Adoption of harnessed energy supply practices for improved production efficiency of smallholder poultry farmers in Tshwane District, Gauteng

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DECLARATION

I hereby state that the research project, "Adoption of harnessed energy supply practices for improved production efficiency of smallholder poultry farmers in Tshwane District, Gauteng" is completely original to me and has never been submitted, in whole or in part, for any academic purpose to another university. For each source that has been cited or used, full references have been included.

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Mogashoa, hereby certifies that she is aware of the North-West University's policy on research ethics and that he has taken all reasonable steps to abide by it. Reference number: NWU-01434-24-A9. I have a certificate of ethical clearance from the research ethics committee at North-West University.

DEDICATION

This is dedicated to my late grandmother, Lydia Mogashoa.

ABSTRACT

There is a growing demand for sustainable agriculture, which serves as a major force behind innovation in the agricultural sector. This novel approach intends to increase agricultural sustainability by improving the production efficiency of smallholder poultry farmers through reliable energy sources. By providing access to harnessed energy solutions, farmers can optimize their operations, reduce reliance on fossil fuels, and ultimately enhance their profitability. This shift enables rural, urban, and peri-urban communities achieve the broader goal of sustainable development in addition to benefiting individual households. The purpose of this study was to analyse the production efficiency of smallholder farmers who used electricity compared to those who have incorporated solar and wind energy. The study's aim was to investigate adoption of harnessed energy supply practices for improved production efficiency of smallholder poultry farmers in Tshwane District, Gauteng Province. This aim was achieved through four objectives: describing socioeconomic characteristics of smallholder poultry farmers in Tshwane district, to determine the constraints faced by smallholder farmers under the current energy supply, to investigate the factors influencing the adoption of harnessed energy supply, and to compare the production efficiency of smallholder farmers under the conventional energy supply and harnessed energy supply.

To achieve the study objectives, a probability sampling approach, specifically stratified sampling, was used to select smallholder poultry farmers in Tshwane Municipality. Primary data were then collected from the selected respondents using a semi-structured questionnaire. Descriptive statistical analysis was employed to examine the demographic and socio-economic characteristics of smallholder poultry farmers in Tshwane. The results indicate that the majority of respondents were between the ages of 35 and 44, with 56% being male. Furthermore, 51% of the respondents reported being single. Finally, 76% of respondents had 0–5 years of agricultural experience, and 35% have tertiary level education. This indicates that most respondents were less experienced in poultry farming. The second objective made use of the probit regression models, which were through identified independent variables such as family size, age, monthly income, farming experience, perception of harnessed energy, awareness of harnessed energy, and influence to adopt harnessed energy, to mention a few. Emanating from these variables, age was statistically insignificant ($p > 0.05$), as was farming experience ($p = 0.131$). However, the influence to adopt harnessed energy was statistically significant ($p = 0.043$) at the 5% level. The hypothesis tests were conducted at the 5% and 10% levels of significance.

The third objective was aimed at determining the primary constraints smallholder poultry farmers encounter with the current energy use, through Kendall's Coefficient of concord (W). These constraints were ranked based on a 5-point scale, where high cost of production scored a mean of 3.76. This indicates that this was a key barrier towards adoption of harnessed energy and production efficiency. The respondents also indicated that shortage of funding is key. The last objective employed the stochastic model to assess production efficiency between the use of conventional energy and harnessed energy. When compared to the use of conventional energy, the results showed that harnessed energy practices do improve production efficiency. Conventional energy system has a mean of 0.5708, whilst harnessed energy system had a mean of 0.9437. Conventional energy had a standard deviation of 0.2948, and harnessed energy systems had 0.6894. This study suggests diversifying energy systems in smallholder farming practices to improve production efficiency. This analysis also supports policymakers in proposing measures to enhance control over the importation and manufacturing of harnessed energy components, facilitating their accessibility and usability.

Key words: Harnessed Energy, Production Efficiency, Adoption, Smallholder Farmers, Poultry.

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ACRONYMS

SAPA	South African Poultry Association
SMMEs	Small Medium and Micro Enterprises
GIES	Gauteng Integrated Energy Strategy
GDP	Gross Domestic Product
FAO	Food and Agricultural Organization
CIS	Commonwealth independent states
OECD	Organization for Economic Co-Operation And Development
NERSA	National Energy Regulator of South Africa
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
DARD	Department of Agriculture and Rural Development
NAMC	National Agricultural Marketing Council
AGRISETA	Agricultural Sector Education and Training Authority

CHAPTER 1: INTRODUCTION

1.0 Background of the study

Recent evidence shows that the poultry industry remains one of the most important subsectors within South African agriculture, contributing a significant share of the sector's gross value and serving as a major source of affordable protein and employment (Madibana et al., 2024; Myeki et al., 2022) . The poultry sub-sector accounted for around 17-18 % of total agricultural gross value in 2023 and nearly 43 % of the animal products gross value while also supporting extensive value chains across feed, processing and retail (Chamboko, 2025). According to the Agricultural Sector Education and Training Authority (AGRISETA) report, the South African agricultural sector is divided into 11 sub-sectors, with poultry being one of the sub-sectors (Pengelly et al., 2021). The poultry sub-sector in 2021 remained the largest sub-sector in the country, with 16.6% of production and an overall R 62.3 billion of combined farm income (McIver et al., 2020).

This reflects a steady growth in poultry production, from R 60.8 billion in 2020 to R 62.3 billion in 2021 (Osmani, 2023). Poultry's growth tendency may be attributed to the subsector's resilience and ability to fulfil increasing local and global demand (Silva & Dematawewa, 2020). Improvements in biosecurity protocols, production method advancements, and suitable infrastructure investments are all contributing elements that have helped the industry become more competitive globally and increase its productivity (Téllez-Isaías, 2023). Poultry is still an economical source of protein for most people, with a critical role in food security (Chowdhury et al., 2023).

Smallholder farmers contribute significantly to the poultry industry, particularly in rural and peri-urban areas where production is often conducted on a small scale with limited capital and infrastructure(Sime, 2022) . These farmers typically produce modest quantities of broilers and eggs for household consumption, informal markets, and supplementary income generation (McIntyre et al., 2022; Wilson, 2021). Despite their contribution to local food security, the broiler industry in South Africa remains largely dominated by vertically integrated commercial firms that account for the majority of national output (Queenan et al., 2022)

Smallholder producers, however, face increasing production constraints, particularly rising input costs associated with feed, housing infrastructure, equipment, and, importantly, electricity

(Gasparatos, 2025; Giller et al., 2021). Energy has become a critical cost driver in intensive poultry systems, as reliable electricity is required for heating, lighting, ventilation, automated feeding systems, and water supply management(George & George, 2023). In contexts characterised by escalating electricity tariffs and supply instability, energy insecurity directly affects production efficiency, broilers survival rates, feed conversion ratios, and overall profitability(Queenan et al., 2022).

Efficient poultry production therefore depends on a careful integration of housing, energy, labour, feed, and water systems(George & George, 2023) . Among these factors, energy plays a foundational role, particularly in intensive broiler systems where temperature regulation, artificial lighting schedules, and ventilation systems are essential for optimal growth performance (Apalowo et al., 2024; Wu et al., 2025). Commercial broiler breeds, which form the focus of this study, require highly specialised and energy-intensive production environments to achieve optimal weight gain within short production cycles (Oke et al., 2025; SULTAN, 2022). As such, the sustainability and competitiveness of smallholder broiler enterprises are increasingly linked to reliable and cost-effective energy supply options, including alternative and harnessed energy systems (Sleem et al., 2024).

Energy is a crucial component for meeting all of our fundamental requirements, from sustaining the food chain to conducting different economic activities (Molajou et al., 2021). These operations include everything that one needs for daily living, including building/construction, conveyance, agriculture (instruments and equipment for energy supply and water supply), and household use (illumination, cooling, heating, preparing meals, and conservation) (Sleem et al., 2024). Energy is essential in the agricultural sector, as it handles primary issues that concern the production of food (Babu et al., 2022; Pawlak & Kołodziejczak, 2020). The following operations related to the production of food in the poultry industry require energy: electric motors are essential components of poultry production, powering operations like refrigeration, feeding, ventilation, egg collection, air scrubbing, and manure drying (Chel & Kaushik, 2011; Hilarydoss, 2023). Achieving and maintaining equilibrium between economics and energy consumption is essential for the goals of sustainable agricultural practices (Streimikis & Baležentis, 2020).

Many emerging economies are finding it difficult to meet the rising demands for food, clean water, and alternative energy sources in the face of climate change (Kookana et al., 2020). Global warming and population growth combined contribute to the rapid increase in energy

consumption, which accelerates both technical and economic development (Song et al., 2011). By 2035, there will be a 50% increase in the world's energy usage (Newell et al., 2020). This increase in energy consumption will lead to higher power costs, which will have an immediate impact on the agriculture sector because of the extraordinarily high energy needed for various agricultural operations (Paris et al., 2022) . Food prices will increase as a result of the high input costs involved in farming, which puts food safety at threat, particularly in developing countries. (Mujuru & Obi, 2020). The rising energy consumption linked to agriculture and the high cost of inputs may be resolved by implementing sustainable energy systems and better energy utilisation strategies (Rahman et al., 2022).

Power outages in South Africa have immensely impacted the South African economy (Naidoo, 2023). According to the NAMC (National Agricultural Marketing Council), load shedding reached an all-time high of 1054 hours (or 47.7% of the time) in 2022, resulting in a 2.1% decline in GDP in the 3rd quarter of 2022 (Ige-Gbadeyan, 2023). As a result, the agriculture industry has suffered greatly from the sudden decline in production, and poultry producers have also suffered losses (Mthembu et al., 2022). Most farmers have been compelled to use harnessed energy due to a lack of alternatives, but some are still unable to do so (Emetere et al., 2021). Increased energy utilisation, food safety, and sustainability will result from using eco-friendly energy systems for agricultural production in order to meet the objectives of environmentally friendly agriculture practices (Gayathiri et al., 2022). Globally, the energy difficulties facing agriculture differ according to the degree of development, the area, and the methods used in agriculture production (Rokicki et al., 2021).

Hence, several farms are adapting to advanced ways of producing (Stringer et al., 2020). In an effort to support the smallholder farmers and stimulate the adoption of harnessed energy, the former Minister of Agriculture, Thoko Didiza, announced the Agriculture Energy Fund, which seeks to alleviate the energy shortages faced by smallholder farmers in South Africa (Sihlobo, 2023). Farmers are permitted funding of up to R500 000. However, efforts to reduce the severity of the energy crisis have resulted in a partial solution that is not tailored to all situations farmers encounter (Sihlobo, 2023). Key stakeholders and academia’s effort in finding short-term interventions to reduce the severity of the crisis has resulted in a partial solution due to problems encountered by private and government bodies (Etemad, 2020).

1.1 Problem Statement

South Africa's energy output per household and industry is insufficient to fulfil demand throughout the nation (Akinbami et al., 2021). A country's development and industrial expansion are influenced by its accessibility to energy resources, which are lacking behind in South Africa in terms of voltage supply, industries and household energy usage (Hanto et al., 2022). According to Kleyn and Ciacciariello (2021), the energy required to keep the agricultural industry operating smoothly is insufficient, particularly for smallholder farmers who are into poultry production, which is energy-intensive. Additionally, the sector has been severely impacted by the load-shedding circumstances that led to production failure and subsequently bankruptcy (Mfulwane, 2023).

An and Mikhaylov (2020) established that South African electricity tariffs have risen dramatically over the last decade, affecting both smallholder farmers and commercial farmers. Electricity in poultry farms accounts for the largest quantity of energy used in ventilation, lighting, heaters, and motor runners for feeders, resulting in high energy cost (Tewari, 2022). The significant rise in energy costs in South Africa is due to a complex of multiple reasons, relating to mismanagement, corruption, and inefficiency at Eskom, the major national electricity producer system, hence the load shedding, uneven and expensive tariff (Kessides, 2020).

Similar to other regions globally, South Africa has encountered a slow and challenging transition to harnessed energy; however, recent developments suggest improvement (Lin & Sai, 2022). Despite the progress made by harnessed energy firms, government and private sectors in South Africa, fossil fuels continue to be the primary energy source (Mutezo & Mulopo, 2021). The main issue facing most nations, including South Africa, is the efficiency rate of harnessed energy adoption, which has been lagging for years (Ibrahim et al., 2021). As a result, researchers have attempted to create a platform where solutions of harnessed energy can be offered, but the scope of studies on this subject has been limited in South Africa (Nwaiwu, 2021).

South Africa's agriculture sector, especially smallholder farmers, has historically faced high maintenance costs and limited infrastructure, which is another issue with the country's adoption of harnessed energy (Mapiye, 2022) . Accompanied by a lack of extension service by either the private or government sectors. The lack of extension services has been a major constraint to the effective adoption of harnessed energy by farmers (Elahi et al., 2022). A study by Abegunde

et al. (2019) found that farmers' low adoption and poor management of the harnessed energy are due to a lack of proper guidance and education.

In most rural and peri-urban areas, socioeconomic characteristics, including education, gender, age, and family size, were significant barriers to the successful adoption and maintenance of captured energy (Haque et al., 2021). There are several examples of female farmers in rural and peri-urban areas that lack information, power, and decision-making authority; as a result, women are less able to access funding, land, and extension services, and they encounter comparable barriers when it involves technology adoption (Witinok-Huber et al., 2021). It has been demonstrated that elderly farmers are less tech-literate and more resistant to change (Hodge et al., 2017). The younger generation, on the other hand, reflects the opposite traits; they are flexible and ready to learn and pride themselves in their adoption of technology (Bhardwaj, 2021). Therefore, the aim of this study was to offer an alternative for the use of fossil fuels. This study raises challenges because there has not been much research conducted regarding topic

1.2 Research Questions

i. What are the socio-economic characteristics of smallholder poultry farmers in the selected study area?

ii. What are the factors influencing the adoption of harnessed energy supply?

iii. What are the constraints faced by smallholder farmers using conventional and harnessed energy supply?

iv. How efficient are farmers under conventional energy and harnessed energy supply?

1.3 Objectives of the Study

1.3.1 Aim of the Study.

I. To investigate adoption of harnessed energy supply practices for improved production efficiency of smallholder poultry farmers in Tshwane District, Gauteng Province.

1.3.2 Objectives

To achieve the aim of this study, the following objectives was be addressed:

i. To examine socio-economic characteristics of smallholder poultry farmers in Tshwane District.
ii. To determine the constraints faced by smallholder farmers under current energy supply;
iii. To investigate the factors influencing the adoption of harnessed energy supply; and
iv. To compare the production efficiency of smallholder farmers under the conventional energy supply and harnessed energy supply.

1.4 Hypotheses.

Objective 2: Null hypothesis (H_0): There are no constraints faced by smallholder farmers under the current energy supply in Tshwane District, Gauteng Province.

Alternative hypothesis (H_1): There are constraints faced by smallholder farmers under the current energy supply in Tshwane District, Gauteng Province.

Objective 3: **Null hypothesis (H_0):** There are no significant factors influencing the adoption of harnessed energy supply by smallholder poultry farmers in Tshwane District.

Alternative hypothesis (H_1): There are significant factors influencing the adoption of harnessed energy supply by smallholder poultry farmers in Tshwane District

Objective 4: Null hypothesis (H_0): There is no significant difference between the production efficiency of harnessed energy adaptors and non-adaptors.

Alternative hypothesis (H_1): There is a significant difference between the production efficiency of harnessed energy adaptors and non-adaptors.

1.5 Justification of the study

The South African Poultry Association (SAPA) aims to work with all Small, Medium, Micro, and Enterprises (SMMEs) to diversify and adopt new farming techniques supported by technology to increase poultry farm production. This study is part of the SAPA's economic recovery plan strategies and rural economic development.

To achieve the goals of the Gauteng Integrated Energy Strategy (GIES), this study develops a comprehensive plan that would guide the energy transition and expansion of the Gauteng Province of South Africa. This study will address key concerns and offer a way ahead for a more effective and sustainable energy system, given the region's significance to the nation's economy and energy use.

In addition to serving as a model for other parts of South Africa and beyond, this study provides researchers and individual empowerment organisations with specific information to assist smallholder poultry farmers in providing the resources required to fully participate in the effective adoption of harnessed energy in the study area. Studying the importance of adopting harnessed energy sources by these farmers contributes to sustainable poultry production, thereby improving their poultry yields. This knowledge informs smallholder poultry farmers about the means to harness energy and how it enhances their farming practices. This also provides farmers with pertinent information on the efficiency and advantages of adopting new technology, while encouraging engagement with important stakeholders and prompting a shift in their farming mindset from just producing for their own consumption. This also helps policymakers to drastically develop policy formation and execution, which will in turn help the economy of South Africa at large. Implementation is also be made easier due to the availability of data on adoption rates and the efficient use of harnessed energy.

In view of this, this research project aimed to provide empirical evidence for Gauteng to better understand the importance of poultry farmers adopting harnessed energy practices and in improving the poultry production.

1.6 Limitations of the study

This study only identified three limitations; however, they do not diminish the significance of the findings; rather, they serve as useful guidelines for key areas of further study. The first challenge was the restricted access to the farmers database covering the province and the Tshwane district; data is collected from farmers who were already in focus-groups, leaving out those who were not. The study's dependence on one-time data collection made it hard to monitor possible changes or mutual effects over time. Lastly, only a limited numbers of smallholder farmers were able to be reached due to financial limitations such as insufficient budget for field travel. To address the limited budget for field travel and the challenge of hiring enumerators, a QR code survey was shared online through the Tshwane municipality's

agricultural extension officers, allowing farmers to participate easily without the need for costly in-person visits.

1.7 Delimitations of the Study

This study only focused on smallholder farmers who produce broiler poultry in the Tshwane district to maintain a clear focus on the objectives set forth. This study was restricted to broiler and not layers because broilers have a predictable production cycle and meat is the only measured result, as compared to layers where we pay attention to eggs and meat production. Overall, both layers and broiler require high energy production. The study was restricted to smallholder farmers in the Tshwane district to investigate the production efficiency under different energy systems (electricity vs harnessed energy) as well as the adoption behaviour of farmers who usually experience resource and knowledge constraints. Additionally, due to the study area's practical viability, only solar and wind energy were considered as harnessed energy systems.

Production efficiency was prioritized over technical efficiency. When it comes to production efficiency, output growth involves making the greatest use of available resources to produce the maximum output within the constraints. In contrast technical efficiency uses specific inputs to achieve maximum output, output growth in production efficiency entails making the greatest use of available resources to produce the highest feasible output for the given any set of constraints. Although, technical efficiency adds to the total productive efficiency metric. The idea of the production frontier or best practice structure serves as the benchmark for technical efficiency.

Lastly, the study focuses on how socio-economic characteristics affect adoption of harnessed energy. Income levels, education, credit availability, and general livelihoods all have an impact on the adoption of harnessed energy since they are crucial to the in-depth analysis of the findings. Taking socio-economic characteristics into account ensures that the development of the solutions thereof is practical, inclusive, and truly beneficial for smallholder farmers. Socio-economic characteristics are useful to comprehend these smallholder farmers realities.

1.8 Structure of the study

This study sought to analyses the production efficiency of electricity-using smallholder poultry farmers with those that integrated solar and wind energy practices. The focus on the adoption of harnessed energy has a potential influence on policies by the government and other stakeholders aimed at reducing pollution (burning fossil fuels). The study is divided into five chapters:

- Chapter one provides the introduction and background of the study.
- Chapter two provides a review of the research on adoption of harnessed energy supply, and an overview study of the poultry subsector in Tshwane district. The chapter also outlines literature on adoption of solar and wind energy for production efficiency.
- Chapter three focuses on the methodology used in the study, whilst
- Chapter four provides analysis and presentation of findings and the discussion.
- Chapter five is the summary of the findings and conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction.

Poultry farming is significant globally, and particularly in South Africa, due to its nutritional benefits, including a rich source of protein (Mnisi et al., 2021) . Poultry production has increased across time, with the United States leading the globe in production, followed by China and Brazil (Govoni et al., 2021). Although South Africa was emphasised as the leading producer of poultry meat in 2020, Egypt has led Africa from 2022 to date, with Nigeria following closely after (Erdaw & Beyene, 2022; Walakira et al., 2023).

This chapter addressed the conceptual framework, as well as the poultry industry and its challenges. The rate of adoption was also investigated, along with how poultry farmers have benefitted from adopting new technologies.

2.1 Conceptual and Theoretical Framework

2.2.1 Adoption of Technology

According to Suchman (1993), technology includes the circumstances and elements that call for altering production processes while taking into account current ambiguities, whether imagined or objective. Over time, the unpredictability and feelings of indecision they produce may become less pronounced. This results from the accumulation of significant experience as well as sufficient and pertinent knowledge for individuals, which would then affect the way production functions (Machlup, 2014) . This increases the effectiveness and capability of those implementing the modifications when implementing and utilising the modified technology (Feder et al., 1985; Suchman, 1993).

In this context, technology adoption refers to the degree to which new, improved techniques and technologies are recognised, adopted, and used with the aim of increasing productivity and improving lifestyles (Feder et al., 1985; Kalantari, 2017; Lee et al., 2009; Pathak et al., 2019). The accessibility of knowledge and assets necessary for short-term technology use, as well as long-term extension and continued use of the technology, aids small- and medium-sized agricultural households in adopting novel technologies and techniques (Davis et al., 2019; Jama & Pizarro, 2008).

