# Integrating Renewable Energy at the the Kgora Farmer's Training Center

By

Vinicius Briganti, Rachel Kaup, and Jack Teener

A project submitted in partial fulfillment of the requirements for the degree of Master of Science (Environment and Sustainability) in the University of Michigan
April 2022

# ABSTRACT

In 2019, a partnership was established between the Kgora Farmer Training Center in Mahikeng, South Africa, and the Sustainability Without Borders group at the University of Michigan's School for Environment and Sustainability. The partnership at the time uncovered a ripe opportunity for implementing renewable energy at Kgora as a means to support economic growth through more reliable income activities, reduce electricity expenses, and demonstrate renewable energy practices for local small- and medium-scale farmers. Additionally, the University of Michigan team secured funding from the Institute for Research on Women and Gender to study the unique challenges faced by women in agriculture and understand their interest in renewable energy. The scope of this project is designed to assess the resource potential of a renewable energy system, model the financial outlook of such a system, and understand perceptions around renewable energy from local farmers. The model demonstrates financially optimized renewable energy system size based on real load data from Kgora and parameters gathered through stakeholder engagement and research. The financially optimal system size would be a 27.6 kW photovoltaic system paired with 8 kWh of battery storage and 30 kW of biomass gasification capacity. Using the UN's Bioenergy and Food Security approach and information from Kgora staff, storage and labor costs associated with the biomass feedstock supply chain were estimated to amount to $17.5 per metric ton of feedstock. A sensitivity analysis of the energy model demonstrated that the levelized cost of electricity would improve upon the business-as-usual case for feedstock costs between $10-20 per metric ton. With the goal to act as a renewable energy demonstration site for local farmers, the survey results indicate that sunflowers and maize are likely the most promising feedstocks and that nearly all farmers interviewed have some interest in implementing renewable energy into their practices in order to reduce long-term costs and improve electricity reliability.

# ACKNOWLEDGEMENTS

The team would like to acknowledge the extensive support provided by Professors Jose Alfaro and Aline Cotel. Project transition was supported a great deal by previous SEAS students Julia Magee and Adriane Kline. Kgora Head Manager Thuthukani Hlangu has been a fierce advocate for implementing renewable energy and an incredibly supportive partner. The project as it currently stands would not have been possible without the partnerships formed with residents of Mahikeng. Professor Simon Letsoalo of North West University, Wisdom Matsheka of the Department of Agriculture, and Mr. Skweyiya of the Department of Agriculture in particular acted as critical movers of project inputs. The team would like to thank all the local farmers who were willing to speak to us about their hopes, desires, setbacks, and perspectives.

# TABLE OF CONTENTS

# 1. Introduction

The Kgora Farmer Training Centre ("Kgora"), located in Mahikeng in the North West Province of South Africa, is a government institution managed under the Department of Agriculture and Rural Development. Kgora is dedicated to, and accredited solely for, the development, empowerment, and training of farmers.[1] Training at Kgora takes various forms from theoretical to practical training. Kgora devotes significant attention to hands-on intensive training where farmers are housed at Kgora to gain exposure to real production cycles. Kgora extends a radius of support that ranges about 40 km and includes 138 villages. In the past year, Kgora provided training for approximately 2,000 farmers across the entire country. Recently, Kgora has also committed to supporting 600 families in the region through food production.

Kgora acts as a support network for livelihood and income with immense opportunity to improve common struggles faced by farmers. For instance, high electricity rates and lack of grid reliability are a financial energy burden that has historically been increasing, cutting directly into the development and empowerment of local farmers. In 2021 alone, Kgora suffered from the equivalent of 27 full days of blackouts. Such loss of electricity is reported by Kgora staff to lead to major losses of income. For instance, in one day of load shedding, Kgora can lose up to 6,000 chicken eggs and 800 chickens and be forced to shut down abattoir operations at a steep loss. In order to prevent lost income, Kgora operates a diesel generator during periods of outages. Operating the generator is a significant cost for Kgora with fuel prices that continue to rise. Kgora currently pays about $1.30 per Liter of diesel to keep it operating.

Farmers in the Mahikeng area and throughout South Africa experience the same difficulties of astronomical electricity bills and random periods of load shedding that leave them helpless to livestock fatalities and unable to work. In a world where electricity has become just as integral an input as seed and fertilizer to a farm's success, small-scale farmers are kept from growing their farms and achieving their goals. To help both Kgora and these farmers, it was determined to turn Kgora into a renewable energy demonstration site. Becoming a demonstration site would allow Kgora to become much less reliant on costly diesel generators and unreliable grids. In addition, it becomes a place where farmers can see and learn how to integrate the technologies into their own farming practices.

