address	Was the recruitment strategy appropriate to the	Was the data collected in a way that addressed the	Was the data analysis sufficiently rigourous?	Have ethical issues been taken into consideration?	Is there a clear statement of findings?	Has the role of the researcher been addressed?			
	Study	Paper	Method	1	2	3	4	5	6	7	8		Over all	Comments
Qualitative		(Nampijja & Birevu, 2016)	Interviews, Focus Group											Sampling method may not permit for

														generalisation.
		(Okello, Zhou, Barker, & Schulte-Geldermann, 2019)	Interviews											Data collection procedure is described into details.
Mixed Methods		(Tinh, Hung, Dzung, & Trinh, 2019)	Survey											There is no presentation on participants characteristics. Saturation is mentioned.
		(Momvandi, Najafabadi, Hosseini, & Lashgarara, 2018)	Literature review, survey											Sample size drawn from population is practically logical. Sample is

														drawn from specific group target of farmers using a particular technology.
		(Nyairo, Pfeiffer, Spaulding, & Russell, 2022)	Survey, Focus group											Sampling technique is elaborative with justification. Instrument used was tested for reliability and validity.
		(Cafer & Rikoon, 2018)	Survey, Focus group											Sampling technique and data collection

													procedure is limited. Rationale for sampling method is limited.
	(Chinseu, Dougill, & Stringer, 2019)	Survey, Focus group											Limitations of the study were not highlighted.
	(Kondo, Cacho, Fleming, Villano, & Asante, 2020)	Interviews, Focus Groups, Survey, Focus Groups, **Workshop**											Response rate of survey not mentioned. Saturation of data is not highlighted.

	(Contillo & Tiongco, 2019)	Survey, Focus group												Sampling technique and rationale is quite limited. Doesn't really highlight the relevance just repeats the results from the focus groups. No quotes presented.
	(Khoza, de Beer, van Niekerk, & Nemakonde, 2021)	Survey, Focus group												Participants characteristics in results not mentioned.

													Information in the methods section is limited.
(Lwiza, Mugisha, Walekhwa, Smith, & Balana, 2017)	WTP - contingent valuation, Indepth-Interviews												Findings are not generalisable. Sample size does not suite generalisation of findings.
(Sebuliba et al.)	Cross-sectional survey, interviews												Sample size not adequate to generalise findings. Research method not appropriate

													for generalisation.
	(Jambo, Groot, Descheemaeker, Bekunda, & Tittonell, 2019)	**Survey, Focus group**											Conclusion is comprehensive. Study method may not permit for generalisation of findings.
	(Acheampong, Owusu, & Nurah, 2018)	Choice experiment, survey											Research design is quite elaborate. Research design is well defined.
	(Shallo, Ayele, & Sime, 2020)	Cross-sectiona											Rationale of study is

			l survey, interviews											clearly outlined. Conclusion of study is coherent with discussion of findings.
		(Musungwini, van Zyl, & Kroeze, 2022)	Interviews, Naturalistic inquiry											There are no quotes from participants.
Quantitative		(Bagheri & Teymouri, 2022)	Survey								n/a			TPB was used to explain farmers' intended and actual adoption of soil and

														water conservation practices.
		(Gwara, Wale, & Odindo, 2022)	Survey								n/a			Sample size is too small to make conclusive generalisation.
		(Landmann, Lagerkvist, & Otter, 2021)	Survey, Focus group								n/a			Sample size is too small to make conclusive generalisation.
		(Mutyasira, Hoag, & Pendell, 2018)	Cross-sectional survey								n/a			There is no description of the characteristics of participants.

		(Zhou & Abdullah, 2017)	Survey								n/a			Ethical issues not mentioned.
		(Bagheri, Bondori, Allahyari, & Damalas, 2019)	Survey								n/a			Clear demonstration of validation of survey instrument.
		(Dadzie, Ndebugri, Inkoom, & Akuamoah-Boateng, 2022)	Survey								n/a			Demographic characteristics of participants do not mention or discussed.
		(Danso-Abbeam, Dagunga, & Ehiakpor, 2019	Survey											Analytical framework is detailed but sampling

														choice and justification not described extensively.
		(Ndeke et al., 2021)	Survey								n/a			There is no mention of reliability of instrument.
		(L. J. S. Baiyegunhi, 2015)	Survey								n/a			Limitations are not mentioned.
		(Chandio & Jiang, 2018)	Survey								n/a			Validity and reliability of instrument is not mentioned.
		(Mango, Makate, Tamene, Mponela, & Ndengu, 2018)	Survey											Population is not representative due to

														sampling type from population.
	(Massresha, Lema, Neway, & Degu, 2021)	Survey												Literature review is extensive, but method section is not comprehensive.
	(Ng'ang'a, Jalang'o, & Girvetz, 2020)	Secondary Database (Extracted data)												Data collection procedure is not extensively explained as data is from secondary source.