A number of variables influence small-scale farmers' decisions to embrace and employ new technology (Nigussie et al., 2017). The issue here is the necessity of educating farmers about current practices and technology and how to effectively use them to satisfy production demands and, more crucially, to enhance both short- and long-term livelihoods (Feder & O'Mara, 1981).

The discussions make it evident that several factors influence small-scale farmers' adoption of contemporary innovations, including age, proximity to both formal and informal marketplaces, accessibility to financing facilities, and the availability of land and resources for production (Adams, 2015). These factors work in concert to influence how well farmers make judgments about implementing strategies that are focused on utilising the technology (Akudugu et al., 2012).

Understanding the diverse processes that compel the adoption of new technologies is important for government, lawmakers, development organisations, and governance institutions at both national and regional levels (Akudugu et al., 2012). This would make it easier to understand the dynamic nature of the adoption-facilitating elements and how they interact to influence farmers' choices to engage in enhanced farming.

It would also assist the department of agriculture, other development organisations, local and national governmental entities, and non-governmental organisations in efficiently resolving agricultural households' concerns throughout the adoption and ongoing use of technology.

2.2. Agricultural Technology Adoption and Its Utilisation in Farming

One key way to guarantee agricultural transformation is through the adoption and application of agricultural technology (Das, 2008; Timmer, 1988). Furthermore, it can raise the standard of living for small-scale agricultural households and lower poverty levels (Adesina & Baidu-Forson, 1995; Das, 2008). This problem becomes pertinent to the development of modern agriculture. It is necessary to conduct sufficient research on one side and provide small-scale farmers with pertinent knowledge and tools for their adoption to facilitate technological transformations in farming (Osun, 2015). This offers sufficient room for raising agricultural output and significantly increasing the standard of living for small-scale agricultural families and the agricultural sector.

In developing nations, farmers' incomes and overall lives are improved, and technical advances brought about by the use of advanced farming technology are viewed as significant and beneficial (Feder et al., 1985; Nin et al., 2003). Even though South Africa's agriculture industry employs the majority of the nation's workforce and accounts for a sizable portion of its GDP, it exhibits an extremely low rate of adoption of agricultural technology, particularly among small-scale producers who primarily produce food crops (Greyling, 2012).

According to the department of agriculture (2010), one of the main factors influencing agricultural production and livelihoods in the nation's rural communities is the poor adoption of technology (Ntshangase et al., 2018). To enhance livelihoods and guarantee significant productivity, this necessitates examining the elements impacting the acceptance and advancement of agricultural practices. Farmers on a small scale have used several technologies to improve their farming, despite the low adoption of modern technology, which is currently seen to define the nation's food and agricultural production (Akudugu et al., 2012). These technologies include the usage of fertiliser, insecticides, herbicides, advanced irrigation techniques, and motor tricycles for moving agricultural products and tools. To unlock the patterns that are presented in technology adoption, it is crucial for this study to conceptualise technology adoption within smallholder farming. Additionally, it assists in determining an array of reasons that motivate farmers to adopt the latest innovations.

2.3 The Adoption Challenge and Transfer of Technology

The process of moving new information, ideas, techniques, and resources from one point to another with a range of recipients and senders, both domestically and internationally, is referred to as the transfer of technology (Robertson & Jacobson, 2011). In the context of development, technology transfer might involve the introduction and dissemination of novel approaches and information, followed by the extension and application of novel techniques and instruments by the inventors to the receivers (N. Pandey et al., 2022) . Technology can be transferred from the commercial sector to the governmental sector, as well as from private companies and organisations to other people (Radosevich & Lombana, 1993).

Small-scale farmers have viewed technological advances in agriculture as crucial to boosting their agricultural operations' efficiency and production (Mgbenka et al., 2016). Technology adoption and dissemination offer opportunities to guarantee farming's durability and viability in poor nations (Takahashi et al., 2020). Despite this, there is ongoing discussion on how to

effectively transfer technology and advance technical advancements in small-scale farming while considering the many obstacles that surround the implementation of technology and transfers.

Glover et al. (2019) argue that the term "information technology transfers and adoption" oversimplifies the processes involved in technological development (Parker & Castleman, 2009). Change is a complicated process that encompasses several socio-political and structural factors (Herrfahrdt-Pähle et al., 2020). Adopters and professionals, particularly small-scale farmers, play a crucial role in implementing advanced technology (Smidt & Jokonya, 2022).

A major issue that may occur with technological advancement and adoption is the inclination to regard and approach technology as a black box (Rosenberg, 1994). This occurs in most situations when technology is viewed as an embodiment of knowledge through its inventions, processes, and tools (Glover et al., 2016). In some ways, the perception of technology as a memory box encourages the simplistic view of technology as being generic and separable, that can be readily extracted from one vantage point and accepted and utilised elsewhere. This way of thinking about technology could make it difficult to discuss its technical and material aspects while ignoring or paying less attention to the organisational, social, and political, societal, and epistemological frameworks that support technological adoption alongside transformation (Glover et al., 2016).

The labelling and use of technology as a straightforward linear outflow process from subpar techniques, materials, and equipment towards better and more effective ones is another barrier that restricts technological diffusion and acceptance (Glover et al., 2019). This results in a description of technology adoption that oversimplifies the difference between users and non-adopters. This suggests paying less attention to various experimental and learning procedures and dynamics, even though they remain important to the process (Glover et al., 2016). It is crucial to consider farmers' agency, expertise, and ideas when considering technical progress, as well as the socioeconomic relationships that support their acceptance (McCown, 2002) .

2.4 Rogers' adoption theory and dissemination

Rogers' idea of adoption and dissemination is a prominent adoption theory that has achieved widespread acceptance(Kee, 2017). Therefore, this hypothesis becomes important when researching the organisational and demographic aspects that explain the adoption or failure to adopt agricultural technology (Feder et al., 1985) . Although diffusion and adoption are distinct concepts, they are occasionally used interchangeably when talking about technology transfer and advancements (Orr, 2003).

2.4.1 The Theory of Individualized Creative thinking

According to Orr (2003), various people and groups may embrace innovations or technologies at different times within a framework of society. As a result, several time series may cover how members of a society embrace and employ new ideas, technologies, and inventions (Orr, 2003). In this sense, farmers in rural areas may also embrace (or reject) new technologies and innovations at varying rates and during varying time periods.

As a result, within society, adopters may fall into many groups (Nickman, 1985). The groups are categorised as laggards, early adopters, early majority, and late majority. The concept of innovativeness is used to categorise adopters (Carter, 1998) . In this context, innovativeness includes the pace at which members of a social group adopt and use new inventions in comparison to one another(Subramanian, 1996). According to this, innovators are those who have a willingness to adopt new concepts and are prepared to apply them in their job (Dearing, 2009). People have varying motivations when it comes to adopting new ideas; therefore, innovators or adopters who exhibit more aspirations may utilise and apply a new concept more than others (Wisdom et al., 2014) . Orr (2003) suggests that innovators may not be considered the most outstanding within a framework of society, because they could possibly be perceived as deviating from its principles and customs by other categories of people.

According to Orr (2003), early adopters are typically respected farmers who play important roles in the community or social structure. They occasionally hold positions in the community as opinion leaders, cooperative leaders, and similar roles. In addition, they could be considerably wealthier than other farmers when considering the value of land and additional resources that are productive. Because of their status in a community, early adopters are sometimes regarded as a sign of acceptance for the use of new inventions and technology.

Because of this, early adopters could be seen as role models for additional social community members who want to embrace new concepts and innovations (Orr, 2003). Thus, initial adopters in the present instance, farmers who initially use the technology, could transfer acceptance or usage of new concepts or innovations to other adopter subcategories through ongoing communication and information exchange in both social and personal settings.

In addition, the early majority are the group that follows the early adopters in terms of utilising newly released technologies. One of the main traits of the early majority group is that they often discuss and debate ideas with their peers before choosing to accept or reject new innovations or technologies introduced into the social structure (Orr, 2003). Because of their active relationships and exchanges with other members of the social fabric, this group can be influential in decision-making and information dissemination.

However, given the financial advantages and requirements that come with the new concept, the late majority is more inclined to utilise and exploit emerging technologies (Dearing, 2009; Orr, 2003). The late majority group is particularly interested in the social and economic ramifications, which may include novel concepts and technologies. Furthermore, the majority of farmers in this group accept technology based on the knowledge, concepts, and arguments they hear from their close friends and colleagues (Orr, 2003). This is typically caused by a lack of trust; alongside any doubts or misunderstandings they may have about the new concepts and technologies being used. When selecting whether or not to use the technology, the group considers that individuals who share their conservative views have adopted the technology and recognised its economic and social value (Dearing, 2009). Consequently, when evaluating adoption choices made by the last-minute majority group and all other groups in the adoption process, agricultural agencies and those who implement projects must pay close consideration to social and cultural customs and concepts along with the significance that characterises novel innovations and concepts (Sahin, 2006).

The last set of adopters in the whole adoption sequence is represented by the lagging category. Because they often have less access to resources, farmers in this group are significantly less willing to take chances and use newly developed technology (Orr, 2003). Furthermore, they have relatively few contacts within the social system; therefore, they carefully evaluate and pay close attention to the feasibility and attractiveness of new ideas when deciding whether to use new technology. Consequently, farmers who may be more hesitant to use new technology and more eager to reap the rewards of it fall into the category of these laggards. Given this,

their adoption process may take a lot longer (Orr, 2003). It should be highlighted, however, that some farmers may exhibit early adopter traits yet fail to obviously accept the technology at the beginning of the implementation process; other farmers might embrace the latest innovations more quickly for a variety of reasons, including extension assistance, instructional support, and conversations from project implementing organisations, in addition to communication and knowledge sharing between farmers (Dearing, 2009).

Furthermore, class might be a significant determinant of how quickly farmers adapt. As a result, compared to farmers in lower social classes, those in higher social classes who have access to more productive resources, such as land and capital, may exhibit indications of embracing new technology. In this instance, financial limitations might be a significant barrier to the use of modern technology by the poorer classes.

2.5 Treadmill for Agricultural Technology

The concept of agricultural treadmill examines how new technologies affect people, particularly those who adopt them later (Ward, 1993). Due to the rather elastic character of agricultural goods, small-scale farmers must constantly guarantee a rise in their output (Colman & Young, 1989; Ward, 1993). According to the economic theory of elasticity, this can lead to a decrease in the price of the produce (Binswanger, 1974; Cochrane, 1958).

Early adopters of the latest innovations may see an increase in production, but as more farmers embrace the technologies, overall farmer productivity continues to climb, which may ultimately result in a decline in food prices (Cochrane, 1958; Suppan, 2020). Cochrane asserts that farmers must constantly use technology to adapt to a changing environment, which ultimately gives rise to the idea of the "technological treadmill" (Cochrane, 1958). Farmers could risk losing their property to other farmers who can take over if they are unable to adopt the new technology, continue using it, and remain on the treadmill (Hansen, 2019). This can lead to the accumulation dilemma, where a few wealthy farmers would dominate output and the entire market.

Howard (2009) asserts that off-farm treadmills may also be viewed as a crucial component of agricultural treadmills (Ward, 1994). This includes three types of treadmills, which are categorised as commercial seed running machines, insecticide treadmills, and artificial fertiliser treadmills (Howard, 2009). Farmers' use of technology tends to increase output and total yields, but the downside is that they must stick to using abroad treadmills to avoid losing

out on their company and the marketplace. Farmers may incur high costs as a result of this circumstance, as they need to invest more money to sustain their output and remain in business (Howard, 2009; Weis, 2007). This might make farmers the losers while multinational corporations and bigger input-dealing businesses become the winners, profiting at the expense of small-scale farms (Weis, 2007).

2.6 Global Energy Availability

Energy availability in the context of poultry refers to the phenomenon that makes energy sources consistently and continuously available (Nawalany et al., 2021). These energy sources are needed to power various equipment, heat poultry houses, and maintain an ideal temperature for the well-being and productivity of the chickens (Thapa, 2023). Reviewing the global historical energy consumption and the projected demand is crucial to understanding how the poultry industry is performing in relation to other sectors of the economy.

While the demand for fossil fuels will continue to be strong, particularly in Asia, their key estimates include substantial decreases in energy consumption and CO2 emissions through greater efficiency (Ahmad & Zhang, 2020). With the world's gas consumption forecast to rise sharply by 2040, renewable energy sources are predicted to account for the majority of energy produced (Newell et al., 2019). Energy-saving technology and emerging industries like hydrogen will be essential for ensuring a sustainable future (Ahmad & Zhang, 2020; Hassan et al., 2023).

In-depth analyses of past energy use (1990–2017) and projected energy needs (2020–2040) were offered by that research for a number of different geographic regions, including the Middle East, Asia, the Pacific, Europe, the CIS, North America, Latin America, and the OECD (Ahmad & Zhang, 2020; Keramidas et al., 2020).These analyses showed that there will be rapid changes in energy use and project future needs using Van Ruijven et al. (2019) data, taking into account coal, oil, electricity, and gas, as well as harnessed energy and CO2 emissions (Kabeyi & Olanrewaju, 2022).

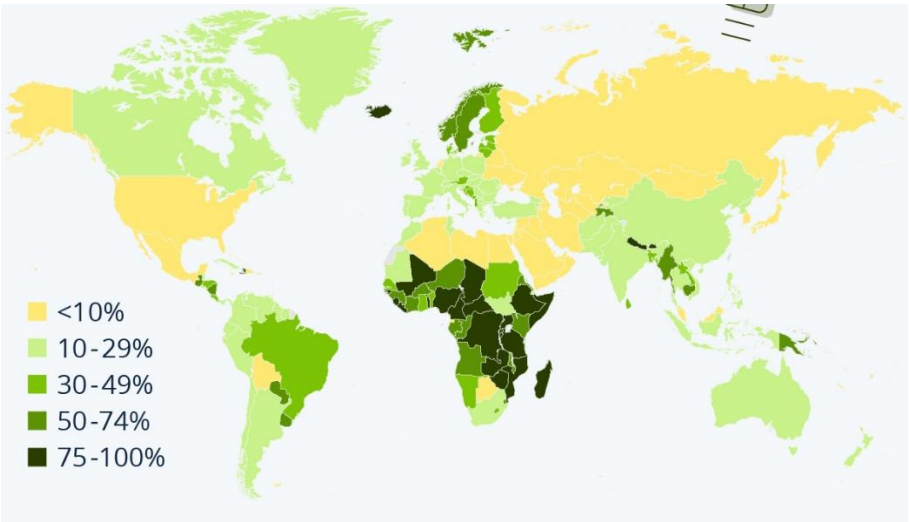


Figure 2.1: A Percentage of Energy Utilised Worldwide

Source: (Martin Armstrong, 2022)

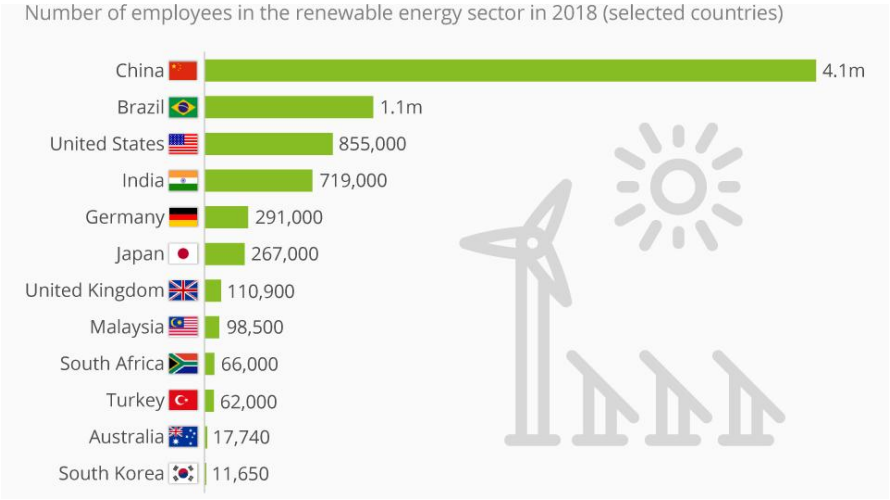


Figure 2.2: The State of Global Renewable Energy Employment

Source:(Statista, 2019)

2.7 Energy Accessibility in South Africa

South Africa has a complex electricity system, and coal combustion has been the main source of energy from the 1880s to date (Mabasa, 2021). In 2024, Coal accounts for around 85% of South Africa's energy production, mostly through the state-owned Eskom utility, which runs a number of major coal-fired power plants (Afrane et al., 2024; du Venage, 2020). The coal-based system presents serious environmental and sustainability issues despite its crucial role in

the generation of energy and contributing to high levels of greenhouse gas emissions and other pollutants (Ivanova et al., 2022). In response to the environmental effects and to deal with the problems brought on by the outdated coal infrastructure (Finkelman et al., 2021).

The dependability and distribution of the South African grid rely on the infrastructure and its maintenance, which is a contributing factor to load shedding (Zaidi et al., 2021). Poor Eskom operations management is another factor contributing to load shedding (Kock & Govender, 2021). A more robust and sustainable energy infrastructure is essential to a gradual transition to harnessed energy sources and regulatory obstacles (Kabeyi & Olanrewaju, 2022). It will need extensive changes, financial investments in modern infrastructure, and a deliberate move towards greener energy sources to address these problems (Chenic et al., 2022).

Poultry was the most affected industry, even though the effect was uniform across small, medium and large-scale farmers (Nanda Kumar et al., 2022). In 2022, loadshedding reached an all-time high of 1 054 hours (or 47.7% of the time), whilst in the third quarter, there was 2.1% decline in GDP (Ddamba, 2024). In poultry, energy is used to operate ventilators, motors, heaters, lighting, feeders and other factors (Sanford & Go, 2022).

Several farmers are adopting more advanced agricultural practices and machines that do not require electricity to operate. For example, some use diesel, and some studies show that smallholders spend an average of R10 000 per month on Diesel (Engel, 2023). The former Minister of Agriculture, Thoko Didiza, introduced the Agricultural Energy Fund as a result of a survey that indicated that farmers need to be assisted with alternative energy sources because of high costs of diesel and electricity tariffs (Hattingh et al., 2024). Smallholder farmers will be supported with a 70% grant, matched with a 30% loan (Mokgomo et al., 2022).

Electricity prices have increased exponentially over time. Eskom implemented a 12.7% price increase on 1 April 2024, with municipalities across the country hiking their prices by similar amounts (ranging from 11% to 16%) from the 1st of July 2024 (Havemann, 2024). Whilst arguably NERSA is aware of these changes and regulates the overall annual Eskom hikes, prices are largely opaque, insufficiently regulated, and very messy at the local municipal level, where all sorts of additional charges are included (Kelly & Geyer, 2018; Lawrence & Lawrence, 2020). To diversify energy and to reduce reliance on coal, different stakeholders have derived programmes such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) and Gauteng Integrated Energy Strategy (GIES) amongst other programmes (Sonday, 2021). Both programmes have attracted significant investments in

solar and wind projects, contributing to a growing share of renewables in the national energy grid. Despite these advancements, energy affordability remains a critical issue, particularly for low-income smallholder farmers who struggle with high electricity tariffs (Babayomi et al., 2023).

2.8 Types of Energy and Usage Style among Small Holder Poultry Farmers

Smallholder poultry farmers utilise an array of energy sources to produce eggs and chicken meat; many of these farmers rely on fossil fuels like coal (Lingayat et al., 2022).

2.8.1 Harnessed Energy in South Africa.

In order to meet the increasing demand for energy, harnessed energy is used while modifying and shaping the country's energy landscape (Norouzi et al., 2021). This is because of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (Davies, 2021). This project fosters the growth of green energy by attracting. Wind energy, solar energy, biogas, and nuclear energy are all being harnessed and may be utilised by farmers in the future (Obileke et al., 2024). Harnessed energy has enabled South Africa to address climate change issues, drive economic growth, improve energy access, and, most critically, establish itself as a leader in renewable energy on the African continent (Pistelli, 2020).