This report details the design of a renewable energy system based around photovoltaics, gasification, and energy storage that is expected to make daily operations at Kgora less reliant on the grid. The system is expected to lower energy expenditures at Kgora. This report also details the analysis done to understand resource availability. Finally, the renewable energy system model is supplemented by the results of a survey designed to obtain insights into nearby farmer's common struggles and interest in renewable energy. As black female farmers in the region face among the highest historic disadvantages in careers in agriculture, surveying this population was of the utmost importance to project success. In the long term, the work completed in this project and future initiatives is expected to provide a meaningful demonstration of productive uses of renewable energy for farmers to learn from and potentially implement on their own farms, furthering Kgora's mission of empowerment and development.

[1]("Farmers")

## 2. Background

With a population of approximately 60 million people and a GDP of $368.3 billion,[2] South Africa is one of the most important economies in the African continent. The country is considered a great point of entry for "regional expansion," with excellent business opportunities in neighboring countries such as Zambia, Zimbabwe, Angola, Mozambique, and Botswana. South Africa has a productive and diverse agricultural system with approximately 32,000 commercial farmers, of which between 5,000 and 7,000 produce approximately 80 percent of agricultural output. The agricultural sector plays a major role in South Africa's economy, with a diverse production that includes all the major grains (except rice), oilseeds, deciduous and subtropical fruits, sugar, citrus, wine, and most vegetables. Livestock production includes cattle, dairy, hogs, sheep, and a well-developed poultry and egg industry.[3] Value-added activities in the sector include slaughtering, processing, and preserving of meat; processing and preserving of fruit and vegetables; dairy products; grain mill products; crushing of oilseeds; prepared animal feeds; sugar refining and cocoa, chocolate, and sugar confectionery amongst other food products. In 2020 alone, the sector represented a year-over-year growth rate of 13.1%, reaching $10.2 billion worth of exports. With this increase, there is an imminent growing demand to improve subsistence farming or informal small-scale farming in South Africa. Forecasts show that the country's economic growth will remain under pressure, as consumers spend less money because of a contracted economy and higher inflation over the last year. Investment in agriculture and new policies are widely recognized as key preconditions in achieving goals related to creating jobs, improving food security, generating wealth, and thereby reducing poverty. There are additional challenges that the farming sector faces, such as weak global growth, domestic input costs, the impact of Covid-19, policy uncertainty, and the electricity access in the country.

Problems with power supply in the country are extensive coal dependence, prices, lack of a formal billing system from the utility, and grid reliability being the most important ones. The total electricity capacity installed in the country is close to 58 GW, with thermal resources representing 48.3 GW (approximately 83% of the total generation). When it comes to grid reliability, the situation is concerning as the grid had a record of 1,150 hours of power outages in 2020.

This report addresses current farmer's challenges and models a microgrid intervention using a combination of three technologies: a biomass gasifier, solar panels, and battery storage. A microgrid is a group of distributed energy resources connected to a controllable local energy grid that might or might not be connected to the grid, but give autonomy to the owner to operate as they see fit[4]. The microgrid will help farmers to generate their own electricity with sunlight and their crop residues in a cheaper way, reducing their dependency on the grid and exposure to power outages. The feasibility of implementing the technology is also assessed through the lens of resource and land availability and labor, storage, and supply chain parameters.

[2] ("Power Africa")
[3] ("South Africa")
[4] ("How")

# 3. Methods

Recommendations for a renewable energy system at Kgora require robust methods for system sizing as well as an assessment of capacity to maintain and run the system. The recommendations are also meant to provide a preliminary analysis of how other smallholder farmers may pursue their own renewable energy systems and the barriers they may face.

### *3.1 Resource Assessment: Bioenergy and Food Security Approach*

Production of bioenergy requires careful consideration for the tradeoff between food and fuel as well as considerations around risks and synergies. The Food and Agricultural Organization of the United Nations (FAO) has developed a support package for Decision-Making for Sustainable Bioenergy.[5] The package is designed to be modular, such that different elements can be used independently or in tandem to assess bioenergy development. The Bioenergy and Food Security (BEFS) approach is meant for countries to assess large-scale implementation of bioenergy production and biomass supply chains.