	(Ojiako, Manyong, & Ikpi, 2007)	Survey											Conceptualisation of the study is extensively described.
	(Okpukpara, 2010)	Survey											Sampling and data collection procedure not elaborative enough.
	(Tolassa & Jara, 2022)	Survey											Analytical framework is conceptualised to the study context.
	(Awotide, Karimov, & Diagne, 2016)	Survey											Actual data collection procedure

													not elaborative.
(Meda, Egyir, Zahonogo, Jatoe, & Atewamba, 2018)	Survey												Discussion of findings is limited.
(Musyoki, Busienei, Gathiaka, & Karuku, 2022)	Survey												No indication of the use of a reliable or valid instrument.
(Mogaka, Bett, & Ng'ang'a, 2021)	Survey									n/a			Sample size is not adequate to make generalisation.
(Sileshi, Kadigi, Mutabazi, & Sieber, 2019)	Survey									n/a			Sampling technique is extensively explained,

													and study can make a generalised conclusion.
	(Simtowe, 2006)	Survey											Sample technique and research design quite limited.
	(Sodjinou, Glin, Nicolay, Tovignan, & Hinvi, 2015)	Survey											It is not clear whether a reliable and valid instrument was used to collect the data.
	(Tanko, 2022)	Survey											No limitations to the study

													have been mentioned.
	(Bhatta, Paudel, & Liu, 2022)	Survey											Study method is not adequately explained.
	(Mihretie, Abebe, & Misganaw, 2022)	Survey											Data analysis section is elaborate.
	(Mwaura et al., 2021)	Survey											Introduction is adequate with a clear objective of the study.
	(Goswami, Choudhury, & Saikia, 2012)	Survey											Sample size may not well correspond to

													generalisation.
(Jha, Kaechele, & Sieber, 2019)	Survey												Sampling method is limited.
(Kwade, Lugu, Lukman, Quist, & Chu, 2019)	Survey								n/a				Introduction and objectives are well articulated.
(Sharifzadeh, Damalas, Abdollahzadeh, & Ahmadi-Gorgi, 2017)	Survey								n/a				Rationale of study is clearly outlined.
(Kamwamba-Mtethiwa, Wiyo, Knox, & Weatherhead, 2021)	Survey								n/a				The introduction is sound and clearly states the aim of the study.

		(Ommani, Chizari, Salmanzadeh, & Hosaini, 2009)	Survey											Discussion is quite limited.
		(Bagheri, Bondori, Allahyari, & Surujlal, 2021)	Survey								n/a			Discussed the use of a valid and reliable instrument.
		(Nwokoye, Oyim, Dimnwobi, & Ekesiobi, 2019)	Survey								n/a			Sampling method is quite elaborative. Discussion of findings is well articulated.
		Sampling technique was random .	Survey								n/a			Sampling technique was random.

	(Mercurio & Hernandez, 2020)	Survey								n/a			Sampling method is brief and lacks more details.
	(Valizadeh, Rezaei-Moghaddam, & Hayati, 2020)	Survey								n/a			Sampling method and data analysis has depth.
	(Lubua & Kyobe, 2019)	Survey								n/a			Introduction is succinct with well-defined study objectives.
	(Zeweld, Van Huylenbroeck, Tesfay, & Speelman, 2017)	Survey								n/a			Conclusion and limitations of the study is

												well articulated.
	Van Hulst and Posthumus (2016)	Survey										Sample size is not adequate to make generalisation.
	(Anang & Zakariah, 2022)	Survey										Sampling method is adequately explained to include participant confidentiality.
	(L. Baiyegunhi, Akinbosoye, & Bello, 2022)	Survey										Ethical approval was obtained for

													the data collection.
	(Rahman, Sujan, Sherf-Ui-Alam, & Kabir, 2021)	Survey											Sample size is drawn from a major household survey hence adequate for generalisation of findings.
	(Sheikh, Mugera, Pandit, Burton, & Davies, 2022)	Survey											Sample size may not be adequate for generalisation.
	(Akello, Turinawe, Wauters, & Naziri, 2022)	Survey											Stated limitations of the study makes it impossible

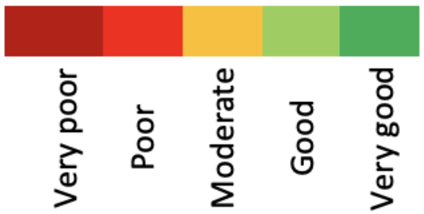
			to generalise the findings.
	(Danso-Abbeam, Bosiako, Ehiakpor, & Mabe, 2018)	Survey	Sampling technique can allow for generalisation of findings.
	(Nonvide, 2020)	Survey	introduction and study objectives are clearly outlined.
	(Saliou, Zannou, Aoudji, & Honlonkou, 2020)	Survey	Introduction is very brief.
	(Sunny, Fu, Rahman, & Huang, 2022)	Survey	Sampling method is quite limited.
	(Abebaw & Haile, 2013	Survey	Sample size is not adequate to

													make generalisation.
	(Eweoya, Okuboyejo, Odetunmibi, & Odusote, 2021)	Survey											Sample size not adequate to generalise findings.
	(Mulugo et al., 2020)	Survey											Methodology of the study is well described.
	(Rezaei-Moghaddam, Vatankhah, & Ajili, 2020)	Survey											Discussion of findings is extensive.
	(Shi et al., 2022)	Cross-sectional survey											Hypothesis for the study tested and reported on accordingly.