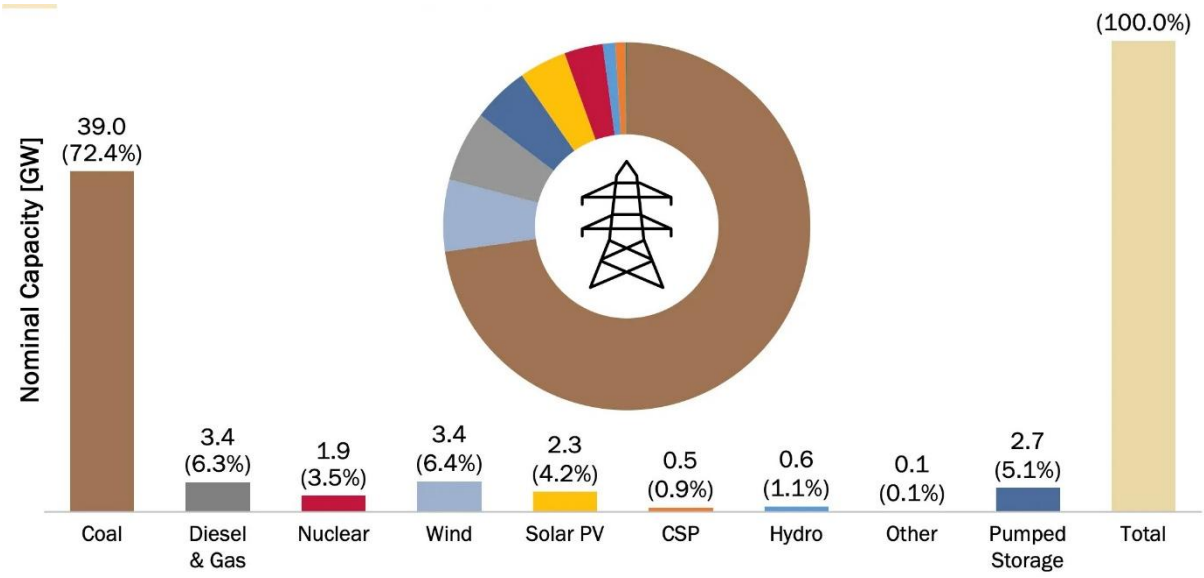


Figure 2.3: The South African Total Nominal Capacity

Source: (Eskom, 2024)

2.8.2 Solar Energy and its Properties.

Solar energy is described as radiant light and heat from the Sun produced by several tools, including solar panels, solar thermal systems, and photovoltaic cells (A. K. Pandey et al., 2022). This type of energy is classified as renewable and environmentally friendly. The abundant energy, Solar energy has the distinct advantage of being both expandable and adaptable, where it can be utilised for large-scale power generation in solar farms or for smallholder poultry farms (Trommsdorff et al., 2022). Furthermore, it has no direct greenhouse gas emissions, making it substantially less polluting than fossil fuels (Trommsdorff et al., 2022). Geographic location, weather conditions, and technology may all affect the efficiency of solar energy conversion and storage (Ahmadizadeh et al., 2024).

2.8.3 Wind Energy and its Properties.

Wind energy, like the previously mentioned energy, is a renewable energy source obtained from wind turbines (Roga et al., 2022). The produced energy is captured by wind turbines, which turn the kinetic energy of the wind into electricity (Chaudhuri et al., 2022). Wind energy is clean and sustainable, emitting no greenhouse gases during operation (Olabi et al., 2023). Wind energy is based on the natural movement of air induced by the sun's uneven heating of the Earth's surface, which is copious and limitless (Olusegun, 2020). Wind energy conversion efficiency is determined by wind speed, turbine design, and location (Chaudhuri et al., 2022). Wind power is a versatile ene9rgy source that may be used both onshore and offshore, contributing considerably to world energy demands (Letcher, 2023).

2.8.4 Adoption of Harnessed Energy in South Africa.

Harnessed energy has grown significantly in South Africa in recent years (Aliyu et al., 2018). The amount of renewable energy generated in South Africa in 2021 was 16.5 TWh, a 5% increase over 2020 (Pollet et al., 2015). Given the growing number of green energy projects being implemented in this country, it is anticipated to rise further (Andronicean & Sabie, 2022). The renewable energy market in South Africa is estimated to reach 16.58 gigawatts in 2024 and increase at a compound annual growth rate (CAGR) of 11.05% to reach 28.00 gigawatts by 2029.

One of the provinces that is at the forefront of the use and production of renewable energy is the Northern Cape, followed by the Eastern Cape, and finally, the Western Cape (Lugogo, 2022). The Northern Cape has possibilities for wind generation and significant levels of solar exposure (Kritzinger & Snyman, 2022). The Northern Cape Province has the potential to play a key role in South Africa's complex of renewable energy sources, according to the Minister of Power (Malope, 2022). This indicates that although having enormous potential for renewable energy, the Eastern, Western, and Northern Capes have low-capacity potential (Aliyu et al., 2018). On the other hand, the only provinces that can add new renewable energy to the grid are KwaZulu-Natal, Mpumalanga, and Gauteng (Akinbami et al., 2021). These provinces have a sizeable infrastructure that can accommodate the installation of more renewable energy, such as transmission lines and grid capacity (Lombard & Ferreira, 2015).

KwaZulu-Natal, Gauteng, and Mpumalanga Provinces already have a sizeable infrastructure, including transmission lines and grid capacity, that can accommodate the addition of additional renewable energy sources like solar and wind power (Lombard & Ferreira, 2015). Due to its significant economic activity and high-power consumption, Gauteng is well-positioned to be close to hubs and demand centres. It is more practical to build new energy capacity when it is close to these demand centres, since it lowers transmission losses (Thenga, 2020). Furthermore, these provinces have been given priority in South Africa's strategic energy planning, which considers factors like the capacity to finance new energy projects, economic growth, and regional energy demands (Davies et al., 2018).

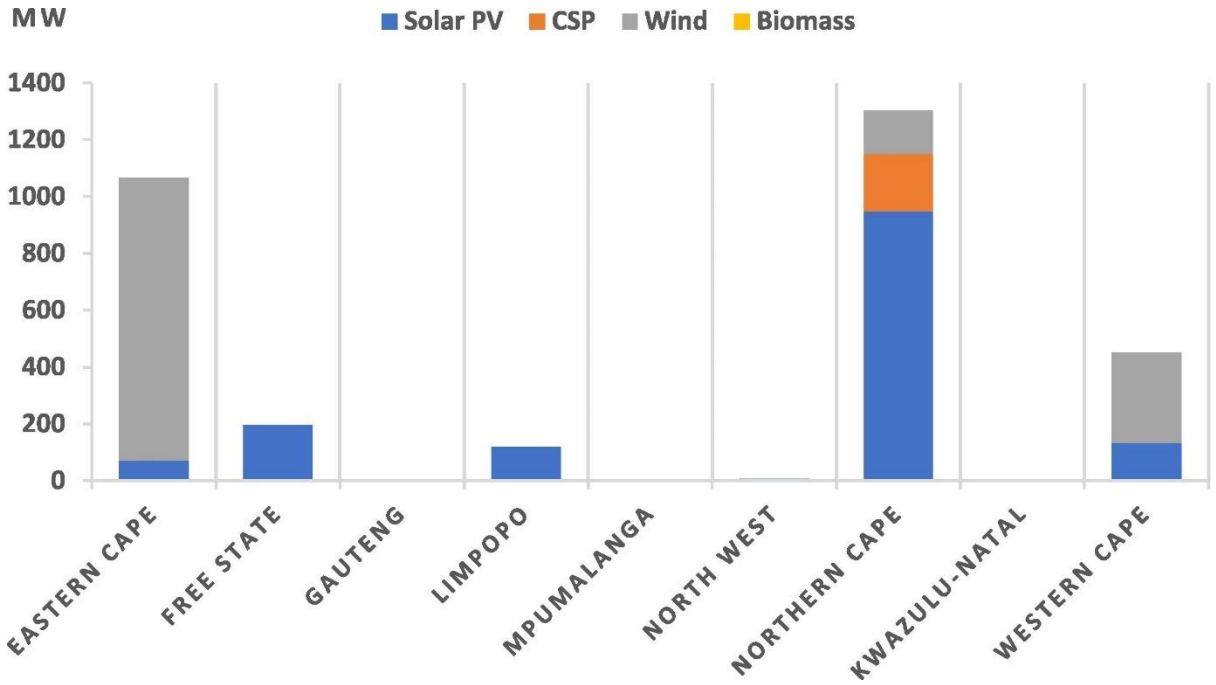


Figure 2.4: Adoption of Harnessed Energy in Different Provinces, South Africa.

Source :(Akinbami et al., 2021)

2.9 Socio-Economic Characteristics of Small Holder Farmers in Tshwane, Gauteng.

Smallholder farmers are often distinguished by a variety of socioeconomic characteristics, such as maintaining land ranging from two to five hectares in size and often practising mixed farming, which involves keeping both livestock and crops alternatively or simultaneously (Melketo et al., 2020). On the contrary, farmers who solely concentrate on livestock, or poultry, sometimes have few resources, including credit (Mhlongo, 2017; Villano et al., 2023). These farmers are frequently vulnerable to external factors. With farming expertise and techniques passed down through generations, most of them are middle-aged or older (Liu et al., 2023).

While smallholder farmers in Tshwane have a wide range of economic experiences, the majority are considered low-income peri-urban settlers who primarily depend on agricultural products for their subsistence (Khutlapye, 2022). Their restricted access to credit facilities, agricultural supplies, and contemporary farming technologies, such as harnessed energy sources, exacerbates their financial difficulties (Mperejekumana et al., 2024). Poor roads and restricted access to water are two examples of the insufficient infrastructure that many farmers contend with, which has an impact on their production and ability to reach markets (Hanjra et al., 2009). Some smallholder farmers have established cooperatives in spite of these obstacles

in order to combine resources and strengthen their negotiating position in regional marketplaces (Onumah et al., 2007).

It is important to highlight that Tshwane's smallholder farmers are frequently well integrated into their communities on a social level (Seko et al., 2021). They support local food security, the economies of the district and province, and ultimately, South Africa, via their work (Plagerson et al., 2023). Gender relations are important, as women often assume important roles in both home and farming management (Leder, 2022). Nonetheless, farmers who identify as men and women also frequently confront unique difficulties, such as unequal access to resources and land (Perez et al., 2015). These farmers show perseverance and adaptation in the face of adversity; many have adopted sustainable strategies to deal with financial and environmental demands (Perez et al., 2015).

2.9.1 The Effect of Age Distribution on Smallholders' Farmers.

It is estimated that 43% of South African farmers are between the ages of 52 and 66, 26% are over 67, and just 8% are young persons under the age of 35 (Mama, 2020). It is interesting to note that in 2016, 21,5% of agricultural heads were between the ages of 45 and 54; of them, 11,4% were men and 10,1% were women (Diiro et al., 2018). On the contrary, Tshwane is one of the youngest cities in South Africa, with about 37% of the population considered youthful. The lowest proportion over the years is due to young people perceiving the agricultural industry as outdated and unproductive (Phiri, 2018). All of these older farmers claim that there is now a shortage of access to land, money, technology, education, and agribusiness-related skills (Adeyanju, 2023).

Even in these circumstances, there are many variables that affect young people's participation in the agricultural sector (Consentino et al., 2023). Nevertheless, it is crucial to understand that a decline in the number of young people engaged in agriculture can have an impact on the farm's financial viability (Venter, 2022). Farmers who are getting older may eventually find it difficult to meet the physical demands of farming, which may affect their business's profitability. This may result in lower output and perhaps the cessation of farming operations (Corsi et al., 2021). According to a study, older farmers are less likely to accept technology, which will also limit their ability to innovate and increase agricultural productivity (Chuang et al., 2020).

The ageing populations of smallholder farmers may lead to a labour shortage (LAWS). The younger generations may relocate to cities in pursuit of better opportunities, leaving the elderly farmers to oversee farms with fewer labourers (Simões et al., 2021). About 32.6% of Tshwane's youth, ages 15 to 35, were unemployed in 2011 (Kobedi et al., 2022). This might affect productivity and the use of harnessed energy from farming sources or methods. Considering that, this will influence the dynamics of rural communities. Older farmers could have different social and economic needs than younger farmers, which could affect the community's ability to thrive and adopt technology (Kendall et al., 2022).

2.9.2 Education Level

Highly educated individuals often adopt technology with greater ease than individuals with lower levels of education, according to prior studies (Mazorodze & Maduku, 2024). However, the direct relationship between education and technology adoption may not be fully reflected by these positive correlations between the rate of technology adoption and educational attainment. At the same time, the Tshwane municipality had 22.2%, 19.8%, and 23.0% of higher education in 2022, 2016 & 2011. In comparison, 38.5% and 34.0% of matric holders had the same years in order (Mfumu, 2024).

Higher education levels typically result in a better understanding of new practices or technologies, which increases farmers' likelihood of seeing the potential advantages of innovations, while also improving their understanding of the risks and rewards of implementing them (Rizzo et al., 2024). This allows farmers to make more thoughtful and well-informed decisions. Better access to information and resources is frequently correlated with education, allowing people to keep up to date on the newest technologies and how best to put them into practice. Remarkably, educated people are frequently seen as opinion leaders or leaders in their communities, encouraging others to embrace advances as well.

2.9.3 Income Relating to Cost Implication on Smallholder Farmers in Tshwane District

The adoption of new technology is strongly correlated with factors such as cost, risk tolerance, financial availability, social influence, economies of scale, and access to information and education (Tanveer et al., 2021). Although most small-scale farmers make lower profits, they have limited access to financing, cannot afford modern technologies, and have not fully used energy resources (Smaje, 2020). Better access to knowledge and information, which are

necessary for comprehending and using technology, can be correlated with higher wealth. Social networks and exposure to new trends can be influenced by income as well (Neumeyer et al., 2020). Farmers with higher incomes are more likely to adopt new technology because they frequently have greater relationships with early adopters (Palm, 2020). Similar to this, more revenue enables new technology to be adopted more widely, which can lower costs per unit through economies of scale (Elia et al., 2021).

In light of their position and the prominence of the Tshwane area, smallholder farmers in Tshwane confront a variety of costs, both direct and indirect (Seko, 2020). The price of labour, maintaining equipment, and buying supplies are all considered as direct costs (Wolpe, 2023). The operations of farmers are also greatly impacted by indirect expenses, which include training, loan availability, and knowledge of best practices (Ruwanza et al., 2022). High input expenditures without commensurate revenue might result in lower quality yields and decreased agricultural productivity, which further reduces the possibility for profitability (Alston & Pardey, 2021). Farmers find it challenging to adequately plan and budget due to the economic strain caused by irregular weather patterns and shifting market prices (Mafongoya et al., 2022).

Smallholder farmers in Tshwane require assistance in a number of areas in order to increase revenue and control expenses (Chepape & Maoba, 2020). Productivity may be increased, and operating expenses can be decreased by having access to inexpensive finance and subsidies for necessary supplies (Boks & Mazenda, 2023). Farmers who participate in training programmes on contemporary agricultural methods and money management might boost their revenue and make better judgments (Sennuga & Oyewole, 2020). Smallholders can also benefit from cooperative activities, such as the creation of cooperatives, by gaining greater access to markets and negotiating lower input costs (Morakile et al., 2022). Interventions by the government and non-governmental organisations are essential in supplying the tools, resources, and assistance required to enable these farmers to become financially sustainable and enhance their standard of living (Mokgomo et al., 2022).

2.10 Empirical Studies on Adoption of Harnessed Energy.

According to Mohsin and Saqib (2024), a more resilient and sustainable energy future will stimulate sustainability because of continued investment possibilities or economic development, and harnessed energy is important. Mohsin and Saqib (2024) add that researching harnessed energy is crucial because it enables the creation of policy that can guarantee reliable

and consistent electricity for South African farmers' productivity. By achieving this, the concept of "energy security" will be fully achieved, referring to the provision of continuous availability of energy in a variety of forms, in sufficient amounts, and at affordable prices (Sotnyk et al., 2021). Energy security has social benefits such as reducing poverty, fostering less conflict within society, lowering unemployment, easing financial challenges for society, and, ultimately, minimising harmful emissions (Li & Qamruzzaman, 2023).

Rahman et al. (2022) stated that there has been a noticeable growth in farmers using harnessed energy on a worldwide scale. Approximately 87% of the world's renewable energy capacity has been developed in G20 member nations (Miyake et al., 2024). The European Union and the African Union are the two regional organisations that make up the Group of Twenty (G20), which is composed of 19 countries (Bery, 2022). With 6.2 GW of installed capacity, harnessed energy technologies wind, solar photovoltaic (PV), and concentrated solar power (CSP) accounted for 7.3% of South Africa's overall energy mix in 2022 (Adebiyi & Moloi, 2024). A minimum of 2% of participants mentioned are utilising an external connection, which is indicative of harnessed energy (Ngqendesha, 2020). In Gauteng, about 2% of respondents reported using renewable energy sources like wind or solar power in 2019 (Ngqendesha, 2020). This is in line with the Group Strategy, Policy Coordination and Relations' Issue 18 - March 2019 report.

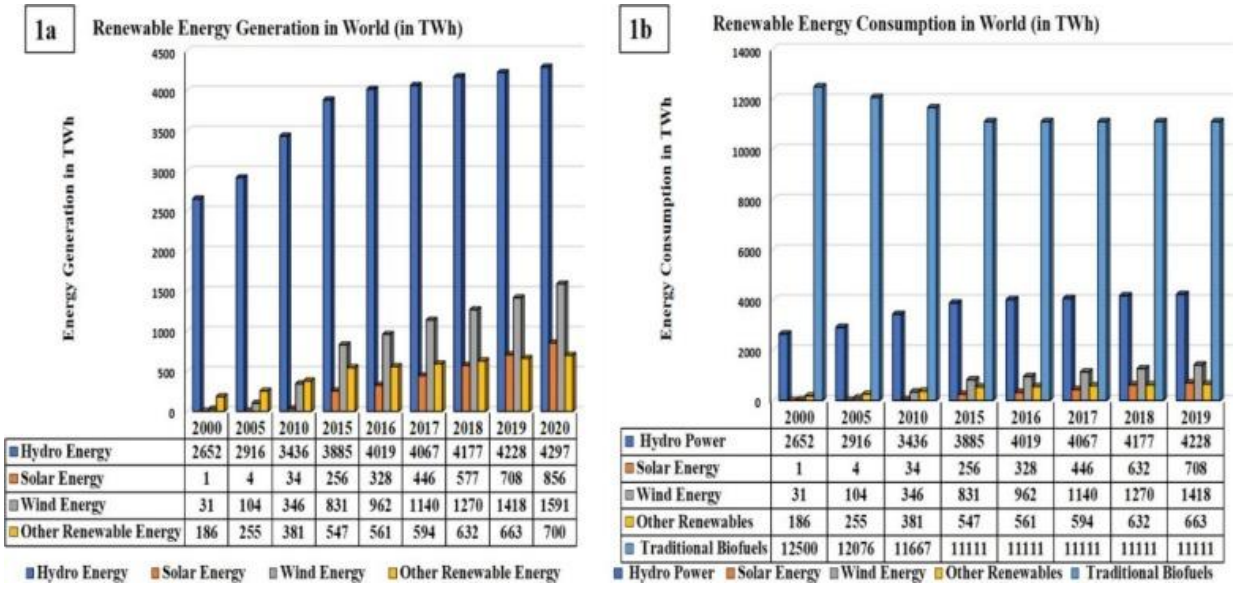


Figure 2.5: Global Harnessed Energy Trends

Source: (Miyake et al., 2024)

The diffusion of innovations theory explains the behaviours, or goods spread across a community and the rate at which they do so (García-Avilés, 2020). The theory's principal participants are laggards, early adopters, innovators, early majority, and late majority (Dale et al., 2021). Since both theories look at how people or groups decide which new behaviours or technologies to adopt, behavioural theories of energy adoption and the Diffusion of Innovation theory are closely related (Alipour et al., 2021). The diffusion of innovations through a population over time is explained by Everett Rogers' DOI model, which highlights elements such as perceived advantages, social impact, and communication routes (Hains & Hains, 2020). Comparably, behavioural theories like the Technology Acceptance Model (TAM) or the Theory of Planned Behaviour (TPB) concentrate on the social and psychological elements that impact people's ability to make decisions for themselves (Abou Kamar et al., 2024).

These theories support the DOI model by providing insight into the reasons behind early adopters, possible barriers to adoption, and the ways in which attitudes, standards and perceived control influence the adoption of new energy technology (Borragán et al., 2024). When combined, they provide an extensive understanding of the adoption process from both macro and micro levels, which is what the study's theoretical framework suggests, or more accurately, what subsequent research has discovered over time (Hooks et al., 2022).

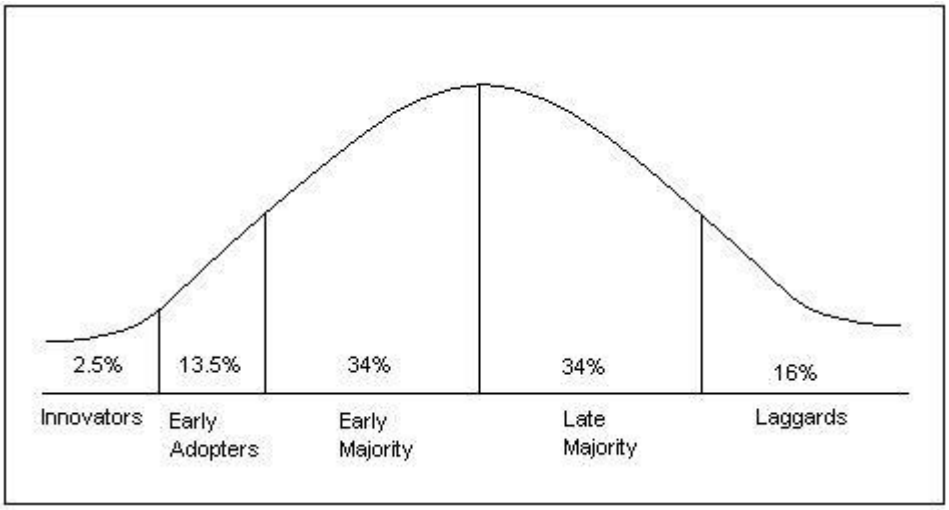


Figure 2.6: Adopter Categorisation Based on Innovativeness.