For the scope of this project, the BEFS approach was utilized to guide quantification of critical considerations for implementing bioenergy at Kgora. Specifically, the BEFS Gasification Tool is meant to “assist the user in evaluating the potential to develop biomass gasification to supply electricity in rural areas without current access to electricity and where extension of the national grid is not feasible.”[6] The outputs of the Tool that were deemed to be relevant to this project are the estimated cost of feedstock collection & storage, cost of labor, and a feedstock availability assessment. The boundary of the analysis is shown in Figure 1 below.

[5] (“Bioenergy”)
[6] (“Bioenergy and”)

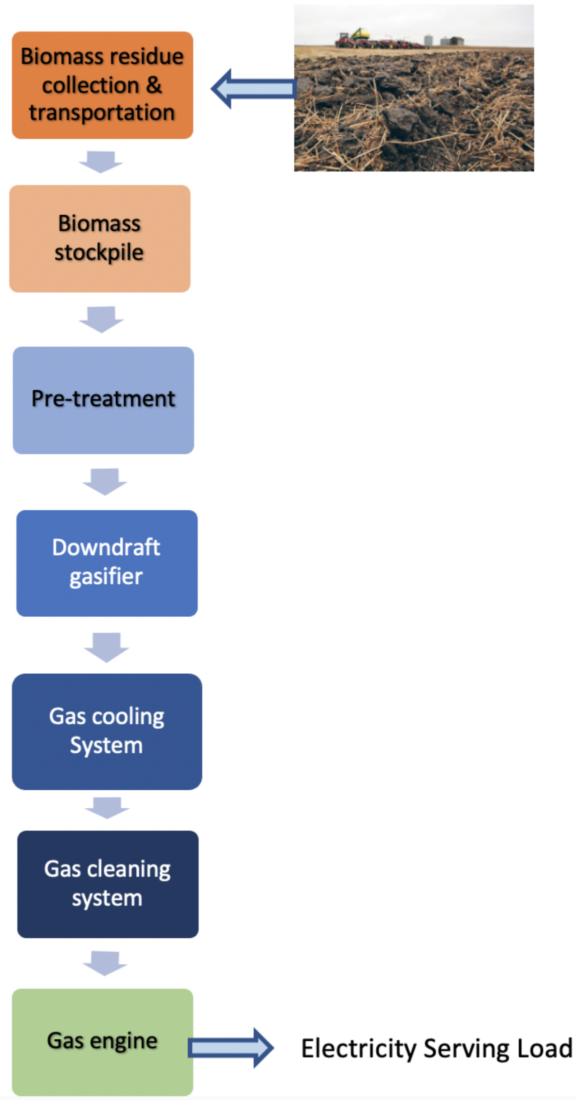



Fig. 1. The Food and Agriculture Organization of the United Nations' Bioenergy and Food Security approach gasification framework. The scope of this analysis goes beyond the interests of the project, considering the use of exclusively agricultural residue, smaller scale gasification, and use of resources that are already on-site.

The tool starts with the input of agricultural components. A specific feedstock to be studied is selected. For the purposes of this project, it is assumed that the feedstock in question is maize stover which is known to be available on Kgora's property. An annual energy load is entered, which was drawn from the energy load determined by the 2021 energy meter data for the HOMER Pro model. The source of biomass and collection method is entered. In this case, maize stover is assumed to be spread in the field and subsequently collected using mechanized means. An estimate of the number of skilled workers, their wages, fuel economy of the machines, area of the crop in question, and estimated tons of residue per acre. These variables are displayed in Table 1 below.

Table 1. Parameters used in the BEFS framework.

| **Parameter** | Number of skilled workers | Wages for skilled workers | Fuel economy of machines | Cost of diesel ($/L) | Area of maize growth (ha) | Tons of residue per hectare |
|---|---|---|---|---|---|---|
| **Value** | 5 | $8.50/hr | 20 L/hr | 1.3 | 120 ha | 87 ton/ha |
| **Notes** | | Reported value from Kgora staff | Reported values from Kgora staff | Reported values from Kgora staff | Reported value from Kgora staff | Assuming a 25% safety factor for residue used for other purposes |

Next, parameters are entered to determine storage cost estimates. Figure 2 below contains information entered for this purpose; Kgora harvests maize once per year in May, and the "storage safety rate" is meant to provide a minimum storage capacity at all times of the year to ensure consistent resource availability. The value is recommended by the UN FAO to be 25%.