	(Masimba & Zuva, 2022)	Survey											Study hypothesis is well stated and tested with analytical framework.
	(Beza et al., 2018)	Survey											Rationale of study is clearly outlined.
	(Mgale & Yunxian, 2021)	Survey											Sample method not elaborative enough.
	(Afful-Dadzie, Lartey, & Clottey, 2022)	Survey											Research design of the study is adequately described.

		(Bukchin & Kerret, 2020)	Survey											Introduction and objectives are well articulated.
		(Donkor, Owusu, Owusu-Sekyere, & Ogundeji, 2018)	Survey											Discussion of findings is extensive.

Key



Appendix C. In-depth interview guides for farmers and non-farmer stakeholders

Farmer Interview Guide

Name of Community: ………………………………… Questionnaire No: ………

A). Energy Use in Agriculture.

1. What do your farm?
2. What is your farm size?
3. How much is produced from your farm?
4. What inputs do you need on your farm? (pesticides, fertilizer, energy, others).
5. What energy is used on your farm? (electricity, petrol, diesel, wood, solar, wind, hydro, biomass, others).
    a. Do you use solar and/or biomass energy? (traditional/technology enhanced).
    b. If no, will you be willing to adopt solar and/or biomass energy?
6. What do you use energy for? (agriculture and domestic)
7. In a farming season, what will be the cost of each energy used?
8. What is your view about these energy forms contributing to Climate Change?

Energy	Positive Impact	Negative Impact	Neither Positive/Negative	I don't know
Electricity				
Petrol				
Diesel				
Wood				
Solar				
Wind				
Hydro				
Biomass				

Other				

9. How long have you used each of the energy sources?

B). Socio-economic Drivers (Barriers and Facilitators to Adoption).

10. What will facilitate your adoption of renewable energy? (social, economic, environment, cultural, technology type, others).
11. What will hinder your adoption of renewable energy?

C). Psychological Drivers (Barriers and Facilitators to Adoption).

12. Emphasis on behavioural, normative and control forms of belief.

    Behavioural belief

    - What will be the advantages of using renewable energy for agriculture?
    - What will be the disadvantages of using renewable energy for agriculture?
    - Will these advantages/disadvantages influence your decision to adopt renewable energy?

    Normative belief

    - Who do you think will approve or disapprove your adoption of renewable energy for agriculture?
    - What group(s) do you think will approve or disapprove your adoption of renewable energy for agriculture?
    - Will these approvals/disapprovals influence your decision to adopt renewable energy?

    Control belief

    - Do you think you can personally adopt renewable energy for agriculture?
    - What personal factors will impede your adoption of renewable energy for agriculture?
    - What is your perception of smallholder farmers adoption of renewable energy for agriculture?
    - Do you think there are any ethical/moral reasons to adopt renewable energy?

- Will this influence your decision to adopt renewable energy?

D). External Drivers.

13. Do you receive support regarding renewable energy adoption?
    a. If yes, what form of support?
    b. If no, will you like to receive some support to adopt renewable energy?
        i. If no, why not?
        ii. If yes, what kind of support will you like to receive?
            1. From where will you want to receive support?
            2. In what way will the support benefit your adoption of renewable energy?

E). Background Information.

14. How long have you been farming?
15. What is/are your source(s) of labour on your farm?
    a. Household
    b. External
    c. Type of compensation for labour.
16. What is your main motive for farming?
17. What is your annual farm income?
18. What is your highest level of education?
19. What is your household size?
20. Gender
21. Age

Do you have further comments?

Summarise and highlight key points from interview to enable respondent make additions, subtractions or clarification if need be.

The End

Non-Farmer Stakeholder

A). Energy Use in Agriculture.

1. What energy forms from your organisation are generated/promoted?
2. What energy forms are generated/promoted for agricultural purposes? (Including fuels, fertilizer, pesticides, weedicides, electricity, others).
3. What is the extent of generation/promotion of the said energy forms? (Including cost, volume, quantity, others).
4. What is your view on these energy forms contributing to GHG emissions (Climate Change)?
5. What type(s) of renewable energy technologies (RE) is/are produced/promoted by your organisation?
6. Which of the RE technologies are appropriate for rural areas?
7. Which of the stated RE technologies is/are produced/promoted for agricultural purposes? (Including crop production, processing etc). (Including solar and biomass renewable energy types).
8. Which stakeholders use RE technologies in rural areas? (Including smallholder agriculture vs commercial agriculture, cost, volume, quantity, others).

B). Socio-economic Drivers (Barriers and Facilitators to Adoption).

9. What are the most important factors to adoption of RE technologies?
10. What characteristics of the farm facilitate solar and/or biomass use in agriculture?
11. Are there suitable local environmental conditions for RE adoption?

(Including farm size, land tenure, type of production, others).

12. What technological features facilitate solar and/or biomass use in agriculture?
13. (Including compatibility, advantage, complementary, complexity, trialability, others).
14. What economic drivers facilitate solar and/or biomass use in agriculture?

(Including technology cost, time factor, profitability, increase production, others).

15. Do farmers want to reduce the environmental impacts of farming? Does this link to perceived demand for sustainable products in Ghana and in export markets?
16. Are there other farmers in local networks adopting RE?

C). External Drivers.

17. Is your organisation contributing to promoting RE use in agriculture? If yes, how?
18. Are you aware of any policies/programmes/projects that support the adoption of solar and/or biomass energy for agricultural purposes? If yes, please describe.