Source: (Press, 2003)

Khanna and Miao (2022) agree with Elahi et al. (2022) that adoption of harnessed energy in the agricultural sector is influenced by a number of variables, but this is solely to demonstrate how they interact. Financial expenses, such as the initial cost of wind turbines or solar panels, might be pricey, particularly for small-scale farmers (Leary et al., 2020; Rahman et al., 2022). Regardless of the emphasis by (Pannell & Claassen, 2020), government grants or incentives can lessen this cost and increase the likelihood of adoption. Another important factor is technological understanding; farmers need to know how to manage and maintain these systems efficiently (Shang et al., 2021). Farmers may also be encouraged to make the transition to renewable energy sources by the environmental advantages of lowering carbon footprints and guaranteeing long-term sustainability (Batra, 2023). Government assistance may increase cost and knowledge, while policy changes that encourage adoption might be driven by environmental concerns (Lăzăroiu et al., 2020). These issues are interconnected (Piñeiro et al., 2020).

To better understand harnessed energy usage and its implication on production efficiency, previous studies have employed survey data alongside economic modelling techniques such as the Cobb–Douglas Production Function, Stochastic Frontier Analysis, and regression models (Aboaba, 2020; M. Wang et al., 2021). To get insight into poultry farmers' energy usage habits, preferences, and the factors affecting their decisions to adopt renewable energy technology such as solar or wind power, surveys frequently involve gathering data from them (Ali et al., 2023). Typically, these surveys collect data on farm size, location, financial capability, and perceived advantages (Magesa et al., 2020). The data is then statistically examined to find patterns and usual adoption hurdles (Ruzzante et al., 2021). Through the process of quantifying these variables, scholars such as (Tikász et al., 2023) may ascertain the most noteworthy facilitators and impediments, consequently presenting important insights for policymakers and industry stakeholders to customise actions that foster the utilisation of renewable energy in poultry farming.

2.10.1 Results of Models (Wind and Solar Panels).

A sustainable energy solution may be achieved on poultry farms by combining wind turbines with solar panels, with solar panels being more extensively used since they are more affordable and simpler to integrate into the current farm buildings (Thobejane, 2022). Particularly in windy areas, wind energy might be a useful addition, but because it requires space and upkeep,

it might need to be carefully considered. On chicken farms, hybrid systems that combine the two technologies are becoming increasingly common as a means of optimising dependability and energy efficiency. By utilising energy that is already available, especially solar panels, a smallholder chicken farm in South Africa may be able to lower its daily expenses by 50% to 80% of what they now pay for power (Gorjian et al., 2020; Kaup et al., 2022).

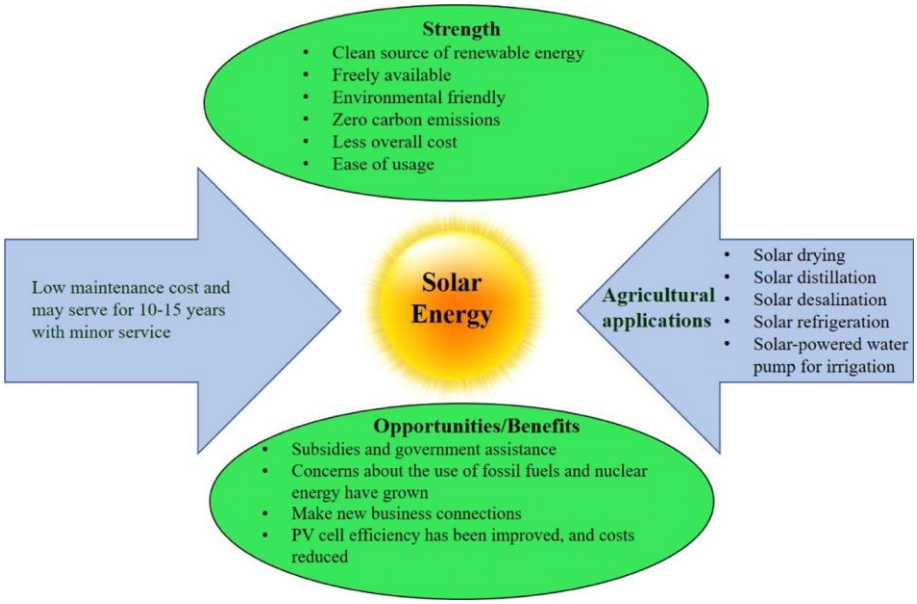


Figure 2.7: Solar energy utilisation results

Source: (Ch. Mohan Sai Kumar a, 2023)

2.11 Estimates on Adoption of Harnessed Energy in The Tshwane District.

Although precise data about the proportion of farmers in this district who use renewable energy is not easily accessible, there are more comprehensive projects that demonstrate an increasing trend toward sustainability (Thobejane, 2022). Given Gauteng's advantage over harnessed energy and the area of the City of Tshwane with the largest percentage of electrified homes, it makes sense to investigate advising farmers to utilise harnessed energy (Maswanganyi, 2024) . Tshwane is aggressively promoting the switch to alternative and harnessed energy sources and has recognised the need for a green city. This will lower the cost of power for the final user while also greatly decreasing the environmental effect of conventional energy generation.

CHAPTER 3: METHODOLOGY

3.0 Introduction

The study area is briefly described in this section, its main economic activities, geographical characteristics, demographic characteristics, agricultural status and energy status in Tshwane District, Gauteng. The second section focuses on the research design, followed by the sampling technique and sampling size that is derived from the Rao Soft formula. The third section focuses on the data collection instruments, followed by the data analysis. Lastly, the fourth section concludes and summarises the entire chapter, respectively. All of this was relevant to the stated objectives and ethical concerns of the research.

3.1 Description and Selection of the Study Area

This study was conducted in the Gauteng Province, Tshwane District. Tshwane District is one of three metropolitan municipalities in Gauteng Province, being the largest metropolitan municipality in South Africa (Namanyane, 2020). The Tshwane municipality is the administrative heart of South Africa, which houses several national government institutions, including union buildings and embassy offices for several foreign nations (Sokhela, 2006). Community services, finance, trade, manufacturing, and transport are the main economic activities of Tshwane District, Gauteng Province (Ramokgopa, 2018)

Amongst the three metropolitan municipalities (Johannesburg, Tshwane, Ekurhuleni) in South Africa, the City of Tshwane has one of the largest land areas (Hamann & Horn, 2022; Ogra & Onatu, 2024). Its topography combines vast rural areas, which expands to peri-urban areas, and developed urban areas (Manganyi, 2006) . The administrative centre is in Pretoria, and the surrounding regions such as Soshanguve, Hammanskraal, Mamelodi, and Centurion creates a broad and varied spatial footprint (Ballard et al., 2021) . Given this combination of peri-urban, urban and village setting of land uses, the Tshwane municipality is different from the more compact Gauteng metros, it is responsible for both rural development and urban operations (Manganyi, 2006) .

Tshwane's population consists of a wide range of age groups, from young adults to elderly citizens, and strongly reflects a mix of professionals from the city, students from large institutions, township settlements, and rural households (Roux & Geyer, 2017) . The population

of the City of Tshwane increased from 2,478 557 in 2007 to 3,555 741 in 2017, or 2,92% yearly, which is double the growth rate of both the province's and South Africa's total population (Hamann & Horn, 2022) . More people relocate to the municipality in search of work, education, and government-related opportunities, the population keeps expanding (Nyamukachi, 2006) . In addition, fostering this lively social atmosphere, puts pressure on infrastructure, housing, services, and nutrition (Bokaba, 2024) . Additionally, this diversity promotes economic engagement and cultural diversity among different communities (Nawa, 2012) .

The agricultural profile of the northern and eastern regions of the Tshwane municipality is recognized as a significant economic pillar within the municipality (Ndwandwe, 2017; Shava & Hofisi, 2019). The northern and eastern regions of the Tshwane municipality in the Gauteng province feature some of the greatest farming land, with over 80% of the land being arable (Hay, 2023) . Moreover, smallholder farmers in areas such as Bronkhorstspruit, Tshwane's eastern region, thrive with crop and livestock production (Chepape & Maoba, 2020) . The northern region such as Hammanskraal is notable for its high concentration of wheat and production of grain (Ntila et al., 2017) .

Tshwane municipality supports smallholder farmers engaged in crops, livestock, poultry, and mixed farming production (Chepape & Maoba, 2020) . The agriculture sector is a major source of income for many communities, and peri-urban farming supports local food supply networks (Maponya & Oelofse, 2023; Msomi & Zenda, 2024) . This is achieved through the support of extension officers and municipal agricultural initiatives that strengthen production, open market access, and encourage the adoption of modern and harnessed energy systems (Prajapati et al., 2025) .

Tshwane municipality has steadily increased its use of harnessed energy due to the energy difficulties endured by the country (Senosha, 2017). The municipality needs more reliable energy systems (Senosha, 2017) . This is one of the municipality that enjoys year-round abundance of sunlight and the modest wind speeds of averagely 28 km/h (Adebiyi & Moloi, 2024; Lindeire, 2008) . This makes solar energy and wind energy the most practical and extensively used harnessed energy system options for households, farms, and businesses. Over the years there has been an increase in solar installations and just a moderate installation of wind turbines as there’s a limit towards possibilities for large-scale wind energy plants(Oladejo et al., 2025) .This phenomenon of increased solar and wind turbine installations has increased

municipality's harnessed energy landscape by 20% - 30%. These efforts are concentrated on decentralized energy systems and lowering reliance on the national grid (Mphahlele, 2023).

Overall Tshwane experiences a warm, temperate climate with hot summers and mild to cool winters (Mashamaite, 2023) . In summer months households and farmers experience most of the rainfall, often in the form of short, intense thunderstorms (Sebaiwa, 2016) . However, in winters it is dry, with clear skies and occasional frost in low-lying areas of the municipality. These climate patterns influence agricultural productivity and make solar energy particularly reliable throughout most of the year (Sebaiwa, 2016) . Overall farming choices, water availability and energy availability is dependent on a range seasonal temperature. Tshwane District in Gauteng Province presents a unique opportunity for research due to its diverse characteristics and strategic location, diverse population, economic activity, and infrastructure development, to mention a few (Ramokgopa, 2018; Singo, 2012) .



Figure 3.1 Map of Tshwane District in Gauteng Province

Source: Adapted from (Maponya & Oelofse, 2023)

3.2 Research Design

A research design is one of the most important parts of any study because it guides how the research will be structured, conducted, and analysed. It shapes every step of the research process by choosing the right research design whether qualitative, quantitative, or mix-method approach (Kroll & Neri, 2009) . A research design also aids researchers structure the best guidelines for their research questions (Asenahabi, 2019) . Additionally, this aids in producing results that are credible, reliable and valid. This study used a cross-sectional research design, which is used for the purpose of not only collecting and describing data, but also examining the relationships between variables and producing models that are appropriate for the study objectives (Creswell & Creswell, 2017).

Cross-sectional study designs are observational studies that analyse data from a population at a single point in time (Wang & Cheng, 2020). They are often used to measure the prevalence of economic outcomes and trends, understand determinants of trends, and describe features of a population involved in the trend (Gaitán-Rossi et al., 2021). However, unlike other types of observational studies, cross-sectional studies are usually inexpensive and efficient for data collection (Maier et al., 2023). Most importantly, allowing one to capture the current energy systems used by smallholder farmers, their socio-economic behaviours, adoption stages, and production efficiency outcomes at a single point in time, making it practical and insightful for understanding existing patterns and influencing factors (Mnukwa et al., 2025) .

3.3 Sampling Procedure

A sampling procedure is a process of selecting a sample (Meyer & Mayrhofer, 2022) . The sampling procedure aligns with the research approach this is to ensure that the sample, and the research method match the study's overall design, objectives, and how data will be collected (Lynch, 2013) . A mixed method research approach is a research strategy that incorporates techniques from both qualitative and quantitative methods to answer research questions This study adopted a mixed methods research approach (Almeida, 2018) . A mixed method approach is noted to be good in triangulating findings through cross-verifying findings (Singh et al., 2021).

Initially, a comprehensive literature review was conducted to identify existing practices, challenges, and potential benefits associated with energy harnessing in smallholder poultry

farming contexts (Ahmed & Alam, 2025). Quantitative data was collected through structured surveys administered to a representative sample of smallholder poultry farmers in Tshwane. In comparison, qualitative data was analysed thematically to provide deeper insights into the economic, socio-cultural, and innovative factors shaping adoption behaviours.

The decision to select a qualitative technique rather than a quantitative one should be prompted by its fit towards answering the research questions (Mulisa, 2022) . A list of locations of individuals or family-owned farmers in poultry production in Tshwane District Municipality was to be obtained from the local offices of the Department of Rural Development and Agrarian Reform (DRDAR) in compliance with POPIA Act (Fransman, 2024). Farmers were categorised into adopters and non-adopters of harnessed energy (Tate et al., 2012) . The traits of all smallholder farmers were completely expressed by stratifying the data using the probability sampling technique (Shamsudin et al., 2024).

A multistage sampling technique was employed to select the respondents for this study. In the first stage, Tshwane Metropolitan Municipality was purposively selected from Gauteng Province due to the predominance of smallholder poultry farmers and its strategic importance in agricultural production within the province. Tshwane comprises several regions and areas, including Akasia, Rosslyn, Pretoria North, Klip-Kruisfontein, Ga-Rankuwa, Mabopane, Winterveldt, Soshanguve, Kudube, Hammanskraal, Stinkwater, Suurman, Babelegi, Montana (including Annlin, Sinoville, Doornpoort, and Wonderboom), as well as Brooklyn, the Central Business District (CBD), and Hatfield.

In the second stage, six regions, namely: Cullinan, Mabopane, Bronkhorstspruit, Hammanskraal, Atteridgeville, and Winterveldt. These regions were purposively selected from the municipality because they represent key smallholder broiler production zones and collectively reflect the rural, peri-urban, and urban farming dynamics within Tshwane.

In the third stage, a list of registered and identifiable smallholder poultry farmers was obtained from local agricultural extension offices focus groups and farmer associations within the selected regions. From this sampling frame, proportionate random sampling was applied to ensure fair representation across the six areas. A total of 108 farmers were ultimately selected and interviewed, constituting the final sample size for the study.

Table 3.1 A Multi-stage sampling

Peri-Urban areas in Tshwane Municipality	Population Sampled
Cullinan	18
Mabopane	12
Bronkhorstspruit	20
Hammanskraal	25
Attridgeville	8
Winterveld	25
Total	108

Source: Author's collection from field (2025)

3.4 Sampling Frame and Sampling Size

For this study, an estimated sample size of 108 was calculated using Rao Soft formula. This formula ensures that the sample size is neither too large nor too small (Ringle et al., 2023). Sample size was calculated using Rao soft formula as shown below:

Rao soft formula for sample size.

$$n=\frac{z^2\times P\times(1-p)}{E^2}$$

$$n=\frac{1.96^2\times 0.5\times(1-0.5)}{0.05^2}$$

n=384.16

Margin error (E) = 5%

Confidence level (z) =1.96 for 95% confidence

Population size (N) = 150

Responsive distribution (p) = 50% or 0.5 for maximum variability

$$N_{adj}=\frac{n}{1+(\frac{386.16-1}{150})}$$

N_{adj}= 108

3.5 Data Collection Instruments

This study employed both primary and secondary data (Rabianski, 2003) . A questionnaire was essentially used for the primary data where else existent research and published work was used for the secondary data. In primary data the questionnaire, the collection tools were structured in such a way that what captures both qualitative and quantitative data. The questionnaire was piloted to a small group of poultry smallholder farmers to check if the farmers understood the questionnaire (Msoffe et al., 2018) . Feedback from this trial assisted in refining the questionnaire, making it clear, relevant, and relevant to the smallholder poultry farmers in Tshwane municipality (Hanley et al., 2001) . Additionally, the questionnaire structure, choice of words, and overall consistency of the questionnaire were improved too.

Once the questionnaire was completed, respondents were engaged about their consent to participate in this study (Marshall et al., 2006) . At such, the participation was voluntary. Additionally, the respondents were informed on the confidentiality standard and most importantly emphasis was made on how enumerators are restricted from influencing responses from the respondents (Marshall et al., 2006) . The questionnaire had both open-ended questions and closed-ended questions this was done to ensure that all the relevant details were well captured (Hansen & Świderska, 2024) . Whilst the closed-ended questions had a Yes/No and categorical questions, open-ended questions allowed the respondents to be honest and freely express themselves using their own language and experiences (Hansen & Świderska, 2024) .

Initially, questionnaires were administered in person during organised focus-group sessions in the selected areas in Tshwane, allowing participants to seek clarification and provide responses in a supportive environment. For farmers who could not attend these focus-group sessions, a QR code linking to the online questionnaire was shared, ensuring that all respondents had an opportunity to participate. The data that was collected included demographics, socio-economic characteristics of smallholder poultry farmers, and awareness of harnessed energy sources like solar or wind for poultry farm operations.

The study employed a mixed data collection technique with a combined face-to-face distribution of questionnaires to smallholder farmers and online distribution. Initially, questionnaires were administered in person during organised focus-group sessions, allowing participants to seek clarification and provide responses in a supportive manner. For farmers who could not attend sessions on the day of data collection and for farmers who left earlier due to commitments, a QR code and a questionnaire link was distributed on online platform. These

online communication platforms include example such as WhatsApp. WhatsApp was particularly useful and instrumental for circulating information and the questionnaire because many farmers were already active in their local focus-group networks, while email was used for those without access to WhatsApp.

3.6 Data Analysis

A Google Forms questionnaire was used to collect the data for this research. Some responses were analysed directly in Google Forms, but some data was exported to Microsoft Excel for extra processing and graph creation. The dataset was then imported into SPSS version 26 to conduct advanced statistical analysis. Certain results were also organised and presented in tables using Microsoft Word. Descriptive statistics were applied to compare the efficiency of traditional electricity sources with the adoption of harnessed energy alternatives such as solar and wind power.

Table 3.2: Research matrix.

Objective	**Data required**	**Analytical tools**
To examine socio-economic characteristics of smallholder poultry farmers in Tshwane district:	Demographic information, economic characteristics of poultry farmers in Tshwane District and farming characteristics.	Descriptive statistics (frequency and percentage)
To determine the constraints faced by smallholder farmers under current energy supply.	Awareness of harnessed energy sources like solar or wind for farm operations. If the farmer has adopted harnessed energy, challenges faced during the adoption process and potential to adopt harnessed energy.	Kendall's Coefficient of Concordance (W).
To investigate the factors influencing the adoption of harnessed energy supply: and	The main reasons towards poultry farming, mortality Rate of chickens, satisfaction with their current poultry farm, current energy source used at the farm, which farm operations consume the most energy and	Probit regression model

	the average amount of energy used for each source of energy.	
To compare the production efficiency of smallholder farmers under the conventional energy supply and harnessed energy supply	If farmers, would you recommend that other farmers transition to harnessed energy sources and ideal improvements or support that are needed to optimise energy use for better efficiency on different farms and	Stochastic frontier model

Source: Author conception (2024)

3.7Analytical Tool

I. Objective One: Descriptive Statistics

Descriptive analysis was used to analyse the socio-economic characteristics of farmers in the selected area. Descriptive statistical analysis (means± standard deviation, percentage and Chi-square) was used in describing socio-economic characteristics of smallholder farmers, harnessed energy adoption practices and other related harnessed energy practices by the farmers (Hesselink & Chappin, 2019). The age and family size of respondents, major source of educational levels, gender, marital status, and income, were analysed (Hesselink & Clack, 2024) .

Mean $\bar{X} = \Sigma X/n$ n = sample size

Where $\bar{X}$ = Mean of data Standard Deviation = S. D= $\sqrt{((\Sigma (X-\bar{X}))/n)}$

ΣX = Summation of values Where X = each value of the given

II. Objective Two: Probit regression model

To determine factors influencing adoption of harnessed energy supply by smallholder poultry farms, Probit-regression model was employed (Mafenya, 2024) . The data was Pre-processed to handle missing values and encode variables appropriately (Mafenya, 2024) .

This model is appropriate when attempting to model a dichotomous dependent variable. Firstly, we defined the binary dependent variable, representing whether a household has adopted such solutions (1) or not (0). Subsequently, we selected relevant independent variables

such as income, education, awareness, and subsidies) to run the regression analysis (Kimbi et al., 2020). Additionally, we chose the Probit model, which assumes a latent variable has a normal distribution and connects it linearly to the independent variables. We utilised statistical software to estimate the model parameters (Stata/SPSS).

Hence, the assumption is that Y^* can be specified as follows:

$$Y_i^* = \beta_0 + \sum_{k=1}^{n} \beta_k X_{ik} + \varepsilon_i$$

Where:

Y_i^*= latent (unobserved) propensity to adopt harnessed energy

X_{ik}= vector of explanatory variables (e.g., age, education, farming experience, farm size, access to credit, extension contact)

β_k= parameters to be estimated

$\varepsilon_i \sim N(0,1)$= error term assumed to follow a standard normal distribution

The observed binary outcome variable is defined as:

$$Y_i = \begin{cases} 1 & \text{if } Y_i^* > 0 \text{(adopter)} \\ 0 & \text{if } Y_i^* \leq 0 \text{(non-adopter)} \end{cases}$$

Table 3.3: Definition and measurements of variables modelled in Probit linear regression model.