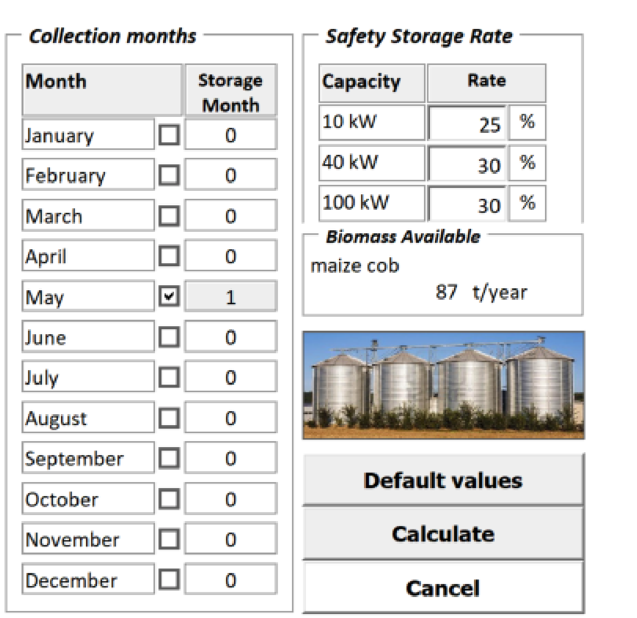



Fig. 2. Storage planning calculator values used within the BEFS approach.[7]

## *3.2 Model*

Hybrid Optimization of Multiple Electrical Renewables (HOMER Pro®) is a micro power optimization model that simplifies the evaluation of off-grid or grid-connected renewable energy power systems. The software is capable of designing, planning, and simulating a financially optimal microgrid layout equipped with multiple renewable energy sources. The greatest strength of the software is its ability to calculate the optimal cost for fulfilling a given electrical load. The model can be tested under various constraints and conditions including, but not limited to, resource supply availability, cost sensitivity, varying base load conditions, and minimum renewable energy penetration levels. The specific components included in the model are up to

[7] ("Rapid")

the discretion of the user, and the components used for this project are discussed in section 3.1.1 below. The general flow of building a HOMER model is displayed in Figure 3 below.[8]