    (Including access to finance, training, link to industry & technology supplier, logistical support).

19. Are these policies/programmes/projects effective? If yes, in what way and if no, in what way?
20. Who are the key stakeholders in promoting RE?

D). Social Network Analysis (SNA).

21. Which of these stakeholder groups do you primarily represent in relation to RE?

- o Research/Academia
- o Industry
- o Government Agency
- o Non-governmental Organisation
- o Farmers
- o Farmer-Based Organisation
- o Financial Institution
- o Cooperative

- Others, specify

22. Please indicate your connection to the following organisations in relation to RE. (To provide list of institutional stakeholders).
23. What is the frequency of connection to the identified organisations?

- Less than once annually
- Annually
- Once 6 months
- Once 3 months
- Once a month
- Once every 2 weeks
- Weekly
- Daily

24. Generally, what type of activities does your relationship with the following organisations entail?

- Information sharing
- Services provision
- Capacity building
- Sales/Marketing
- Manufacturing/Product development
- Research
- Other

25. Who is an important stakeholder in terms of RE development? And why?
26. Who is important in terms of promoting RE adoption? And why? (Including problem solving, information sharing, support, sales etc). (To provide list of institutional stakeholders).
27. To what extent do you depend on the identified organisations? (Highly dependent, medium, low)
28. To what extend do the identified organisations depend on you? (Highly dependent, medium, low).
29. In the last year which institution was the one you engaged with most for decision-making relating to renewable energy production/promotion?
30. In the last year which organisation was the one you engaged with most for decision-making relating to RE promotion?

E). Background Information.

31. Name of organisation.
32. What is your highest qualification?
33. How long have you worked with your organisation?
34. What is your gender?
35. How many years have you worked in the field of RE?

Do you have further comments?

Summarise and highlight key points from interview to enable respondent make additions, subtractions, or clarification if need be.

Will you like to see the report when its ready?

The End

Appendix D. Farmer survey questionnaire

Dear Respondent,

I am a post-graduate research student at Newcastle University, in the United Kingdom. I am conducting research into farmer use of renewable energy technologies in the Upper West Region of Ghana. The research aims to identify various forms of solar and biomass energy which can be used in smallholder agriculture and understand factors that drive farmers decision to adopt these technologies. We will not collect any names or personal details as part of the survey. Your identity will not be revealed to anyone other than the researchers conducting this survey. Participation is entirely voluntary, and you are free to withdraw from the survey at any time you feel uncomfortable or unwilling to participate, and you do not have to specify a reason. Once you have completed the survey, you will not be required to do anything else.

Section A: General/Background Information

1. Questionnaire code: ………………………………………….
2. Name of interviewer: ………………………………………..
3. Date of interview: ……………………………………………..
4. Name of community: …………………………………………
5. Gender [ ]

   1=Male

   2=Female

   3=Prefer not to say
6. What is your age? [ ]

   1=30 years or less

   2=31 – 40 years

   3=41 – 50 years

   4=51 – 60 years

   5=61 – 70 years

   6=71 years or more
7. What is your religion?

   1= Traditionalist

   2= Christian

   3= Muslim

   4= Others (specify)
8. What is your highest level of education? [ ]

   1=None

   2=Primary School

   3=JHS/Middle School

   4=SHS/Vocational/Technical

   5=Tertiary
9. What is your marital status? [ ]

   1=Single

   2=Married

   3=Divorced

   4=Living with family/partner

   5=Widowed
10. How many people live in your household? [ ]

11. What is the size of your farm? (Acres) [ ]
12. Do you own the farmland?

1=Yes

2=No

13. How many years have you been farming? [ ]
14. What type of farming do you practice? [ ]

1=Crops

2=Livestock

3=Crops and Livestock

4=Other (describe)

15. What crops do you cultivate? (multiple responses) [ ] [ ] [ ] [ ] [ ]

1=Maize

2=Millet

3=Groundnut

4=Cowpea

5=Sorghum

6=Vegetables

7=Other (describe)

16. What livestock do you rear? (multiple responses) [ ] [ ] [ ] [ ] [ ]

1=Goats

2=Sheep

3=Pigs

4=Poultry

5=Cattle

6=Other (describe)

17. What is the main source of labour for your farm? [ ]

1=Household members

2=Extended family

3=Hired labour

4=Other (describe)

18. What is the main purpose of your farming activities? [ ]

1=Food for household consumption

2=Cash

3=Traditional heritage

4=Other (describe)

19. If food is an important purpose for farming, do you produce adequate food to feed your household until the next farming season? Please indicate using a scale of 1 – 5, where 1=highly inadequate and 5=highly adequate *(1=highly inadequate, 2=inadequate, 3=neither adequate nor inadequate, 4=adequate and 5=highly adequate).*

    1=Highly inadequate

    2=Inadequate

    3=Neither adequate nor inadequate

    4=Adequate

    5=Highly adequate

20. How much income is made, on average, after a farming season?

    GHS……………………………..