Variables	**Measurement**	**Unit**	**Expected sign**
Dependent variables (Y)	Nominal: 0= Adopter, 1=non-adopter	Numbers	+

Decision to adopt or not adopt or the adoption of harnessed energy supply			
Independent/explanatory variables (X)			
Household size	Binary: Yes=1, No=0	Numbers	+
Age of farmer	Continuous: 0=18-25, 1=26-35,2=36-50, 3=51-65, 4=65 and older	Years	+/-
Gender of farmer	Binary: Male=1, Female=0	Numbers	+
Farmer experience	Continuous: 0=5 years and less, 1=6-10 years, 2=11-15 years, 3=16-20 years, 4=21 years and more	Years	+
Educational level	Categorical: 0=primary, 1=secondary, 2=tertiary, 3 = no formal school	Years	+
Size of the arable land	Continuous: 1-5 hectares (small)=0 6-10 hectares (medium)=1 11-20 Hectors (Large)=2	Hectares	-
Marital status	Categorical: 0=single, 1=married, 2=divorced, 3=widowed	Numbers.	+/-
Access to harnessed energy (Solar Pannels and Wind turbines)	Binary: Yes=1, No=0	Numbers	-
Available infrastructure	Nominal; Traditional=0, Modern=1 and Mixed=2.	Numbers.	-

Access to funding	Binary: Yes=1, No=0	Numbers.	-
Extension Service	Nominal: Yes=2, No=1 and Partial=0	Numbers.	-
Access to information	Categorial: no access=2 limited access =1 and full access) =0	Numbers	+/-
Perception about harnessed energy.	Binary: Awareness of harnessed energy. Aware= 1 and Not aware=0 Adoption of harnessed energy: yes =1 and No=0.	Numbers	+/-

Source: Author conception (2024)

III. Objective Three: Kendall's Coefficient of Concordance (W)

Participants were asked to rank the constraints faced when adopting harnessed energy in the research field at different levels. The level of agreement among their ranked responses was then measured using Kendall's Coefficient of Concordance (W).

Alsaqr (2021) states that Spearman's rank correlation coefficient evaluates linear correlations between two variables, whereas the Pearson correlation coefficient evaluates monotonic functions. Kendall's Coefficient of Concordance (W) was thus the most appropriate method for this study.

Hypothesis:

Ho: There will not be any consensus among responders' ranks.

Ha: There will be consensus among responders' ranks.

The following is the specification of Kendal's Coefficient of Concordance:

$$W = \frac{12[\sum T^2 - (\sum T^2)/n]/n}{nm^2(n^2 - 1)}$$

Where, m = number of participant and non-participant ranking sets.

n= Numbers of constraints ranked.

The hypothesis and the significance of the rankings were further evaluated using the chi-square test.

Decision Rule:

The null hypothesis (H_o) is rejected if the estimated F-ratio exceeds the F-value from the F-table.
Failure to reject the null hypothesis (H_o) when the estimated F-ratio is smaller than the F-value from the F-table.

IV. Objective Four: Stochastic Frontier Model

This study employed a stochastic frontier model based on the Cobb-Douglas production function. The model measured production efficiency by comparing actual farm performance with the optimum level of production, also referred to as the true frontier (Fried et al., 2008) . Since the true frontier is not directly observable, the performance of best-practice farmers was used as a proxy (Fried et al., 2008) .

The stochastic frontier approach was applied to estimate the production efficiency of smallholder poultry farms under current conditions, following its earlier application in studies such as Haider and Mishra (2021) . This model allowed the study to capture both technical efficiency, which measures how effectively farms utilise available inputs and technology and stochastic efficiency, which accounts for the influence of external factors and random shocks on production outcomes

Defined as:

$$\ln\ Y_i = \beta_0 + \sum_{k=1}^{n} \beta_k \ln\ X_{ik} + V_i - U_i$$

Where:

Y_i= broiler output of the i^{th} farmer

X_{ik}= vector of production inputs (e.g., feed, labour, energy, capital, housing)

β_k= output elasticities of inputs

$V_i \sim N(0, \sigma_v^2)$= symmetric random error (statistical noise)

$U_i \sim |N(0, \sigma_u^2)|$= non-negative inefficiency term

The Cobb-Douglas Production Function

The Cobb–Douglas production function, originally developed by Charles Cobb and Paul Douglas, provides a functional framework for examining the relationship between output and key production inputs such as labour and capital (Hesselink & Chappin, 2019; Mandal & Taku, 2025). It is frequently employed in studies of agricultural output because it makes it possible to directly estimate input elasticities and returns to scale in a form that is comparatively economical and comprehensible (J. Wang et al., 2021).

In this study, the Cobb–Douglas functional model was selected over the translog production function for several reasons. First, the Cobb–Douglas model is less parameter-intensive and more suitable for moderate sample sizes such as the 108 farmers surveyed in this study. The translog model, while more flexible because it allows for interaction effects and variable elasticities, requires estimation of numerous second order and cross-product terms, which may reduce degrees of freedom and introduce multicollinearity in smaller samples(J. Wang et al., 2021). Second, the primary aim of this study is to investigate adoption of harnessed energy supply practices for improved production efficiency of smallholder poultry farmers in Tshwane District, Gauteng Province rather than to model complex substitution elasticities among inputs. The Cobb–Douglas specification therefore provides a stable and interpretable structure for analysing production behaviour among smallholder poultry farmers.

The Cobb–Douglas stochastic frontier production function is expressed in log-linear form as:

$$\ln Q_i = \beta_0 + \beta_1 \ln L_i + \beta_2 \ln K_i + \beta_3 \ln E_i + V_i - U_i$$

Where:

$Q_i$represents broiler output,

L_i, K_i, and $E_i$represent labour, capital, and energy inputs respectively,

βparameters measure output elasticities,

$V_i$captures random shocks beyond the farmer's control (e.g., disease outbreaks, weather variability), and

$U_i \geq 0$captures technical inefficiency.

Furthermore, the Stochastic Frontier Analysis (SFA) approach was chosen over Data Envelopment Analysis (DEA) for efficiency estimation. Although DEA is a non-parametric method that does not impose a functional form, it attributes all deviations from the frontier to inefficiency and does not account for statistical noise (Simar & Wilson, 2015) . In agricultural settings where production is influenced by random shocks such as fluctuating energy supply, disease outbreaks, and market instability, ignoring stochastic variation may bias efficiency estimates (Jones & Hiller, 2017) . SFA, by contrast, decomposes the error term into two components, random noise (V_i) and inefficiency (U_i) which makes it more appropriate for analysing poultry production under uncertain and energy-constrained conditions (Forleo et al., 2025; Hassan, 2018).Therefore, the Cobb–Douglas stochastic frontier model was considered most suitable for this study, it clarifies data, whilst statistical robust and it has the ability to separate inefficiency effects from external random shocks (Hassan, 2018; Mandal & Taku, 2025).

3.8. Ethical Consideration

Ethical considerations in research are essential principles that guide researchers in conducting their work responsibly, ensuring the protection of participants and the integrity of the research process (Autiero, 2020; Khan, 2024) . An ethics approval letter was issued by the (FNASREC), the Faculty of Natural and Agricultural Sciences Ethics Committee. This study was therefore approved with the following ethics number: NWU-01434-24-A9, with a minimal risk category.

3.8.1. Informed Consent

Informed consent is a voluntary agreement to participate in research (Kirby, 1983). This voluntary agreement was used in the research and served as a process to ensure that the participant understands the research and the risks involved (Millum & Bromwich, 2021).

3.8.2. Confidentiality

Confidentiality is an ethical practice used to protect participants while collecting, analysing, and reporting data in research (Kang & Hwang, 2021)**.** Various pathways are considered to keep participant information safe; they included the use of passwords to protect files and reporting research findings in aggregate (Rowlands, 2021).

3.9. Reliability and validity

At These ideas formed the foundation for evaluating the overall quality of this study. The criteria helped clarify how sound the methods and approaches used for measurement were. While validity focuses on the accuracy and truthfulness of a measurement, reliability concerns the consistency and dependability of that measurement across different applications or time periods; thus, the participation was voluntary.

3.9.1. Reliability

The reliability refers to a measurement that supplies consistent results with equal values (Sürücü & Maslakci, 2020). Reliability was applied in the research for constancy consistency, repeatability, trustworthiness and precision (Sumrin & Gupta, 2021). Reliability in this study referred to the extent to which the research instrument consistently produced stable and dependable results (Kakar et al., 2023) . In the context of qualitative research, reliability was understood as the consistency, stability, and repeatability of the findings across different contexts or over time (Kakar et al., 2023). Reliability occurs when consistent results are obtained in identical situations; in different circumstances, the results are considered reliable (Kheradmandi & Mehranfar, 2022) . However, in qualitative research, reliability is obtained when a researcher's approach is consistent across different research (Rose & Johnson, 2020).

3.9.2. Validity

Validity is the degree to which an instrument accurately measures what it is intended or claims to measure (Blumberg et al., 2014). It reflects the extent to which the study's results will be accurate and credible (Kimberlin & Winterstein, 2008) . Ensuring the validity of a research instrument is essential, as it determines how effectively the instrument serves its intended purpose.

3.9.3. Threats To Validity and Reliability

Several factors could have posed risks to the validity and reliability of the research findings; therefore, the researcher found it important to remain cautious about potential sources of error when planning and implementing the study (Nichols & Edlund, 2020). Moreover, errors could have arisen from researcher carelessness, the social context, the characteristics of the participants, or the methods employed for data collection and analysis (Nichols & Edlund, 2020) .

3.10. Chapter Summary

The methodology chapter provides a detailed description of the study area, focusing on the Tshwane District in the Gauteng Province, South Africa. The City of Tshwane has an estimated population of approximately 3.4 million people, excluding undocumented immigrants (Malebatja et al., 2024)**.** According to the research design, a self-administered questionnaire was employed for data collection. The study examined the socio-economic characteristics of smallholder poultry farmers, their preferences, and the factors influencing their willingness to adopt harnessed energy for improved production efficiency. A probability sampling approach, specifically the stratified sampling technique, was used to ensure representation across diverse groups. The final sample consisted of 108 smallholder farmers from Tshwane District. The data collected using an online survey was administered through Google Forms, which included both direct and categorical questions.

Equally important, for data analysis, information from the Google Forms questionnaire was analysed directly on the platform, while additional data is exported to Microsoft Excel for further organisation and visualisation. Graphs, tables, and pie charts were created using Microsoft Excel and Word, while SPSS version 26 was employed for advanced statistical

analysis. Overall, the study objectives were analysed using descriptive statistics and the Probit regression model. Ethical considerations, as well as procedures for ensuring reliability and validity, were adhered to in accordance with North-West University's research guidelines.

CHAPTER 4: RESULTS AND DISCUSSION

4.0 Introduction

Chapter four covers the results obtained from the analyses. The chapter is divided into 4 main sections. The first section is devoted to analyses concerned with the socio-economic characteristics of smallholder poultry farmers while the second section is devoted to analyses concerning factors influencing the adoption of harnessed energy supply. The third section is devoted to analyses of constraints faced by smallholder poultry farmers in Tshwane and lastly, the fourth section is devoted to analyses of production efficiency of smallholder farmers under the conventional electricity supply and harnessed energy supply. Each main section is again

divided into a various point that covers the results from calculating production efficiency of conventional and harnessed energy systems smallholder farmers.

4.1 Socio-economic Characteristics of Smallholder farmers

Socio-economic characteristics are an important component of data analysis; it mirrors characteristics and trends of the far various points influence the overall household or farming dynamics and the overall efficiency household activities (Niles et al., 2021). Characteristics such as age, gender, marital status, family size, education level, employment status, and farming experience are among the demographic data that were collected. A total of 108 farmers were sampled.

4.1.1 Gender

Table 4.1.1 Socio- demography (n =108)

		Frequency	Percent	Valid Percent	Cumulative Percent
Gender	Female	48	44,0	44,4	44,4
	Male	60	55,0	55,6	100,0
	Total	108	99,1	100,0	
Age of Household Heads	15-24	4	3,7	3,7	3,7
	25-34	23	21,1	21,3	25,0
	35-44	27	24,8	25,0	50,0
	45-54	19	17,4	17,6	67,6
	55-64	13	11,9	12,0	79,6
	65+	22	20,2	20,4	100,0
	Total	108	99,1	100,0	
Marital Status	Single	56	51,4	51,9	51,9
	Married	32	29,4	29,6	81,5
	Divorced	11	10,1	10,2	91,7
	Widower	9	8,3	8,3	100,0
	Total	108	99,1	100,0	
Education Level	No formal Schooling	1	0,9	0,9	0,9
	Primary level	7	6,4	6,5	7,4
	Secondary level	62	56,9	57,4	64,8
	Tertiary level	38	34,9	35,2	100,0
	Total	108	99,1	100,0	

Source: Author's conception (2025)

The results in Table 4.1.1 showed that 56% of poultry smallholder farmers in Tshwane were males, whilst 44% of them were females. This shows that both males and females are recognised as household's heads for smallholder farmers in Tshwane. However, for peri-urban settings such as Hammanskraal, Winterveldt and Mabopane, men are recognised, however for urban settings such as Cullinan, and Bronkhorstspruit, women are mostly recognised. This implies that both males and females in Tshwane municipality are responsible for household decisions. Naidoo emphasised that in the metropolitan municipalities, there is clustering of female household headship, especially in low-income areas, as compared to high-income areas (Naidoo et al., 2023). Sobantu (2021) reinforced the idea by indicating that there is a pattern of financial allocation adopted in metropolitan contexts, which affects household control and decision-making.

4.1.2 Age of household heads

According to the findings presented in Table 4.1.1, the age group 15–24 years recorded the lowest participation rate at 4%. This was followed by the 55–64 and 45–54 age groups, which accounted for 12% and 17% of responses, respectively. By contrast, the highest levels of participation were observed among respondents aged 25–34 years (21%) and 35–44 years (25%). In addition, 20% of respondents were 65 years or older. These results indicate that most participants were adults, suggesting that most household heads were also within adult age groups. Notably, individuals over the age of 35 represented the largest share of farmers in both urban and peri-urban areas (Dlamini et al., 2020).

According to the Gauteng Spatial Framework, a significant proportion of farmers aged 35 and older are actively engaged in farming, primarily for food security, income generation, and broader economic development (Moyo, 2016). The framework further highlights that young adults (20–34 years), adults (25–44 years), and youth (15–34 years) constitute a large segment of urban households, whereas the proportion of elderly individuals aged 65 and above is relatively low (Tshililo, 2019). In contrast, peri-urban areas within the province tend to have higher concentrations of both children (0–14 years) and elderly residents (65 years and older) (Ntila et al., 2017). The predominance of young and working-age populations in metropolitan areas is largely attributed to factors such as employment opportunities, better access to healthcare and education, improved facilities, economic mobility, and vibrant social environments (Gotz et al., 2014).

4.1.3 Marital Status

According to Table 4.1.1, 8% of the smallholder poultry farmers in Tshwane District who responded to the questionnaire were widowers, 10% were divorced, 29% were divorced, and 51% were single. In general, the likelihood of getting married was 1.3 times lower among urban and peri-urban dwellers than among rural dwellers (Mokoditoa, 2022). Since marriage is seen as a social institution and is becoming less common, alternative relationship models like cohabitation and delayed marriage are growing in popularity in Gauteng and across South Africa as a result of a change in attitudes toward marriage and a desire for economic balance (Mohlabane et al., 2019; Moore & Govender, 2013). While Marginean contends that there is a correlation between the marriage model and home stability, Russell argues that there is none (Marginean et al., 2019; Russell, 2017).

4.1.4 Education Level

Table 4.1.1 indicates that 35% of the sampled respondents have university education, whereas the majority have secondary education (57%). Many respondents are educated, as evidenced by the fact that only 1% have no formal education and 6% have only completed primary school. According to Jamison, there is a correlation between cognitive abilities, extension agents, and level of education (Jamison & Moock, 1984). Farmers who have had formal education are typically better able to make productive decisions (Taramuel-Taramuel et al., 2023). This indicates that education still has the ability to put people on the path to skill acquisition, which enhances productivity and raises the likelihood that rural households will find employment, which will result in greater salaries in the future (Iyer & Rao, 2024).

Table 4.1.2 Socio-economic characteristics

		Frequency	Percent	Valid Percent	Cumulative Percent
Employment	Employed	28	25,7	25,9	25,9
	Unemployed	37	33,9	34,3	60,2
	Self-Employed	43	39,4	39,8	100,0
	Total	108	99,1	100,0	
Household Size	1-2 Members	27	24,8	25,0	25,0
	3-4 Members	46	42,2	42,6	67,6
	5-6 Members	19	17,4	17,6	85,2

	7+ Members	16	14,7	14,8	100,0
	Total	108	99,1	100,0	
Farming Experience	0-5 Years	82	75,2	75,9	75,9
	6-15 Years	23	21,1	21,3	97,2
	16-30 Years	3	2,8	2,8	100,0
	Total	108	99,1	100,0	
Farmers Monthly Income	less than R1000	6	5,5	5,6	5,6
	R1000-R5000	28	25,7	25,9	31,5
	R5001-R10 000	30	27,5	27,8	59,3
	More than R10 000	44	40,4	40,7	100,0
	Total	108	99,1	100,0	

Source: Author's conception (2025)

4.1.5 Employment Status

Both non-farming employment and self-employment through farming can provide consistent, reliable income, enabling individuals to support their households and lowering poverty in the municipality's urban and peri-urban areas. In this sense, poverty can be identified as socio-economic vulnerability, which includes unemployment and underemployment (Qithi & Mkhize, 2023). According to Table 4.1.2 above, 26% of the sampled respondents are employed, 39% are self-employed as farmers, and 33% are unemployed. Even though Gauteng is the focal point of most economic activity, the province's 32,9% unemployment rate and South Africa's overall 34,2% unemployment rate have made it necessary for women, young people, and the elderly pursue self-employment (Modiba et al., 2024; Muchemwa & Odimegwu, 2024). Poultry demand for improved nutrition is rising as a result of the rapid population growth in urban and peri-urban areas (Kleyn & Ciacciariello, 2021).

4.1.6 Household Size

The number of individuals living together in a household is referred to as family size in this context (Esteve et al., 2024). This is a socioeconomic and demographic indicator (Chaudhry et al., 2009). In these results, 3–4 members make up 42% of the family, followed by 1-2 members at 25%, 5–6 members at 17%, and 7+ members at 15%, in ascending order, according to Table 4.2. A greater household size indicates the possibility for labour input, making it a beneficial variable(Dossa et al., 2023). However, given the number of people in need of clothing, food,

water, shelter, electricity, sanitation, healthcare, and other necessities, this same variable can also be burdensome (Lusiarani et al., 2024).

4.1.7 Farming Experience

Table 4.1.2's results highlight the fact that many sampled respondents (76%) had 0–5 years of agricultural experience, compared to 21% with 6–15 years and 3% with 16–30 years. Experience is a survival skill in farming and increases workers' accumulation of human capital, in contrast to non-farming experience (Nye, 2021). A study that investigated the relationship between farming experience and adoption of agricultural technologies discovered that experience and adoption of technology are positively correlated (Ainembabazi & Mugisha, 2014). This indicates that the adoption rate of a technology first rises (at a decreasing rate) as farmers have more experience with it, and then gradually falls as experience levels rise (Hu et al., 2022). This means we can be optimistic that farmers with 0–5 years of agricultural experience will adopt harnessed energy, grow with the practices, and attempt alternative energy sources if harnessed energy doesn't work for them.

Table 4.1.3 Livelihood and financial inclusion

		Frequency	Percent	Valid Percent	Cumulative Percent
Source of Income	Government grant (IDC, Agra, Agri Bee, NDAC, Landbank)	2	1,8	1,9	1,9
	Poultry farming wages/salary	50	45,9	46,3	48,1
	Social grant	27	24,8	25,0	73,1
	Salary	29	26,6	26,9	100,0
	Total	108	99,1	100,0	

Access to credit/funding	Yes	10	9,2	9,3	9,3
	No	98	89,9	90,7	100,0
	Total	108	99,1	100,0	
Formal Market access	Yes	31	28,4	28,7	28,7
	No	77	70,6	71,3	100,0
	Total	108	99,1	100,0	
Informal Market access	Yes	77	70,6	71,3	71,3
	No	31	28,4	28,7	100,0
	Total	108	99,1	100,0	

Source: Author's conception (2025)

4.1.8 Access to Formal and Informal Markets

Market structure, seller registration and taxes, and trading mechanisms are the main areas that differentiates formal and informal market structures differs (Davies et al., 2022). In an informal market, buyers and sellers often bargain to divide the surplus between households (Keniston et al., 2024). However, in the formal market, prices are published publicly for everyone to be aware of and to make an informed decision as a customer. Formal market producers are required to register and pay taxes accordingly (Weber et al., 2021). However, in contrast, bilateral negotiation is how buyers and sellers do business in the informal marketplace (Van Campenhout & Nabwire, 2024). According to the sampled respondents in Table 4.1.3, 29% of them do not have access to informal markets, while 71% do. Only 70.6% of respondents stated that they do not have access to formal markets, whilst 28.4% of respondents indicated they do.

Market accessibility is crucial for a number of reasons, including welfare and food security, as households with market accessibility typically have higher income and more purchasing power (Usman & Haile, 2022). Similar to how people in urban areas may access food markets, market accessibility may assist address market deficiencies where people in peri-urban areas have access to food (Nikolaidou, 2021).

4.1.9 Access to Credit and Source of Credit by Peri-Urban Farmers

Studies do indicate that most rural areas are credit-constrained, but most organisations are adaptable in developing financial types that may also support rural, peri-urban, and metropolitan locations (Ogra & Onatu, 2024). In addition to providing financial credit, lending availability gives every household the chance to implement modern energy-harvesting technologies. Households, on the other hand, would have varied their farming practices (Zahari

et al., 2024). In conclusion, credit serves as a buffer during emergencies like natural disasters, public health emergencies, and poultry disease outbreak, to mention a few. Only 10% of the respondents in our sample have access to credit, whereas 90% do not, as Table 4.1.3 shows.

4.1.10 Income and Sources of Income

The flow of money or other financial gains received by a person, household, or business over a given time period, usually a year or a month, is referred to as income (Besustringue et al., 2023). It is a crucial instrument for gauging the welfare of various households or respondents (Mazenda et al., 2022). Tshwane municipality is known as an administrative capital; there is a significant disparity between formal and informal employment (Hamann & Horn, 2022). Tshwane has a vast of administrative-related fields, and the majority of townships have a large number of informal jobs that can be traced to the taxi industry (Mathebula, 2022), street vendors, domestic services, etc (Mathebula, 2022). The discrepancy among occupation categories influences the income variability in Tshwane municipality (Hamann & Horn, 2022).

The majority of households in the municipality experience income gaps as a result of this disparity (Malope, 2023). A significant contributing element is the municipality's educational attainment and skill gap (Setona, 2023). Additionally, some studies contend that the spatial arrangements and distance from the municipality's economic centre make it challenging to commute within and between peri-urban and metropolitan districts, travel expenses and time limitations also lower economic participation and incomes (Chega, 2025; Malope, 2023; Molamo, 2021). Table 4.1.3 shows that 45.9% of respondents get their pay from poultry output, followed by salaries (26.6%) and social grants (24.8%), while just 1.8% of respondents receive their pay from government subsidies such as Landbank, IDC, Agra bee, and NDAC, to mention a few.

Table 4.1.4 Farm management and harnessed energy capacity

		Frequency	Percent	Valid Percent	Cumulative Percent
Average capacity of poultry house	1-100 Chickens	69	63,3	63,9	63,9
	101-300 Chickens	21	19,3	19,4	83,3
	301-600 Chickens	10	9,2	9,3	92,6
	601+ Chickens	8	7,3	7,4	100,0
	Total	108	99,1	100,0	

No of broilers	1	56	51,4	51,9	51,9
	2	22	20,2	20,4	72,2
	3	17	15,6	15,7	88,0
	4	9	8,3	8,3	96,3
	5	4	3,7	3,7	100,0
	Total	108	99,1	100,0	
Materials used for the structure	Bricks	45	41,3	41,7	41,7
	Asbestos	1	0,9	0,9	42,6
	Metal Sheet	62	56,9	57,4	100,0
	Total	108	99,1	100,0	
Roofing Material	Asbestos	2	1,8	1,9	1,9
	Plastic	2	1,8	1,9	3,7
	Metal Sheets	102	93,6	94,4	98,1
	Others	2	1,8	1,9	100,0
	Total	108	99,1	100,0	
Flooring Material	Concrete	102	93,6	94,4	94,4
	Grass	4	3,7	3,7	98,1
	Others	2	1,8	1,9	100,0
	Total	108	99,1	100,0	

Source: Author's conception (2025)

Table 4.1.5 Ventilation systems and workers pay

		Frequency	Percent	Valid Percent	Cumulative Percent
Ventilation system	Natural Ventilation (windows and open side)	100	91,7	92,6	92,6
	Mechanical Ventilation (air ducts, fans, and heaters)	2	1,8	1,9	94,4
	Both	6	5,5	5,6	100,0
	Total	108	99,1	100,0	
Average pay for workers	Less than R2000	7	6,4	6,5	6,5
	R2000- R5000	40	36,7	37,0	43,5
	R5000-R10 000	23	21,1	21,3	64,8
	R10 000+	2	1,8	1,9	66,7
	Do not pay/no workers	36	33,0	33,3	100,0
	Total	108	99,1	100,0	

Source: Author's conception (2025)

4.1.11 summary of concluding remarks

Studying and comprehending the results was made clearer by Table 4.1.1, Table4.1.2, Table 4.1.3, Table 4.1.4 and Table 4.1.5, which precisely illustrated the traits and patterns of Tshwane municipality's smallholder poultry farmers. Young male adults constituted many responders. Fairly, many of them have completed secondary school, during which they have gained up to five years of farming experience. Employment status and access to both formal and informal markets were also major factors in the outcomes. However, the limitations caused by restricted access to financing, financial aid, and extension services that provide valuable knowledge to the poultry sector were concerning.

4.2 Factors Affecting the Adoption of Harnessed Energy

The second objective of the study was aimed at investigating factors affecting the adoption of harnessed energy within smallholder poultry farms in Tshwane Municipality. Probit-regression model was employed. The probit-regression model is binary in nature making it simple to determine if smallholder farmers are to adopt vs. not adopt (Ntsoane et al., 2025). However, the unobservable variable is normally identified as a continuous variable which influences the binary outcome (Berry et al., 2010) . This theory is consistent with the behavioural theory that strongly emphasises how biasness is because of cognitive bias, farming challenges and the general barriers to adopt (Shah & Alharthi, 2024). The data was pre-processed to handle missing values and encode variables appropriately.

4.2.2 Factors Influencing Adoption of Harnessed Energy Supply by Smallholder Poultry Farmers

The results of probit model used in estimating Factors Influencing the Adoption of Harnessed Energy Supply by Smallholder Poultry Farmers in the study area is presented in Table X.

4.2.3 Goodness Fit Test

Table 4.6 Goodness of fit

	Value	df	Value/df
Deviance	132.051	97	1.361
Scaled Deviance	132.051	97	
Pearson chi-square	106.444	97	1.097
Scaled Pearson chi-square	106.444	97	
Log likelihood	-66.026		
Akaike information criterion (AIC)	154.051		
Finite sample corrected AIC (AICC)	156.801		
Bayesian information criterion (BIC)	183.555		
Consistent AIC (CAIC)	194.555		

Source: Author (2025)

The goodness of fit aided us in assessing whether our statistical model is accurate by assessing its ability to represent the observed data (West et al., 2023). Our deviance model, according to the above table, is recorded at 1.321and a Pearson of 1.097. With such a degree of freedom as noted, this suggests that there is a mild overdispersion. An overdispersion occurs when the

observed variance exceeds the model's expected variance; such a pattern is most likely to be observed in linear models (Mushagalusa et al., 2022). A study by Moerkerken et al. (2023)that seeks to evaluate which farmers adopt solar energy through a regression analysis to explain adoption decisions over time used a multilevel modelling approach (Moerkerken et al., 2023). The main discovery from the study in Argentina's Gran Chaco is the paramount importance of informal, local social networks (*parajes*) and formal social capital (producer associations) in driving the adoption of sustainable farming practices among smallholders (Núñez Carrasco et al., 2023).

4.2.4 Omnibus test

Table 4.7 Omnibus test

Likelihood ratio chi-square	**df**	**Sig.**
17.520	10	0.644

Source: Author (2025)

An Omnibus test is used in the event of determining if a model is statistically significant among the different groupings that are identified in the smallholder farmers of Tshwane Municipality (Dag et al., 2018). The model is set to be significant if the different groups can be in hierarchy and these groups will be different, meaning those that want to adopt harnessed energy and those that do not want to adopt harnessed energy (Tian et al., 2018). According to Table 4.7 above, the likelihood ratio chi-square is 17.520, with a df of 10 and a p of 0.064. This suggests that there's a marginal improvement in model fit over the intercept-only model. Although the model might not be statistically significant at the 5% level, it will still be significant at the 10% level, which is acceptable for exploratory studies on the adoption of harnessed energy systems in the poultry industry.

Table 4.8 Tests of model effects

Source	Wald chi-square	Type 1 Df	Sig.	Wald Chi-Square	Type iii df	Sig.

(Intercept)	.098	1	0.755	2.772	1	0.96
Age	.825	1	.364	2.484	1	.115
Family Size	1.817	1	.178	2.282	1	.131
Farming Experience	.212	1	.646	.356	1	.551
Farmers Monthly income	1.089	1	.297	.902	1	.342
Power cut or interruptions experienced	3.084	1	.079	3.007	1	.083
Have you ever adopted harnessed energy	3.346	1	0.67	3.599	1	.058
Perception of harnessed energy	3.268	1	0.71	3.731	1	.053
Are you aware of harnessed energy	1.497	1	.221	1.203	1	.273
What influenced your decision to adopt harnessed energy	4.145	1	0.42	4.078	1	.043

Would you consider adopting harnessed energy sources in the future	.000	1	.987	.000	1	.987

Source: Author (2025)

Table 4.8 above suggests that demographic variables such as age, family size, farming experience, monthly income were not significant as compared to variables such as perception of harnessed energy, power cuts, perception of harnessed energy ($p = 0.053$), previous adoption ($p = 0.058$), and power outage experience ($p = 0.083$) approached significance at the 10% level, indicating potential relevance is practical in a peri-urban settings. The results indicate that respondents are constrained by attitude and experience variables; these findings are consistent with earlier research that emphasised the importance of these elements in the adoption of renewable energy (Scarpa & Willis, 2010; Zografakis et al., 2010). These findings are aligned with the adoption of literature review in a study titled "Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries" (Mills & Schleich, 2012) . This study found that, after accounting for motivational and informational factors, there are only minor demographic effects (Mills & Schleich, 2012).

There are various parameters that are used as independent variables in the Table 4.9 below, such as age, family size, farming experience, farmers' monthly income, power interruptions, whether they have adopted harnessed energy, perception of harnessed energy, awareness of harnessed energy, what influences the decision to adopt harnessed energy, and whether they would consider adopting harnessed energy. Out of these variables, some present as significant, and some are non-significant. To name a few examples of non-significant predictors, they include age of respondents, family size, farming experience, income of the respondents, and awareness. Examples of significant variables include the perception these respondents have towards harnessed energy and what influences them to adopt harnessed energy.

Table 4.9 Parameter estimates

			95% Wald Confidence Interval		Hypothesis Test				95% Wald confidence interval for Exp (B)	
Parameter	**B**	**St. Error**	**Lower**	**Upper**	**Wald Chi-Square**	**Df**	**Sig.**	**Exp(B)**	**Lower**	**upper**
(Intercept)	1.769	1.0624	-.313	3.851	2.772	1	.096*	5.865	.731	47.059
Age	,144	.0915	-.035	0.324	2.484	1	.115-	1.155	.965	1.382
Family Size	-.219	.1447	-.502	.065	2.282	1	.131-	.804	.605	1.067
Farming experience	-.163	.2736	-.700	.373	.356	1	.551-	.849	.497	1.452
Farmers monthly income	-.135	.1424	-.414	.144	.902	1	.342-	.873	.661	1.155
Power cut or interruptions experienced	-.274	.1583	-.585	0.36	3.007	1	.083*	.760	,557	1.036
Have you ever adopted harnessed energy	-.937	.4938	-1.904	.031	3.599	1	.058*	.392	.149	1.032
Perception of harnessed energy	.313	.1619	-.005	.630	3.731	1	.053*	1.367	.995	1.878

Are you aware of harnessed energy	.505	.4609	-.398	1.409	1.203	1	.273-	1.658	.672	4.091
What influenced your decision to adopt harnessed energy	-.218	.1080	-.430	-.006	4.078	1	.043**	.804	.661	.994
Would you consider adopting harnessed energy in the future	.005	.3062	-.595	.605	.000	1	.987-	1.005	.551	1.831
(Scale)										

Source: Author (2025);

Legend:

*** = $p < 0.01$, **= $p < 0.05$, *= $p<0.10$, - = Not significant ($p \geq 0.10$)

Age is not statistically significant, as seen in Table 4.9; it scored p>0.05 with a B=0.144, similar to a study by Albert Moerkerken, which had a p-value of 0.836. These results suggested that age is not significant in predicting solar PV adoption in their logistic regression model (Moerkerken et al., 2023) . When we consider the family size, the results reflect that it is insignificant; however, the larger the family size, the more it tends to negatively influence the adoption level of the farmers in Tshwane. Although farming experience was a -0.163 and p=0.131, these are insignificant and relatively show that in other instances, the more experienced the farmer, the more likely the farmer is to have a better perspective about different farming models and adoption of renewable energy (Wang et al., 2023). Recent evidence shows that income is important in peri-urban settings (both urban and rural settings), and diversification of income is important, hence, the involvement of different sectors in job creation, moreover, with agriculture. Through the same sector as seen in the above Table 4.9, the adoption decision is less about income levels but about awareness, perceptions, and knowledge.

When considering the respondents' perception of harnessed energy, Table 4.9 suggests that it was significant at the 10% level, wherein Sunny agrees with this phenomenon that social influence does influence the adoption level of harnessed energy (Sunny et al., 2022). Apart from social influence, adoption levels are also influenced by external factors such as financial incentives, support from extension officers, government officials, institutions, financial aid, and community opinion. Thus, what influenced the respondent’s decision to adopt was significant at B = -0.218 and p at 0.043.

4.2.5 Conclusion

The second objective made use of the probit regression models, where various factors were significant at different levels; some were insignificant at different levels. Focus was made at the 5% level and 10% level because that is where the P-value conventional cut-offs are applied in econometrics for hypothesis testing and to balance error risk. Probit regression models are used for descriptive and inferential statistics; we can conclude a broader understanding of how smallholder farmers in Tshwane can be characterised. The above was done through interpreting results from the model information, case summary processing, categorical and continuous variable input, the goodness-of-fit test, the omnibus test, and lastly the test of the model effect.

4.3 Adoption of Harnessed Energy Constraints

The third objective of the study was to determine the primary constraints smallholder poultry producers encounter when adopting harnessed energy and the use of energy currently in place. To ascertain the constraints that smallholder farmers experience under the current energy supply, we utilised Kendall's coefficient of concord (W) to rank the constraints that farmers encounter on production efficiency.

4.3.1 Introduction

This section focuses on the constraints which are faced by the respondents from Tshwane municipality small holder farmers. This focus is essential, as most smallholder farmers have the capacity to develop but are challenged by several barriers. Through eliminating or minimising these challenges improves prospects of development. Running a smallholder poultry farm involves different aspects, however for the purpose of this section, focus is on challenges vital to production efficiency.

4.3.2 Constraints faced by smallholder poultry farmers to adoption of harnessed energy

The aim of this section is to outline constraints faced by smallholder poultry farmers in Tshwane municipality, such as the lack of funding, lack of government support, lack of technical knowledge, high costs of maintenance, transportation of harnessed energy resources, prices of harnessed energy equipment installation, theft of equipment or any other harnessed energy resources. Below follows an in-depth discussion of the outlined constraints common in adopting of harnessed energy for improved production efficiency.

4.3.3 Descriptive statistics

Amongst the seven constraints noted in Tshwane Municipality, lack of funds and the transportation of harnessed energy resources were found to be the most pressing. As a result of the lack of funds, most smallholder farmers rely on traditional methods for production. These methods are often not sustainable and perhaps less efficient. This links to a study by Adjei-Mensah on the challenges of small-scale broiler production. In the publication, they emphasise that small-scale broiler farmers often face challenges related to resource proximity (Adjei-Mensah & Kpomasse, 2025) . However, most respondents mentioned the following as their

constraints: lack of funds, lack of government support, lack of technical knowledge, high maintenance costs, transportation of harnessed energy resources, the price of harnessed energy resources, and, lastly, theft of equipment or other harnessed energy resources.

According to Ahmed and Alam (2025), using solar systems is a viable option for reducing energy costs in poultry farms. This could potentially lead to significant energy savings and reduced reliance on electricity (Birhanu et al., 2022). However, they argue that wind turbines can also contribute to energy generation on the same small-holder farms, though they may have limitations in terms of theft of equipment, price of harnessed energy resources and lack of technical knowledge (Ahmed & Alam, 2025). A combination of solar and wind energy systems can be a strategy to overcome the intermittent nature of each, making them more reliable and efficient (Adjei-Mensah et al., 2024).

4.3.4 Ranking of constraints

Table 4.10: Kendall's W Test

Variables	Mean Rank
Lack of Funds	3.77
Lack of government support	3.94
Lack of technical know how	4.11
Prohibitive cost of maintenance	4.07
Transportation of electrical resources	3.84
Prohibitive cost of production	4.28
Theft (stock, equipment, electrical cable)	3.99

Source: Author (2025)

Table 4.10 suggests that the high cost of production scored 3.76 (mean) on a 5-point scale. The high production cost showed a standard deviation of 1,151; this clearly indicates that the respondents found this variable or factor to be a key barrier to the adoption of harnessed energy. A study by Madula (2023) makes emphasis on this phenomenon, where she highlights that high input and production costs are the most common challenges in smallholder poultry farming.

Theft was one of the constraints mentioned by the respondents, including stock and equipment theft. According to Farmers Weekly, a survey conducted in 2021 by South African crime expert Willie Clack, among 730 farmers found that 86% had been exposed to property theft, with livestock and non-mechanised equipment at the top of the list (Hesselink & Clack, 2024; Meško & Eman, 2022) . Whilst in between July and September of 2025, there were 7 339 cases of stock theft countrywide, which saw over 26 300 sheep and 14 000 cattle stolen. In one area of Gauteng alone, it is costing farmers R1 million a month (Ndzungu et al., 2025).

Mabunda et al. (2021) also found in his writing that stock theft and security issues also negatively contribute to the sustainability and productivity in smallholder farming. However, high tariff rates or electricity costs were rated lower than stock theft, they arguably form part of the high cost of production, which scored a mean of 3.76, the highest. Over the years, electrical tariffs have increased (Franks, 2014) . In 2023 alone, there was an 18.65% tariff hike; in 2024, it equated to a 12.72% increase; and Eskom applied in early 2025 for a further 12.5% increase for the 2025/2026 financial year, as part of its Multi-Year Price Determination (MYPD6) process (Zondo, 2025). Economic modelling results presented in the source specifically analyse the effects of a 12.74% electricity tariff hike (Zondo, 2025). Electricity is a crucial input for various agricultural activities, contributing about 6% to total production input costs. In poultry production, energy is crucial for heating, ventilation, lighting, and feeding, to mention a few (Hajiyev et al., 2022).

Kendall's W is a model that is reliable to measure concordance in ordinal data from different variable rankings (de Raadt et al., 2021). The use of Kendall's Coefficient model aids in measuring the degree of significance by ranking the constraints that were established through a non-parametric manner, where the respondents of the questionnaire are regarded as the raters (Salman & Aleem, 2024). These raters rate in accordance with the W range (0-1), suggesting no agreement to complete agreement (de Raadt et al., 2021).

When using Kendall's W model, hypothesis is if $P<0.05$, then the respondents or rankers were consistent in ranking the constraints; this suggests that most of the respondents share a common perspective, as opposed to a $W=0.042$. The above validates that the respondents identified constraints in no order as the most prevalent challenges around Tshwane Municipality, Gauteng province. In conclusion, it is noted from the above results that the high cost of production was the most severe constraint.

Table 4.11Test statistics

N	108
Kendall's W	0.008
Chi-Square	5.040
Df	6
Asump. sig	0.539

Source: Author (2025)

Table 4.11reflects the following results: W=0.008, Chi-square of 5,040, degrees of freedom+ 6 and a significance level of p=0. 539.It is important to note that Kendall's tau ranges from 0-1, as mentioned earlier, with 0 indicating no agreement and 1 indicating perfect agreement. The table above suggests that there is no agreement between the respondents, as seen by W being 0.008. Furthermore, this indicates that there is no concordance in the rankings, and this means that we fail to reject the null hypothesis. The above results strongly suggest that the smallholder farmers or respondents generally have different perceptions when it comes to ranking the severity of constraints.

The variations in the respondents highlighted key agreements in constraints such as high production costs and lack of technical knowledge, which were highlighted in "Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya" study (Autio et al., 2021). This heterogeneous perception could potentially be because of the difference in farm size, even though they are all smallholder poultry farmers, access to different resources and inputs, and lastly, the variations in the energy systems used.

4.3.5 Conclusion

Since the third objective used Kendall's coefficient of concord (W) to rank the production efficiency constraints farmer's encounter. The transportation of harnessed energy resources was found to be the greatest limitation in Tshwane Municipality, based on this section of interpretation, which also cited several other constraints, including a shortage of funding and a high electricity rate.

4.4 Production Efficiency

The fourth and the last objective of the study assess production efficiency of smallholder farmers under conventional and harnessed energy. To assess this production efficiency, the stochastic model was applied. This model allows estimation of the likelihood of production efficiency by assessing input variables from harnessed and conventional energy sources.