Section B: Energy Use in Agriculture

21. What energy forms do you use? (multiple responses) [ ] [ ] [ ] [ ] [ ] [ ] [ ]

    1=Petrol

    2=Diesel

    3=Kerosene

    4=Fertilizer

    5=Wood/charcoal

    6=Electricity

    7=Gas

    8=Human resource

    9= Other (describe)

22. Which of the above selected energy forms do you use for agriculture? (Please tick as applicable).

	Energy Forms	
1	Petrol	
2	Diesel	
3	Kerosene	
4	Fertilizer	
5	Wood/charcoal	
6	Electricity	

7	Human resource	
8	Other (describe)	

23. What agricultural activities are these energy forms used for? (Please tick as applicable).

Energy Forms		Agricultural Activities						
		Ploughing	Irrigation	Drying	Harvesting	Lighting	Heating	Planting
1	Petrol							
2	Diesel							
3	Kerosene							
4	Fertilizer							
5	Wood/charcoal							
6	Electricity							
7	Human resource							
8	Other (describe)							

24. In a farming season, can you estimate how much energy cost?
GHS……………………………..
25. What form of solar energy do you use? [ ]
1=Traditional (i.e. drying crops in the sun)
2=Technology powered (i.e. solar water pumps)
3=Both
4=None
26. If you currently only use solar energy in the traditional form (i.e. open drying of crops), what is the likelihood that you will adopt the technology powered solar for agriculture? Please indicate using a scale 1 – 5, where 1=unlikely and 5=very likely. *(1= unlikely, 2=fairly likely, 3=neither likely nor unlikely, 4=likely and 5=very likely)*.
1=Unlikely
2=Fairly likely
3=Neither likely nor unlikely

4=Likely

5=Very likely

27. What form of biomass energy do you use? [ ]

1=Traditional (i.e. composting)

2=Technology enhanced (i.e. fuel/biogas)

3=Both

4=None

28. If you currently only use biomass energy in the traditional form (i.e. composting), what is the likelihood that you will adopt the technology enhanced biomass for agriculture? Please indicate using a scale 1 – 5, where 1=unlikely and 5=very likely. *(1= unlikely, 2=fairly likely, 3=neither likely nor unlikely, 4=likely and 5=very likely)*.

1=Unlikely

2=Fairly likely

3=Neither likely nor unlikely

4=Likely

5=Very likely

29. Please indicate the extent to which you agree/disagree with the following statement, using a scale of 1 – 5, where 1=strongly disagree and 5=strongly agree *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree)*.

a) Fossil fuels contribute to Green House Gases emissions (i.e. Climate Change) [ ]

b) Renewable energy is a cheaper energy form compared to other energy sources []

c) Renewable energy is a clean energy source compared to other energy sources [ ]

Section C: Socio-economic Drivers (Facilitators and Barriers to Adoption)

30. The following statements relate to the use of solar energy for farming. Using a scale of 1 – 5, please indicate the extent to which you agree/disagree with the following statements. Where 1=strongly disagree and 5=strongly agree. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree)*.

a) A high personal/household income is required to adopt solar technology. [ ]

b) Using solar technology will require me to access a credit/loan facility. [ ]

c) Solar technology is affordable compared to other energy technologies. [ ]

31. The following statements relate to the use of biomass energy for farming. Using a scale of 1 – 5, please indicate the extent to which you agree/disagree with the following statements. Where 1=strongly disagree and 5=strongly agree. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree)*.

a) A high personal/household income is required to adopt biomass technology. [ ]

b) Using biomass technology will require me to access a credit/loan. [ ]

c) Biomass technology is affordable compared to other energy technologies. [ ]

Section D: Psychological Facilitators and Barriers to Adoption

Please indicate the extent to which you agree or disagree with the following statements relating to solar and biomass energy use. Please use a scale of 1 – 5, where 1=strongly disagree and 5=strongly agree. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree)*.

32. It will be stress-free for me to use solar technology for farming.

    1=Strongly disagree

    2=Disagree

    3=Neither agree nor disagree

    4=Agree

    5=Strongly agree

33. I will be comfortable using solar technology for farming alone.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

34. It will be stress-free for me to use biomass technology for farming.

    1=Strongly disagree

    2=Disagree

    3=Neither agree nor disagree

    4=Agree

    5=Strongly agree

35. I will be comfortable using biomass technology for farming alone.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

36. Using solar technology for farming will increase my yields.

    1=Strongly disagree

    2=Disagree

    3=Neither agree nor disagree

    4=Agree

    5=Strongly agree

37. Using solar technology for farming will increase my farm income.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

38. Solar technology is affordable compared to other energy technologies.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

39. Using biomass technology for farming will increase my yields.

    1=Strongly disagree

    2=Disagree

    3=Neither agree nor disagree

    4=Agree

    5=Strongly agree

40. Using biomass technology for farming will increase my farm income.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