4.4.1 Introduction

Energy is a critical factor in modern agricultural production. For smallholder farmers, access to reliable and affordable energy sources determines the extent to which they can mechanise, irrigate, process, and store farm products efficiently. Conventional electricity supply has historically supported production but is often unreliable in rural areas of sub-Saharan Africa, thereby constraining efficiency (Eberhard & Catrina Godinho, 2017). In this context, harnessed energy sources such as solar, wind, and biogas are increasingly being promoted as sustainable alternatives that can improve productivity and reduce inefficiency (Chamdimba et al., 2020; Silva-González et al., 2021).

This section discusses the results of the stochastic Cobb–Douglas production frontier, focusing on the role of conventional electricity and Harnessed energy in determining the production efficiency of smallholder farmers.

4.4.2 Model Fit and Significance

The stochastic frontier analysis (SFA) model was statistically significant, with a Wald chi^2 value of 104.73 ($p<0.01$), confirming that the explanatory variables jointly influenced total farm output. The log-likelihood value of -101.95 further suggests that the estimated model adequately captured the relationship between inputs and outputs. A similar model significance has been reported in related studies on agricultural production efficiency in Malawi and Nigeria (Fapohunda et al., 2019; Tchale, 2009).

4.4.3 Key Determinants of Output:

I. Labour

Labour exhibited a strong and positive elasticity of (0.736, $p<0.01$), suggesting that the increase in labour significantly enhances output. This result is consistent with Alene et al. (2009), who emphasised the role of labour in smallholder crop systems, and Ogunniyi and Ajao, who reported labour as a major determinant of technical efficiency among Nigerian maize farmers (Alene et al., 2009; Belewu et al., 2023; Fapohunda et al., 2019).

II. Feed

Feed quantity also had a positive and significant effect (0.289, $p<0.01$). This is expected in both livestock and mixed farming systems, as feed quality and availability directly influence productivity. The finding is consistent with Adams , who linked feed inputs to efficiency gains in smallholder farming practices.

III. Farm Size

Farm size (0.844, $p<0.01$) showed a strong positive relationship with output. Larger farms are evidently able to achieve economies of scale, enabling more efficient resource allocation and efficient use of resources. Similar results were reported by Binam in Cameroon and Maganga in Tanzania, where larger landholdings were associated with higher production efficiency (Binam et al., 2004; Maganga et al., 2022).

IV. Conventional Electricity

Conventional electricity had a positive and significant elasticity (0.162, $p<0.01$). This indicates that access to grid electricity enhances productivity by enabling mechanised processing, irrigation, and storage. Feyissa et al. (2022) similarly reported that energy access improves agricultural efficiency in Ethiopia. However, unreliable supply and frequent outages limit its effectiveness in many African contexts (Foster et al., 2021).

V. Harnessed Energy

Notably, harnessed energy is positive and significant at (0.184, $p<0.05$). This demonstrates that harnessed energy sources such as solar and wind turbines energy systems play a crucial role in supporting production efficiency. Harnessed energy reduces reliance on unstable grid supply, by providing an affordable and long-term power systems that supports climate-smart practices.

- Komakech et al. found that Tanzanian smallholders using solar irrigation achieved higher costs and a more stable energy supply.
- Baumüller et al. (2025) emphasised the transformative role of solar-powered irrigation in East Africa, highlighting improved yields and labour savings.
- Mbanasor et al. reported similar results in Nigeria, where solar adoption improved efficiency by lowering. This study's results confirm that harnessed energy is not only environmentally sustainable but also economically efficient for smallholder farmers.

VI. Negative Effects of Drugs and Vaccines

Interestingly, the quantity of drugs and vaccines exhibited a negative and significant coefficient (-0.160, $p<0.01$). This suggests that higher usage may reflect disease challenges and inefficiencies, rather than improved productivity. Overuse or misuse of veterinary inputs could increase costs without corresponding output gains. This aligns with findings by Anyanwu et al. , who noted that excessive expenditure on drugs often reduces efficiency in poultry systems (Otieno, 2023).

VII. Returns to Scale

The sum of estimated elasticities (2.055) indicates increasing returns to scale. This means that if farmers simultaneously double their inputs (labour, feed, energy, and land), total output more than doubles. This result suggests that scaling up farm operations while expanding energy access can significantly enhance efficiency. Similar increasing returns were reported Binam et al. (2004) in Cameroon and Alene et al. (2009) in Kenya (Gebrehiwot, 2017).

VIII. Inefficiency Effects

Socio-demographic characteristics such as age, gender, education, and family size were statistically insignificant in explaining inefficiency. Socio-demographics are important because

they impact the society, the economy and overall productivity of the farm. However, the socio-economic characteristics mentioned above imply that inefficiency among farmers is more strongly influenced by farm-level and institutional factors, particularly energy access, rather than household attributes. This result aligns with the study made by Chapman et al. (2021) who found that institutional constraints, rather than demographics, largely explained inefficiency among South African smallholders .

Table 4.12: Stochastic Cobb-Douglas Model Results for Total Output of Smallholder Poultry Farmers

Variable	Coefficient	Std. Err.	z-value	p-value	95% Confidence Interval
Production Function					
Labor_A	0.7360	0.1493	4.93	0.000	0.4434 – 1.0286
Quantity of Drugs/Vaccine	–0.1599	0.0463	–3.46	0.001	–0.2506 – –0.0692
Total Amount of Electricity	0.1624	0.0500	3.25	0.001	0.0644 – 0.2604
Quantity of Feed	0.2887	0.1081	2.67	0.008	0.0769 – 0.5005
Harnessed Energy	0.1845	0.0837	2.21	0.027	0.0205 – 0.3485
Farm Size	0.8436	0.3177	2.66	0.008	0.2210 – 1.4663
_cons	5.0070	1.0349	4.84	0.000	2.9787 – 7.0353
lnsig2v					
_cons	–0.9770	0.1397	–7.00	0.000	–1.2507 – –0.7032
lnsig2u					
Age_A	1.4555	8.0982	0.18	0.857	–14.4167 – 17.3277
Gender_A	–18.8569	32.7190	–0.58	0.564	–82.9850 – 45.2712
Marital Status	–3.5859	7.9407	–0.45	0.652	–19.1493 – 11.9775
Education_A	18.6085	16.0828	1.16	0.247	–12.9132 – 50.1303
Employment Status	–110.2749	8077.095	–0.01	0.989	–15941.090 – 15720.540
Family Size_A	2.1648	4.8688	0.44	0.657	–7.3779 – 11.7075
_cons	–9.9188	9.1687	–1.08	0.279	–27.8892 – 8.0516
sigma_v	0.6136	0.0428	—	—	0.5351 – 0.7036

Model Statistics: Number of obeservations=108 - Wald chi2(6): 104.73 ($p < 0.001$) - Log likelihood: -101.947.

Note: Significance levels: ***p < 0.01***, ***p < 0.05***, $p < 0.10$*.

4.4.4 Comparative analysis: Harnessed energy vs Conventional energy

Empirical findings from Table 4.15 revealed that farmers utilising harnessed energy achieved an average production efficiency score of 0.94, in sharp contrast to the 0.57 recorded among those relying on conventional electricity. This suggests that harnessed energy, which often includes harnessed or decentralised systems such as solar-powered irrigation, enables farmers to operate closer to their production frontier. Importantly, the minimum efficiency score for harnessed energy users (0.84) exceeded the average performance of conventional energy users, highlighting the robustness and reliability of this energy source for improving farm productivity.

The observed differences align with earlier studies emphasising the role of reliable and sustainable energy access in improving smallholder agricultural performance. For instance, Songwe et al. (2022) note that renewable and harnessed energy systems reduce transaction costs, enhance irrigation reliability, and improve the timeliness of farming operations, thereby translating into higher technical efficiency. Conversely, farmers dependent on conventional electricity often face challenges such as high tariffs, unstable supply, and infrastructural bottlenecks, which limit their ability to optimise resource use (Rabbi, 2024; Tondel et al., 2022).

Another key insight is the variability in performance among harnessed energy users. Although average efficiency was higher, the wider spread in results suggests differences in managerial capacity, technology adoption, and learning effects. This finding echoes the work Nkuebele (2024) and Bravo Ureta et al. (2021) who made emphasis that efficiency improvements are not solely a function of technology availability but also of farmer training, experience, and institutional support. Thus, while harnessed energy has demonstrated superior efficiency outcomes, maximising its potential requires complementary policies aimed at capacity building, extension services, and farmer education.

Table 4.13 Production Efficiency Harnessed energy

Variables	Observation	Mean	Std. Dev	Min	Max
PEF	108	0.9437	0.6894	0.8437	1

Source: Author (2025)

Table 4.14 Production Efficiency Conventional Energy

Variables	Observation	Mean	Std. Dev	Min	Max
PEF	108	0.5708	0.2948	0.4357	1

Source: Author (2025)

The total sample comprised 108 smallholder poultry farmers, classified into two mutually exclusive groups based on energy source used: adopters of harnessed energy and users of conventional energy. Descriptive statistics were computed separately for each group to examine mean production efficiency differences prior to conducting inferential analysis. The distribution of observations across the two groups was unequal but collectively summed to the total sample size of 108.

Independent T-test

The independent samples t-test is specified as:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

Where:

$\bar{X}_1, \bar{X}_2$= mean efficiency scores

S_1^2, S_2^2= variances

n_1, n_2= group sample sizes

Table 4.15 Independent sample t-test

Statistic	Harnessed Energy	Conventional Energy	Test Value
Mean Efficiency	0.9437	0.5708	—
Std. Deviation	0.6894	0.2948	—
Sample Size (n)	108	108	—

Statistic	Harnessed Energy	Conventional Energy	Test Value
Mean Difference	—	—	**0.3729**
t-value	—	—	**4.82**
Degrees of Freedom (df)	—	—	**214** *(approx.)*
p-value	—	—	**< 0.001***
Significance	—	—	**Statistically significant at 1% level**

Table 4.16 Comparative Table of Production Efficiency

Energy Source	Observations (n)	Mean Efficiency	Std. Dev.	Min	Max
Harnessed Energy	44	0.9437	0.6894	0.8437	1.0000
Conventional Energy	64	0.5708	0.2948	0.4357	1.0000
Total	108	0.7231	-	0.4357	1.0000

Source: Author (2025)

4.4.5 Conclusion

The stochastic frontier analysis (SFA) model was statistically significant when employing the stochastic Cobb-Douglas production frontier to examine how conventional and harnessed energy affect smallholder farmers' profitability. The following factors were used: labour, feed, farm size, conventional and harnessed energy, the impact of vaccines and immunisations, return to scale, and inefficiencies. The output of poultry was directly affected by feed, even when labour and feed were positively significant. While conventional energy is utilised for typical farm productivity, harnessed energy is mostly recognised for promoting production efficiency because it is economical and sustainable.

In summary, the findings demonstrate that harnessed energy systems significantly enhance production efficiency among smallholder farmers compared to conventional electricity. This supports the argument that energy diversification, particularly towards decentralised and harnessed energy sources, is not only environmentally sustainable but also economically efficient for smallholder agricultural systems.

CHAPTER 5: SUMMARY, FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter provides an overview, recommendations, and a conclusion based on the research's findings on the adoption of harnessed energy for increased production efficiency for Tshwane's smallholder poultry farmers. This chapter is constructed from the questionnaire and findings in Chapter 4, where the methods of both quantitative and qualitative empirical analysis were applied. This study attempts to compare the production efficiency of smallholder poultry farmers in Tshwane Municipality, an urban peri-urban municipality, using conventional energy against harnessed energy. The chapter concludes by recommending key policy areas for additional findings and research.

5.1 Summary

The overall objective of the study was to evaluate how smallholder poultry producers in Tshwane Municipality, Gauteng Province, adopted harnessed energy for increased production efficiency. The overall four objectives of this study include examining socio-economic status of Tshwane Municipality smallholder poultry farmers, investigating factors affecting the adoption of harnessed energy, determination of different constraints faced by smallholder farmers under the current energy supply, and lastly, assessment of production efficiency of smallholder farmers under conventional energy and harnessed energy.

The raw data from the questionnaire that was distributed to the respondents was recoded, organised, and analysed using SPSS (version 21) and Microsoft Excel 360. Mathematical calculations and assumptions were used during this process. The socioeconomic characteristics of the respondents were defined using descriptive statistical analysis (means, standard deviation, percentage, and chi-square). For the second objective, the Probit regression model was used; for the third, Kendall's Coefficient of Concordance (W); and for the fourth, the stochastic frontier model. The study employed analytical methods to identify significant and non-significant factors, including descriptive statistics and multiple regression models.

5.2 Major Findings

The study revealed that most of the respondents involved in smallholder poultry farming are males at 56%. This indicates that, among respondents in the Tshwane Municipality, most males are recognised in peri-urban settings, whilst females are recognised in urban settings (44%). Although both can make household decisions, males have the upper hand. It was also revealed that people over the age of 35 years constitute most of the farmers in the area, at 25% (35-44 years of age). This means that the early middle age is majority of the farmers, 51% of those are single, and 42% of them have a family size of 3-4. A greater household size could potentially mean an increased labour input, as this is an important aspect of human resources and equally a greater potential output. However, this might result in a challenging scenario where these household members need to buy extra food, housing, water, and other necessities.

About 57% of the respondents have secondary education, whilst 35% of the respondents indicated that they have tertiary education. Farmers with formal education can make sound decisions in farming. The results also showed that 26% of the respondents are employed, whilst 39% are self-employed farmers. This increase in self-employed percentage in Tshwane is because of a significant increase in the population and a need to improve nutrition of those in Gauteng Province. Although 76% of these respondents indicated that they have 0-5 years of farming experience, with such experience, 71% of the respondents have access to informal markets, whilst 28.4% of the respondents have access to formal markets. About 10% of the respondents have access to credit, and 46% receive their salaries from poultry production or farming.

According to empirical studies, out of a total of 195 (N), only 108 (N) were included (55,4%), and 44,6% were excluded. The excluded 44,6% is because of a missing variables / variable that are used for the model. The 44,6% exclusion rate suggests that the results will decrease the statistical influence of the results, which would have been used to detect all farming interactions of the respondents. Table 4.3 indicates that a total of 108 respondents were interested in answering the questionnaire, of whom 48.1% (N=52) indicated that they are not interested in adopting harnessed energy, whilst 51,9% showed an interest in adopting harnessed energy (N=56). Out of all the variables listed in Table 4.5 (continuous variable information), the findings are likely those described in objective one; they provide confidence, as well as an extensive investigation of the second objective.

The accuracy of the statistical model utilised is displayed in Table 4.2, which also indicates an overdispersion with a Pearson of 1.097 and a deviation of 1.321. Additionally, the model's relevance within the various groups found among the respondents (age groups, agricultural experience, types of energy used, number of broilers, etc.) is looked at in Table 4.1.1, 4.1.2, 4.1.3, 4.1.4, and 4.1.5. This data revealed that the model is statistically significant at the 10% level but not at the 5% level for smallholder farmers in Tshwane. Only the perception of harnessed energy ($p=0.053$) and power cuts ($p=0.083$) were found to be significant among the variables indicated in Table 4.8. In contrast, Table 4.9 measures the true parameter value using a point estimate, an interval estimate and confidence level. Overall, the results for Tables 4.6, 4.7, 4.8, and 4.9 show that there is an indication of constraints by attitude and that the model is significant at the 10% level.

The Kendall Coefficient of Concordance, which is used to assess the constraints experienced by smallholder poultry farmers, is shown in section 4.3. The following are some of the highlighted constraints: lack of funding, lack of government support, lack of technical knowledge, high costs of maintenance, transportation of harnessed energy resources, prices of harnessed energy equipment installation, theft of equipment or any other harnessed energy resources. Table 4.3 results indicate that, with respective means of 3.39 and 3.49, the only two factors considered severe were the lack of funding and transfer of equipment used for harnessed energy. High manufacturing costs had a mean score of 3.76 and a standard deviation of 1.151 when these constraints were ranked on a 5-point scale in Table 4.4 and Table 4.10. W was 0.008 with a chi-square of 5.040, however, indicating that there was no agreement among the respondents (Table 4.5 and Table 4.10) Since each respondent has a distinctive perspective on energy sources, and more specifically, harnessed energy sources, there is no agreement in the rankings.

Outcomes from the stochastic frontier analysis were statistically significant, with a Wald chi^2 value of 104.73 ($p<0.01$), confirming that the explanatory variables jointly influenced total farm output. Labour showed a substantial and positive elasticity (0.736, $p<0.01$) with the output determinants, indicating that increases in labour use considerably increase output. Feed quantity also had a positive and significant effect (0.289, $p<0.01$). Farm size (0.844, $p<0.01$) showed a strong positive relationship with output. However, it is important to note that there was a significant difference of 0.022 between harnessed energy and conventional electricity. The elasticity of conventional electricity was positive and significant (0.162, $p<0.01$). The effect of harnessed energy was positive and significant (0.184, $p<0.05$).

Oddly, the above-listed factors, the number of drugs and vaccinations showed a negative and significant relationship (-0.160, $p<0.01$). The calculated elasticities added together (2.055) show growing returns to scale. Thus, if farmers double their inputs (land, labour, feed, and energy) at the same time, the overall output more than doubles. Social-demographic factors like gender, age, family size, and education level were statistically insignificant in explaining the inefficiency effect. Accordingly, farm-level and institutional factors, particularly energy access, have a greater impact on farmer inefficiency than family characteristics.

In Comparison to conventional energy, the average production efficiency of harnessed energy was 0.94, in sharp contrast to the 0.57 recorded among those relying on conventional electricity. Whilst they differ by 0.408 in minimum efficiency and both have a maximum efficiency score of 1. This means that harnessed energy scored a minimum efficiency score of 0.8437, and conventional energy scored a minimum efficiency score of 0.4357.

5.3 Conclusion

This study sought to assess the extent to which smallholder poultry farmers in Tshwane District, Gauteng Province, were able to increase their production efficiency using harnessed energy sources. Using a mixed methods approach helped guide this study by utilising both quantitative and qualitative methods to gain a greater understanding of the research problem than would be feasible with a single approach.

To understand present techniques, challenges, and possible benefits related to energy harnessing in smallholder poultry farming, a thorough literature review was first carried out. To analyse the socioeconomic traits of farmers in the chosen area, this study used primary data and descriptive analysis. To put together a comprehensive literature review, the study gathered information from books, journal articles, and official government records. A questionnaire was employed to gather information from 108 peri-urban respondents in Cullinan, Mabopane, Bronkhorspruit, Hammanskraal, Atteridgeville, and the Winterveldt.

The study's motivation stemmed from the South African energy crisis, which has an impact on the growth and trajectory of smallholder poultry production. In summary, the energy crisis is a result of frequent load-shedding events brought on by a lack of energy output to meet national demand. This threatens the continuous supply of energy needed for effective poultry production, and South Africa's electricity prices have increased dramatically in the past ten

years, endangering the financial stability of small farming operations(Odeku & Takalani, 2024).

The study's findings showed how important it is for farmers to employ harnessed energy sources like solar and wind turbines to increase production efficiency. Harnessed energy promotes climate-smart habits, offers long-term, reasonably priced power systems, and lessens dependency on inconsistent grid supplies; by allowing mechanical processing, irrigation, and storage, farmers who choose traditional electrical energy sources are often only productive. The energy crisis was a problematic exposure, and according to the results, most respondents said that they would adopt harnessed energy for increased production efficiency and sustainability if they were exposed to technical knowledge and had a sizable amount of funding.

The absence of statistically significant socio-economic determinants in the adoption of harnessed energy suggests that other structural or contextual factors may be more influential. Factors such as capital intensity, perceived risk, limitations in infrastructure, or broader energy policy dynamics could play a decisive role in farmers' decisions to adopt renewable energy technologies. The results indicate that tangible farm-level inputs, including farm size, feed, and labour, are the primary drivers of output. Larger landholdings are associated with improved technical efficiency, as economies of scale allow for more effective resource allocation, mechanisation, and operational management. Similarly, adequate and quality feed contributes directly to enhanced productivity, while the availability of labour significantly increases output by supporting timely and effective farm operations. Together, these findings imply that while socio-economic characteristics alone may not determine harnessed energy adoption, investments in farm-level resources and structural support are critical for enhancing production efficiency and the potential benefits of renewable energy technologies.

5.4 Recommendations

The findings of this study indicate that while there is considerable interest among smallholder poultry farmers in adopting harnessed energy technologies, technical knowledge and practical understanding of these systems remain limited. Although a substantial proportion of respondents possess secondary and tertiary education, this has not necessarily translated into specialised knowledge of renewable energy applications in broiler production. Strengthening farmer education through structured capacity-building initiatives is therefore essential.

The Department of Agriculture, in collaboration with extension services and energy stakeholders, should intensify farmer training programmes that focus specifically on the technical, economic, and operational aspects of harnessed energy systems. Practical demonstrations, pilot projects, and community-based workshops could improve awareness, reduce uncertainty, and enhance farmers' confidence in adopting sustainable energy solutions. Given the prevailing challenges of high electricity tariffs and recurring load shedding, coordinated educational interventions are likely to improve both production efficiency and long-term farm resilience.

Access to finance also emerged as a critical constraint, with the majority of respondents lacking access to credit facilities or funding mechanisms. Even where interest in adoption exists, the capital-intensive nature of renewable energy technologies may deter investment among resource-constrained smallholder farmers. It is therefore recommended that financial institutions, government agencies, and development partners design targeted financing instruments tailored to renewable energy investments in small-scale agriculture. These may include subsidised loan schemes, blended finance models, or grant-based support for pilot installations. Furthermore, improved dissemination of information regarding available funding opportunities is necessary. Extension officers, farmer associations, and local communication platforms such as community radio and agricultural forums should be leveraged to ensure that farmers are adequately informed about eligibility criteria, application procedures, and funding cycles.