4= Agree

5= Strongly agree

41. Biomass technology is affordable compared to other energy technologies.

 1= Strongly disagree

 2= Disagree

 3= Neither agree nor disagree

 4= Agree

 5= Strongly agree

42. Adopting solar technology suites, the type of farming I practice.

 1=Strongly disagree

 2=Disagree

 3=Neither agree nor disagree

 4=Agree

 5=Strongly agree

43. Adopting solar technology is compatible with my indigenous farming practices.

 1= Strongly disagree

 2= Disagree

 3= Neither agree nor disagree

 4= Agree

 5= Strongly agree

44. Adopting biomass technology suites, the type of farming I practice.

 1=Strongly disagree

 2=Disagree

 3=Neither agree nor disagree

 4=Agree

 5=Strongly agree

45. Adopting biomass technology is compatible with my indigenous farming practices.

 1= Strongly disagree

 2= Disagree

 3= Neither agree nor disagree

 4= Agree

 5= Strongly agree

46. Using solar technology for farming has minimal or no effect on my farm yields.

1= Strongly disagree

2= Disagree

3= Neither agree nor disagree

4= Agree

5= Strongly agree

47. Using solar technology has no effect on my farm income.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

48. Using biomass technology for farming has minimal or no effect on my farm yields.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

49. Using biomass technology has no effect on my farm income.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

    4= Agree

    5= Strongly agree

50. I have the personal ability required to use solar technology for farming.

    1=Strongly disagree

    2=Disagree

    3=Neither agree nor disagree

    4=Agree

    5=Strongly agree

51. I think I understand how solar technology for farming works.

    1= Strongly disagree

    2= Disagree

    3= Neither agree nor disagree

4= Agree

5= Strongly agree

52. I have the personal ability required to use biomass technology for farming.

1=Strongly disagree

2-Disagree

3=Neither agree nor disagree

4=Agree

5=Strongly agree

53. I think I understand how biomass technology for farming works.

1= Strongly disagree

2= Disagree

3= Neither agree nor disagree

4= Agree

5= Strongly agree

54. To what extent do you agree/disagree the following statements relating to the use of solar energy for farming? Please indicate using a scale 1- 5, where 1=strongly disagree and 5=strongly agree. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, 5=strongly agree).*

a) My spouse will approve the use of solar technology for farming.

b) A family member will approve the use of solar technology for farming.

c) An agricultural extension officer will approve the use of solar technology for farming.

d) A neighbour will approve the use of solar technology for farming.

e) Other farmers similar to myself will approve the use of solar technology for farming.

f) Leaders of a farmer cooperative/association will approve the use of solar technology for farming.

g) A chief/traditional leader will approve the use of solar technology for farming.

55. To what extent do you agree/disagree the following statements relating to the use of biomass energy for farming? Please indicate using a scale 1- 5, where 1=strongly disagree and 5=strongly agree. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree, 5=strongly agree).*

a) My spouse will approve the use of biomass energy for farming.

b) A family member will approve the use of biomass energy for farming.

c) An agricultural extension officer will approve the use of biomass energy for farming.

d) A neighbour will approve the use of biomass energy for farming.

e) Other farmers similar to myself will approve the use of biomass energy for farming.

f) Leaders of a farmer cooperative/association will approve the use of biomass energy for farming.

g) A chief/traditional leader will approve the use of biomass energy for farming.

56. In the table below are resource facilitating conditions regarding solar energy for farming. Using a scale of 1 – 5, where 1=strongly disagree and 5=strongly agree, please indicate the extent to which you agree/disagree with the following statements. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree)*.

Resource Facilitating Conditions		**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
1	Using solar energy is time efficient.					
2	Using solar energy will require money/funds.					
3	Using solar energy will require ownership of plot(s) of land(s).					
4	Using solar energy will require adequate sunshine.					

5	Using solar energy will require the availability of water sources.					

57. In the table below are resource facilitating conditions regarding biomass energy for farming. Using a scale of 1 – 5, where 1=strongly disagree and 5=strongly agree, please indicate the extent to which you agree/disagree with the following conditions. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree)*.

Resource Facilitating Conditions		**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
1	Using biomass energy is time efficient.					
2	Using biomass energy will require money.					
3	Using biomass energy will require owning a plot(s) of land(s).					
4	Using biomass energy will require crop/livestock residues.					
5	Using biomass energy will require the availability of water sources.					

58. In the table below are technology facilitating conditions regarding solar energy for farming. Using a scale of 1 – 5, where 1=strongly disagree and 5=strongly agree, please indicate the degree to which you agree/disagree with the following conditions. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly disagree)*.

Technology Facilitating Conditions		**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
1	Solar energy has a relatively lower cost.					
2	To use solar technology, it must be available in the market for adoption.					
3	To use solar technology, the spare parts to mend the equipment must be available.					
4	To use solar technology, technical experts/equipment repairers must be available.					

59. In the table below are technology facilitating conditions regarding biomass energy for farming. Using a scale of 1 – 5, where 1=strongly disagree and 5=strongly agree, please indicate the degree to which you agree/disagree

with the following conditions. *(1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly disagree)*.

Technology Facilitating Conditions		Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	Biomass energy has a relatively lower cost.					
2	To use biomass technology, it must be available in the market adoption.					
3	To use biomass technology, the spare parts to men equipment must be available.					
4	To use biomass technology, technical experts/equipment repairers must be available.					

Section E: External Drivers Facilitating Technology Adoption

60. Have you received any support (i.e. logistics, financial, training etc) that may enable you adopt solar technology? [ ]

    1=No

    2=Yes

    59a. If yes, explain what support was provided and from whom?

61. If no, are you willing to receive support? [ ]

1=No

2=Yes

60a. If yes, explain what support you will prefer and from whom?

62. Have you received any support that may enable you adopt biomass technology? [ ]

1=No

2=Yes

61a. If yes, explain what support was provided and from whom?

63. Are you willing to receive support? [ ]

1=No

2=Yes

62a. If yes, explain what support you will prefer and from whom?

64. The table below constitutes various forms of support relating to solar energy use for farming. Please indicate the degree of importance you perceive the following forms of support to you, using a scale of 1 – 5, where 1=not important and 5=very important. *(1=not important, 2=less important, 3=somewhat important, 4=important and 5=very important)*.

Forms of Support		**Not important**	**Less important**	**Somewhat important**	**Important**	**Very important**
1	Training					
2	Education & awareness creation					
3	Credit					
4	Logistics					
5	Land					
6	Market accessibility					
7	Subsidy					
8	Other (describe)					

65. The table below constitutes various forms of support relating to biomass energy use for farming. Please indicate the degree of importance you perceive the following forms of support to you, using a scale of 1 – 5, where 1=not important and 5=very important. *(1=not important, 2=less important, 3=somewhat important, 4=important and 5=very important)*.

Forms of Support		**Not important**	**Less important**	**Somewhat important**	**Important**	**Very important**
1	Training					
2	Education & awareness creation					
3	Credit					
4	Logistics					
5	Land					
6	Market accessibility					
7	Subsidy					
8	Other (describe)					

66. Which institution(s) do you think should support you to adopt solar/biomass energy use? (multiple responses) [ ] [ ] [ ] [ ] [ ] [ ]

1=Government

2=NGO

3=Financial/Cooperative institutions

4=Farmer Associations/Networks

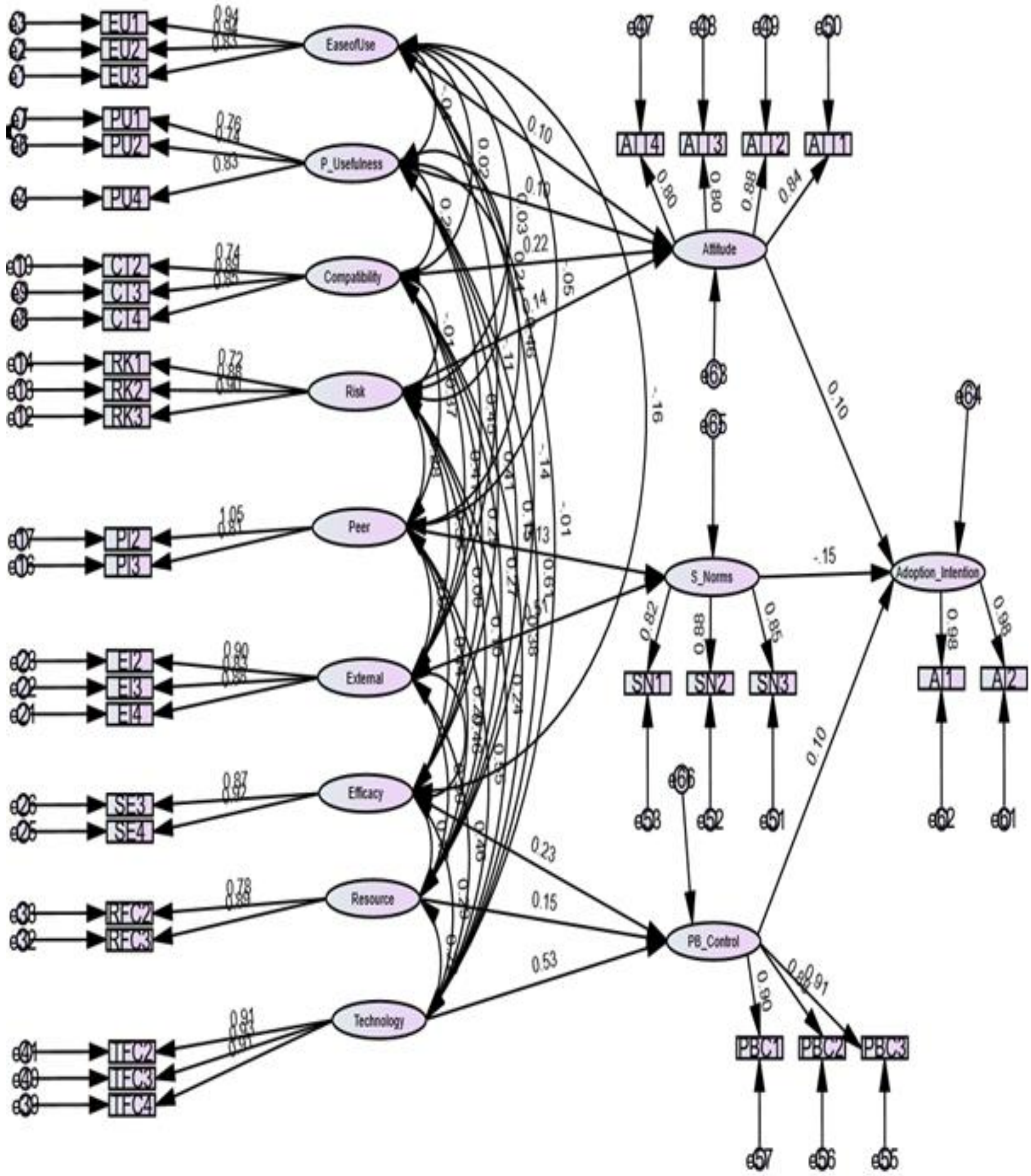
5=Donor/Development partners

6=Other (describe)