Finally, there is a need for stronger policy integration between agricultural development frameworks and renewable energy strategies. Existing agricultural policies and development plans should explicitly incorporate renewable energy adoption as a strategic pillar for enhancing productivity, sustainability, and rural economic growth. Aligning renewable energy

initiatives with broader agricultural action plans would ensure policy coherence and facilitate coordinated implementation across sectors. By embedding harnessed energy adoption within agricultural development strategies, policymakers can create an enabling environment that supports smallholder farmers in transitioning toward more energy-efficient and environmentally sustainable production systems.

This study underscores the importance of strengthening technical capacity, institutional collaboration, and policy alignment to enhance the adoption and effective utilisation of harnessed energy among smallholder poultry farmers. Given that agricultural production operates within a multi-stakeholder environment, coordinated partnerships between higher learning institutions, agricultural colleges, Sector Education and Training Authorities (SETAs), government departments, and extension services are essential. Structured technical training programmes should be developed to improve harnessed energy literacy among both farmers and extension officers. Such programmes should move beyond basic awareness to include system operation, maintenance, troubleshooting, and long-term management of renewable energy technologies. By building local technical expertise, farmers will be better positioned to maximise the efficiency gains associated with harnessed energy systems while reducing dependency on external technical support.

In addition to capacity development, the establishment of decentralised harnessed energy hubs within farming communities presents a strategic pathway for improving energy accessibility and sustainability. These hubs could function as centralised platforms integrating renewable energy generation systems, storage facilities, and smart distribution mechanisms to serve clusters of smallholder farmers. By pooling infrastructure and optimising energy flows, such hubs would enhance reliability, reduce transmission losses, and lower operational costs. Importantly, energy hubs would reduce reliance on fossil fuel-based electricity sources, mitigate carbon emissions, and strengthen the resilience of smallholder poultry enterprises against energy supply disruptions. Beyond their technical function, these hubs could also serve as demonstration centres for innovation, skills transfer, and community-based sustainability initiatives.

Finally, renewable energy adoption should be explicitly integrated into broader agricultural development, food security, and climate policy frameworks. Harnessed energy represents a dual opportunity within the poultry subsector: it supports environmental sustainability through reduced greenhouse gas emissions while simultaneously improving production stability and

cost efficiency. Reliable energy supply is critical for ventilation, heating, lighting, and automated systems that safeguard flock health and optimise feed conversion efficiency. Aligning renewable energy strategies with national food security objectives and climate commitments would therefore create policy coherence and reinforce the role of smallholder farmers in achieving sustainable agricultural transformation. A coordinated approach that links energy transition goals with agricultural productivity imperatives will be instrumental in ensuring long-term sectoral resilience and inclusive rural development.

5.4.7 Policy Implications

The findings highlight the strategic role of harnessed energy in improving smallholder production efficiency:

1. **Energy Diversification:** Harnessed energy reduces reliance on unstable grid supply, ensuring more consistent power for irrigation, mechanisation, and storage.
2. **Cost Reduction:** Solar, wind turbines, and other harnessed energy sources lower long-term production costs, improving allocative efficiency.
3. **Climate Resilience:** Harnessed energy supports climate-smart agriculture, reducing carbon footprints and enhancing long-term sustainability (Scherer & Verburg, 2017).
4. **Scaling Efficiency:** Increasing returns to scale indicate that policies should promote both energy system access and farm expansion to unlock efficiency gains.

To increase the welfare of smallholder farming households, the study's overall conclusions recommended that governments and non-governmental organisations focus on strengthening the social, economic, and human capital resource bases of peri-urban and urban households (Thornton, 2008) .

5.5 Suggested Areas for Future Research

The following recommendations are made for further research consideration:

This study focused only on the Tshwane District in Gauteng Province, which is one district, although the Tshwane District encompasses peri-urban settings. Since the energy crisis is witnessed throughout the entire country, future studies should be conducted across various

provinces and scaled down to municipalities in all 9 provinces in South Africa. Research should analyse the difference in adoption level based on rural and urban farms within Gauteng Province and other provinces.

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Annexure 1

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Questionnaire

Title of the study: "Adoption of Harnessed Energy Supply Practices for Improved Production Efficiency of Small Holder Poultry Farmers in Tshwane District, Gauteng."

My name is Ella Mogashoa, an Agricultural Economics Master's student from the North-West University. I am here to collect data from you as a poultry farmer. This study has its main purpose of assessing how smallholder poultry farmers in Tshwane District. This study aims to assist numerous stakeholders in the poultry farming industry to evaluate opportunities, constraints, and the potential for sustainable energy solutions. You will be asked to fill out a questionnaire if you consent to participate in this study.

Please take note that this is voluntary. The questionnaire will ask you about your current energy usage, whether you are aware of harnessed energy sources, and how you believe harnessed energy can help you as a smallholder poultry farmer. It will take at least five minutes and up to ten minutes to finish all the questions.

As a participant, you are reassured that by completing this form, your information, as well as the information of every other participant, will be kept confidential and secure, and that the researchers will be the only viewers. This will be done to solemnly complete the study. Other stakeholders or researchers may use this study; however, that won't compromise the confidentiality standards. All enumerators are responsible for collecting accurate and impartial

data to ensure the integrity of the study. No enumerator should influence respondents' responses, instead, they should impartially make sure that all respondents understand the study's objectives and questions.

Declaration: By signing the below, you agree that you have read and understood the above information. You consent that your data will be used solely for research purposes and are willing to participate in this study.

Participants reference no _____

Community_____

Participants Signature _____ Enumerator signature_____

Date _____ Date_____

Please kindly indicate your option by putting "X" under the selected column.

SECTION A: SOCIO-ECONOMIC CHARACTERISTICS OF THE FARMERS

i. DEMOGRAPHIC INFORMATION

1.What is your Gender	Male		Female		Prefer not to say	
2. How old are you in Years?	15-24	25-34	35-44	45-54	55-64	65+ Years
3. What is your marital status ?	Single		Married		Divorced	Widower
4.What is your highest education obtained?	No formal Schooling		Primary Level		Secondary level	Tertiary Level
5. What is your employment status?	Unemployed		Employed		Self-Employed	Others
6. What is your family Size?	1-2 Members		3-4 Members		5-6 Members	7+ Members
7. Farming Experience in Years	0-5 Years		6-15 Years		16-30 Years	31 +Years

ii. ECONOMIC CHARACTERISTICS

1.What is your monthly income?	Less than R1000	R1000-R5000	R5001-R10 000		More than R10 000
2. What is your source of income?	Government grant i.e. IDC, Agra, Agri Bee, NDAC, Landbank	Poultry farming wages/ salary	Social Grants	Salary	Others
3. Do you have access to: credit/loans/ funding C/ grant for your poultry farming?	Yes		No		
4. Do you have access to formal market? markets: Abattoirs, Bulk Supply, Super Markets, Institute and government supply contracts, retail chains etc.)	Yes		No		
5. Do you have access to informal markets?	Yes		No		

Markets: community markets, street vendors, Street food stalls, spaza shops, social media sales		

iii. FARMING PRACTICES

1.What is the average capacity of your poultry house?	1-100 Chickens	101-300 Chickens	301-600 Chickens	601+ Chickens	
2.How many broilers house do you have?	1	2	3	4	5
3. What materials are used for the structure of the poultry house?	Bricks	Asbestos	Metal Sheet	Others	
4. What material is used for the roofing of the poultry houses?	Asbestos	Plastic	Metal Sheets	Others	
5. What flooring material is used in the poultry houses?	Concrete	Grass	Bricks	Others	
6. What ventilation system is used?	Natural Ventilation (windows, open sides)	Mechanical Ventilation (air ducts, fans and heaters)	Both	Others	
7. Which of the following best describes the average pay for workers on your farm? (In Rands)	Less than R2000	R2000-R5000	R5000- R10 000	R10 000 +	

SECTION B: CONSTRAINTS FACING POULTRY FARMERS

1.Constraints encountered in Adopting Harnessed Energy	1	2	3	4	5
a. Lack of Funds					
b. Lack of Government support					
c. Lack of technical knowledge					
d. High cost of maintenance					
e. Transportation of harnessed energy resources					
f. Prices of Harnessed energy equipment installation					
g. Theft of equipment or any harnessed energy resources					
h. Others (Please specify)					

2.What is your main reason for poultry farming?	To generate income		Home consumption		Other	
3. Mortality rate of chickens during the past production cycles (In percentages%)	0 -5%		6- 15 %		16-30%	30+%
4. Which energy source do you currently use on your farm?	Wind Energy		Solar Energy		Generator	Electricity
5. Have you used a different energy source in the past?	No		Yes		If, yes, which source?	
6. How much do you normally spend on your farm energy sources averagely?	Less than R1000		R1001 – R2000		R2001- R 3000	R3001+
7. Which farm operations consume the most energy	Lighting	Heating	Water Pumping	Feeding System	Refrigeration	Processing (slaughtering, plucking, freezing, packaging)
8.How often do you experience power cuts or interruptions due to technical faults, loadshedding and non-payment of electricity bills or coupons?	Occasionally		Very Frequent	Frequent	Rarely	Never

SECTION C: ADOPTION OF HARNESSED ENERGY SUPPLY

1. Are you aware of harnessed energy sources like solar or wind for farm operations?	Yes		No		
2. Have you adopted harnessed energy sources (e.g., solar or wind) on your farm?	Yes		No		
3. What influenced your decision to adopt harnessed energy sources?	Cost reduction	Reliability of energy supply	Environmental concerns	Other Farmers influence	Government incentives
4. What are the factors that influenced your decision not to adopt harnessed energy?	Lack of government/ Institutional support for funding	Insufficient training and information	High implementation/ adoption cost	Traditional energy preference	Social/ Peer Influence
5. What difficulties did you encounter while adopting the new practices?	High installation cost	Lack of technical knowledge	Lack of information on harnessed energy	Limited access to service providers	Other
6. Would you consider adopting harnessed energy sources in the future?	Yes		No		
7. If, yes, please elaborate.					

SECTION D: PRODUCTION EFFICIENCY

i. POULTRY (BROILERS) PRODUCTION (Weighted measure):

1.Quantity of Broiler produced per production Cycle (Numbers)					
2. How many labourers do you employ per day? (labour/s per day)					
3. Dosage of vaccine used per production cycle (In -Rand)					
4. Quantity of drugs/vitamins (Rand)					
5. Quantity of feed (kg)					
6. Initial flock size before sale (Number per head)					
7. Total amount of electricity energy source used (rand/Kilowatt)					
8. Total number of harnessed energy sources used (rand/kilowatt)					
9. Amount lost during the usage of conventional Energy					
10. Profit made during the usage of Conventional Energy (Rand)					
11. Total amount of lost during the usage of harnessed energy if applicable (Rand)					
12. Profit made during the usage of renewable energy (Rand)					
13. On a scale of 5, indicate the efficiency of the type of energy listed below	1	2	3	4	5
a. Conventional Energy					
b. Harnessed Energy					

ii. PRICE MEASUREMENT /COST

1. Minimum cost of poultry broiler production per farm in (Rands)	
2. Cost of flock size in R/number:(Rands)	
3. Cost of labour in R/man-day: (Rands)	
4. Cost vaccine of a in R/dose (Rands)	
5. Cost of drug/vitamin in R/g (Rands)	
6. Cost of feed in R/Kg (Rands)	
7. The total cost of electricity energy source used (Rands)	
8. Cost of total harnessed energy sources used (Rands)	

Thank you for participating in this research study. Your responses will help in understanding the role of energy in harnessing smallholder poultry farm productivity and efficiency.

Annexure 2

Model Information

Dependent Variable	Decision to adopt Harnessed energy[a]
Probability Distribution	Binomial
Link Function	Probit

a. The procedure models No as the response, treating Yes as the reference category.

Case Processing Summary

	N	Percent
Included	108	55,4%
Excluded	87	44,6%
Total	195	100,0%

Categorical Variable Information

			N	Percent
Dependent Variable	Decision to adopt Harnessed energy	No	52	48,1%
		Yes	56	51,9%
		Total	108	100,0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Covariate	Marital Status	108	1	4	1,75	,948
	Education	108	0	3	2,27	,621
	Access to credit/ funding	108	1	2	1,91	,291
	Access to extension services	108	0	1	,46	,501
	Access to infastructure	108	0	1	,82	,383
	Perception of harnessed energy	108	1	3	1,94	,835
	Are you aware of harnessed energy	108	0	1	,11	,316
	Access to informal market	108	1	2	1,29	,454
	Acess to fomal market	108	0	1	,71	,454
	What is your landsize	108	240	1200	457,78	273,617
	Would you consider adopting harnessed energy sources in the future	108	0	1	,23	,424
	Awareness of harnessed energy	108	0	1	,91	,291
	what influenced your decision to not adopt harnessed energy	108	0	4	1,05	1,377
	What influenced your decision to adopt harnessed energy	108	0	4	1,02	1,245
	Have you ever adopted harnessed energy	108	1	2	1,90	,304
	Powercut or intersuptions experienced	108	0	4	1,55	,858
	Source of income	108	0	3	1,77	,871
	Farmers monthly income	108	0	3	2,04	,946
	Farming Experience	108	0	2	,27	,504
	Family Size	108	0	3	1,22	,989
	Age	108	1	6	3,74	1,525
	Gender	108	1	2	1,56	,499

Goodness of Fit[a]

	Value	df	Value/df
Deviance	132,051	97	1,361
Scaled Deviance	132,051	97	
Pearson Chi-Square	106,444	97	1,097
Scaled Pearson Chi-Square	106,444	97	
Log Likelihood[b]	-66,026		
Akaike's Information Criterion (AIC)	154,051		
Finite Sample Corrected AIC (AICC)	156,801		
Bayesian Information Criterion (BIC)	183,555		
Consistent AIC (CAIC)	194,555		

Dependent Variable: Decision to adopt Harnessed energy
Model: (Intercept), Age, Family Size, Farming Experience, Farmers monthly income, Powercut or intersuptions experienced , Have you ever adopted harnessed energy, Perception of harnessed energy, Are you aware of harnessed energy, What influenced your decision to adopt harnessed energy, Would you consider adopting harnessed energy sources in the future[a]

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
17,520	10	,064

Dependent Variable: Decision to adopt Harnessed energy
Model: (Intercept), Age, Family Size, Farming Experience, Farmers monthly income, Powercut or intersuptions experienced , Have you ever adopted harnessed energy, Perception of harnessed energy, Are you aware of harnessed energy, What influenced your decision to adopt harnessed energy, Would you consider adopting harnessed energy sources in the future[a]

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects

	Type I			Type III		
Source	Wald Chi-Square	df	Sig.	Wald Chi-Square	df	Sig.
(Intercept)	,098	1	,755	2,772	1	,096
Age	,825	1	,364	2,484	1	,115
Family Size	1,817	1	,178	2,282	1	,131
Farming Experience	,212	1	,646	,356	1	,551
Farmers monthly income	1,089	1	,297	,902	1	,342
Powercut or intersuptions experienced	3,084	1	,079	3,007	1	,083
Have you ever adopted harnessed energy	3,346	1	,067	3,599	1	,058
Perception of harnessed energy	3,268	1	,071	3,731	1	,053
Are you aware of harnessed energy	1,497	1	,221	1,203	1	,273
What influenced your decision to adopt harnessed energy	4,145	1	,042	4,078	1	,043
Would you consider adopting harnessed energy sources in the future	,000	1	,987	,000	1	,987

Dependent Variable: Decision to adopt Harnessed energy
Model: (Intercept), Age, Family Size, Farming Experience, Farmers monthly income, Powercut or intersuptions experienced , Have you ever adopted harnessed energy, Perception of harnessed energy, Are you aware of harnessed energy, What influenced your decision to adopt harnessed energy, Would you consider adopting harnessed energy sources in the future

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
(Intercept)	1,769	1,0624	-,313	3,851	2,772	1	,096	5,865	,731	47,059
Age	,144	,0915	-,035	,324	2,484	1	,115	1,155	,965	1,382
Family Size	-,219	,1447	-,502	,065	2,282	1	,131	,804	,605	1,067
Farming Experience	-,163	,2736	-,700	,373	,356	1	,551	,849	,497	1,452
Farmers monthly income	-,135	,1424	-,414	,144	,902	1	,342	,873	,661	1,155
Powercut or intersuptions experienced	-,274	,1583	-,585	,036	3,007	1	,083	,760	,557	1,036
Have you ever adopted harnessed energy	-,937	,4938	-1,904	,031	3,599	1	,058	,392	,149	1,032
Perception of harnessed energy	,313	,1619	-,005	,630	3,731	1	,053	1,367	,995	1,878
Are you aware of harnessed energy	,505	,4609	-,398	1,409	1,203	1	,273	1,658	,672	4,091
What influenced your decision to adopt harnessed energy	-,218	,1080	-,430	-,006	4,078	1	,043	,804	,651	,994
Would you consider adopting harnessed energy sources in the future	,005	,3062	-,595	,605	,000	1	,987	1,005	,551	1,831
(Scale)	1[a]									

Dependent Variable: Decision to adopt Harnessed energy
Model: (Intercept), Age, Family Size, Farming Experience, Farmers monthly income, Powercut or intersuptions experienced , Have you ever adopted harnessed energy, Perception of harnessed energy, Are you aware of harnessed energy, What influenced your decision to adopt harnessed energy, Would you consider adopting harnessed energy sources in the future

a. Fixed at the displayed value.

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
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Age	,144	,0915	-,035	,324	2,484	1	,115	1,155	,965	1,382
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Would you consider adopting harnessed energy sources in the future	,005	,3062	-,595	,605	,000	1	,987	1,005	,551	1,831
(Scale)	1[a]									

Dependent Variable: Decision to adopt Harnessed energy
Model: (Intercept), Age, Family Size, Farming Experience, Farmers monthly income, Powercut or intersuptions experienced , Have you ever adopted harnessed energy, Perception of harnessed energy, Are you aware of harnessed energy, What influenced your decision to adopt harnessed energy, Would you consider adopting harnessed energy sources in the future

a. Fixed at the displayed value.

Ranks

	Mean Rank
Lack of Funds	3,77
Lack of Government Support	3,94
Lack of Technical Know How	4,11
High Cost of Maintenance	4,07
Trans High Electricity Tarrifs	3,84
High Cost of Production	4,28
Theft (Stocl, equipment, electricity cable)	3,99

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Lack of Funds	108	3,39	1,471	1	6
Lack of Government Support	108	3,56	1,202	1	5
Lack of Technical Know How	108	3,65	1,369	1	5
High Cost of Maintenance	108	3,66	1,129	1	5
Trans High Electricity Tarrifs	108	3,49	1,322	1	5
High Cost of Production	108	3,76	1,151	1	5
Theft (Stocl, equipment, electricity cable)	108	3,64	1,286	1	5

Test Statistics

N	108
Kendall's W[a]	,008
Chi-Square	5,040
df	6
Asymp. Sig.	,539

a. Kendall's Coefficient of Concordance

```
Stoc. frontier normal/half-normal model          Number of obs     =        108
                                                 Wald chi2(5)      =      69.33
Log likelihood = -23.666285                      Prob > chi2       =     0.0000
```

Output_A	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Labour_A	.4169743	.0575296	7.25	0.000	.3042183	.5297303
CostHarnessEnergy	.0983004	.0403873	2.43	0.015	.0191429	.177458
Age_A	-.3693334	.1740801	-2.12	0.034	-.710524	-.0281427
Gender_A	.0366281	.2079246	0.18	0.860	-.3708967	.4441528
MaritalStatus	.1582977	.1597272	0.99	0.322	-.1547618	.4713572
QuantityHarnessenergy	0	(omitted)				
_cons	1.91108	.4356253	4.39	0.000	1.05727	2.764889
/lnsig2v	-2.399632	.1364004	-17.59	0.000	-2.666972	-2.132292
/lnsig2u	-12.22921	475.3527	-0.03	0.979	-943.9034	919.445
sigma_v	.3012497	.0205453			.2635569	.344333
sigma_u	.0022104	.5253487			1.1e-205	4.5e+199
sigma2	.0907562	.0124385			.0663772	.1151353
lambda	.0073373	.5271427			-1.025843	1.040518

```
LR test of sigma_u=0: chibar2(01) = 0.00              Prob >= chibar2 = 1.000

. predict tef, te
variable tef already defined
r(110);

. sum tef
```

Variable	Obs	Mean	Std. Dev.	Min	Max
tef	108	.9902741	.0000874	.9899574	.9905672

```
. predict efficiency, te

. egen fegrp= cut(efficiency), at(0,.3,.6,.9,1)

. tab fegrp
```

fegrp	Freq.	Percent	Cum.
.9	108	100.00	100.00
Total	108	100.00	

```
. egen fegrp= cut(efficiency), at(0,3,6,.9,1)
variable fegrp already defined
r(110);

. log close
      name:  <unnamed>
       log:  C:\Users\40018059\Desktop\New folder\SFPA.smcl
  log type:  smcl
 closed on:   1 Oct 2025, 13:22:03
```