Thank you

Barika yaga zaa

Appendix E. Structural regression path of the hypothesised model



Appendix F. Themes and coding topics used in qualitative data analysis

Farmers:

Main Theme	Subtheme
Farmers Perceived Attitude About Renewable Energy use in Agriculture.	Economic factors; environmental factors; advantages and disadvantages of renewable energy
Farmers Perceived Subjective Norms About Renewable Energy use in Agriculture.	Social factors; institutional approval; family approval; friends' approval; group approval
Farmers Perceived Behavioural Control About Renewable Energy use in Agriculture.	Adoption capacity; type of support; technological factors; financial resources; natural resources

Non-Farmer Stakeholders:

Main Theme	Subtheme
Stakeholders' perspective on renewable energy use in agriculture	Farm energy and inputs; recommendable renewable energy
Drivers and barriers harnessing renewable energy in agriculture	Technology characteristics; farmers motivation for renewable energy use; socio-economic enablers for renewable energy use

Role of agricultural stakeholder institutions in promoting renewable energy use in agriculture	Forms of promoting renewable energy; types of stakeholders promoting renewable energy; role of national policies promoting renewable energy

Appendix G. Ethics approval

⚠ External sender. Take care when opening links or attachments. Do not provide your login details.

Ref: 13797/2020

Thank you for submitting the ethical approval form for the project 'Promoting Renewable Energy Technologies in Smallholder Agriculture: Examining Factors Influencing Smallholder Farmers Adoption of Renewable Energy Technologies in Lawra, Upper West Region-Ghana.' (Lead Investigator: Ransford Teng-viel Karbo). Expected to run from 06/01/2020 to 05/01/2024.

Based on your answers, the University Ethics Committee grants its approval for you to start working on your project. Please be aware that if you make any significant changes to your proposal then you should complete this form again, as further review may be required. This confirmation may be used within a research portfolio as evidence of ethical approval. Please note: this confirmation will be the only correspondence you should expect to receive as evidence of ethical approval. There will be no other confirmation provided. You may now proceed with research. If you have any queries, please review the internal and external ethics FAQ pages before contacting res.policy@ncl.ac.uk.

⚠ External sender. Take care when opening links or attachments. Do not provide your login details.

Ref: 32218/2023

Thank you for submitting the ethical approval form for the project 'Promoting Renewable Energy Technologies in Smallholder Agriculture: Examining Factors Influencing Smallholder Farmers Adoption of Renewable Energy Technologies in Lawra, Upper West Region-Ghana.' (Lead Investigator: Ransford Teng-viel Karbo). Expected to run from 06/01/2020 to 05/01/2024.

Based on your answers, the University Ethics Committee grants its approval for you to start working on your project. Please be aware that if you make any significant changes to your proposal then you should complete this form again, as further review may be required. This confirmation may be used within a research portfolio as evidence of ethical approval. Please note: this confirmation will be the only correspondence you should expect to receive as evidence of ethical approval. There will be no other confirmation provided. You may now proceed with research. If you have any queries, please review the internal and external ethics FAQ pages before contacting res.policy@ncl.ac.uk.

Appendix H. Consent form for research participants

Consent Form for Research Participants

Title of study: Promoting Renewable Energy Technologies in Smallholder Agriculture: Examining Factors Influencing Smallholder Farmers Adoption of Renewable Energy Technologies in Lawra, Upper West Region-Ghana.

Thank you for your interest in taking part in this research. Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research study. You will be given a copy of this Consent Form.

		Please initial box to confirm consent
1.	I confirm that I have read the information sheet dated [15/02/2021] (version 01) for the above study, I have had the opportunity to consider the information, ask questions and I have had any questions answered satisfactorily.	
2.	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected. I understand that if I decide to withdraw, any data that I have provided up to that point will be included in the research project.	
3.	I consent to the processing of my personal information [employment details] for the purposes of this research study, as described in the information sheet dated [15/02/2021] (version 01).	
4.	I consent to my anonymised/pseudonymised research data being stored and used by others for future research.	
5.	I understand that my research data may be published as a report.	
6.	I consent to the retention of my personal information [employment details] for 2 years, for the purpose of being re-contacted.	
7.	I understand that my research data may be looked at by individuals from Newcastle University and the Rufford Foundation, where it is relevant to my taking part in this research.	
8.	I consent to being audio and/or video recorded via the use of recording device platform, and understand that the recordings will be transferred as soon as possible from the recording location/platform to a password-protected folder. The original files in the recording location will be deleted once they are transferred. The copied recordings will be destroyed within 2 years after the data has been collected, and meanwhile stored anonymously on a password-protected software and used for research purposes only. I understand that being audio and/or video recorded is optional and therefore not necessary for my participation in this research.	
9.	I agree to take part in this research project.	

Participant

______________	______________	________
Name of participant	*Signature*	*Date*

Researcher

______________	______________	________
Name of researcher	*Signature*	*Date*