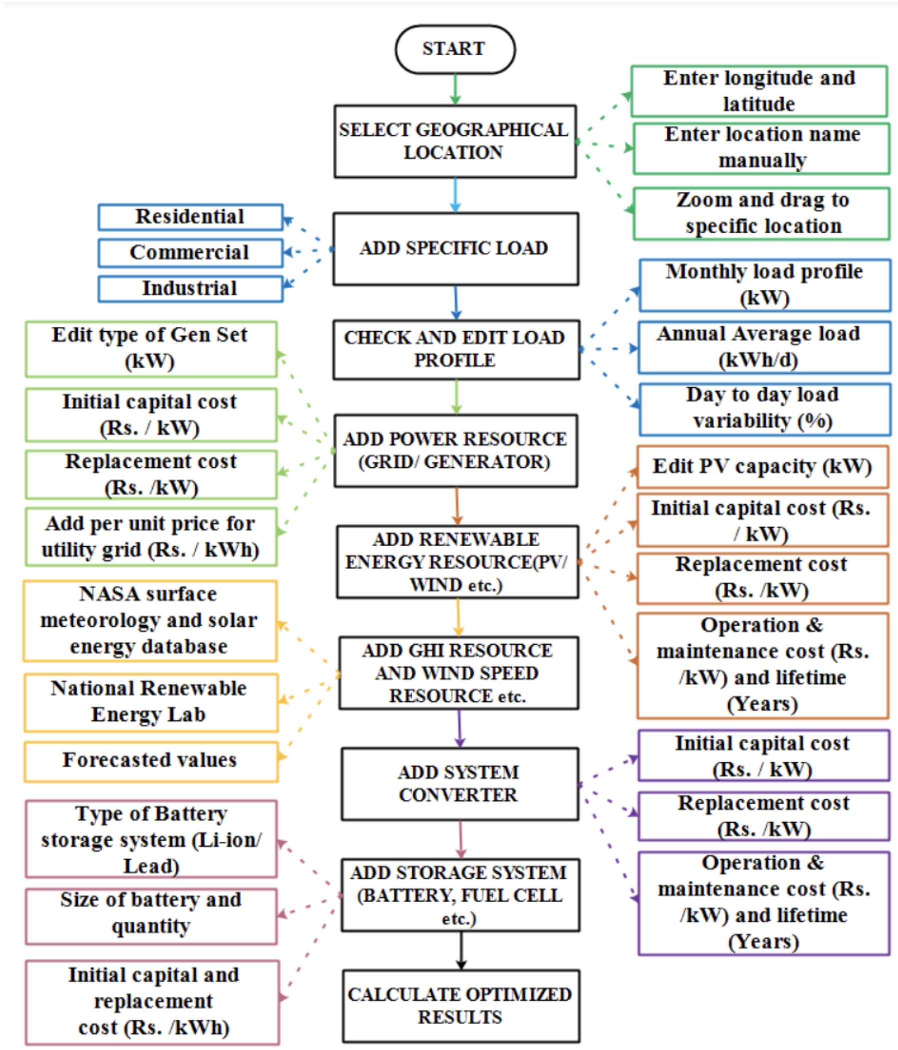



Figure 3. Flowchart of a HOMER Pro model.

Within the flowchart, solid lines represent major steps that are needed in developing the model while the dotted lines are additional inputs that may be considered. First, the user must add the specific geographic location to be modeled, in this case the exact location of Kgora. Next, the load to be analyzed is input. Power resources and their respective parameters are then added, both in terms of grid electricity, generators, and renewable energy resources. A converter module must also be added to account for the hybrid nature of the system in using both AC and DC power resources. Finally, storage systems are added and optimized results are calculated for review by the user.

As with all models, the quality of outputs is only as good as the quality of inputs, and gathering the necessary microgrid inputs described in Section 3.3 below required careful extraction of

[8] (“Mehta”)

information through research and on-the-ground data gathering. Cost parameters were assessed according to cost estimates offered by specific providers and, in the case of components to be purchased in South Africa, according to best country-specific estimates. HOMER Pro runs its optimization according to geographic specifications to ensure accurate renewable energy resource estimates. The energy load at Kgora is known at every hour for the year 2021 thanks to the installation of a PowerStar Energy Meter, which also provided detailed information on load shedding and outages at Kgora. The biggest source of uncertainty in the model is the cost of electricity from Eskom; energy bills at Kgora do not provide a detailed breakdown of charges and energy demand. Moreover, Kgora staff relayed disbelief in the accuracy of the published 2021 Eskom electricity rates, stating they have paid more per month than what is published.[9] The iteration of the HOMER Pro model discussed here uses the 2021 Eskom rates, but a future update might include a more accurate estimate of electricity prices which might make the renewable energy system more desirable.

### 3.2.1 Microgrid Components

Solar, battery, and biomass power generation are cited as logical inclusions in a renewable energy system in the context of agriculture.[10] Solar generation is a staple of microgrid layouts. Biomass power uses organic material to produce usable energy through a variety of processes. Gasification is the thermochemical conversion of biomass chemical energy into synthesis gas or "syngas."[11] The syngas can be used in a common diesel/petrol generator like the one used at Kgora as a backup during periods of load shedding. Batteries are included due to their well-documented benefits for renewable energy systems. Such benefits include increasing flexibility and combating the uncertain and variable nature of renewable energy generators.[12] The component layout is visualized in Figure 4 on page 11 below, with visualizations taken from the HOMER Pro interface.[13]

[9] ("Tariffs and Charges - Distribution")
[10] ("Chel")
[11] ("Biomass")
[12] ("Boost")
[13] ("Homer Pro")

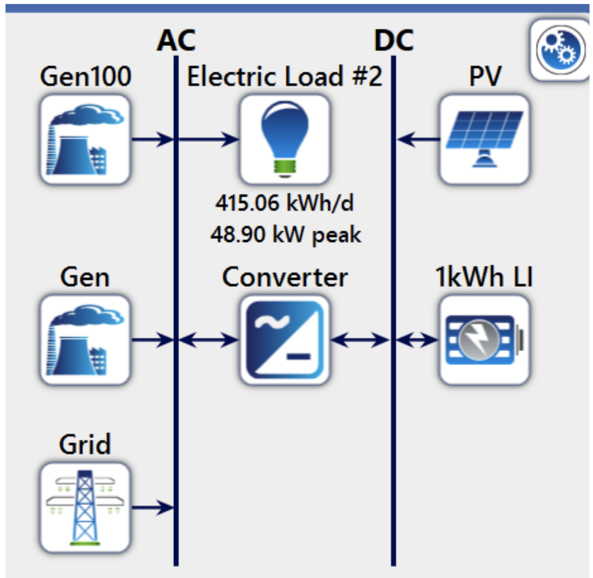



Fig. 4. Layout of the proposed microgrid system.

### 3.2.2 Model Parameters

The following section details the parameters used in HOMER Pro and where they came from.

*3.2.2.1 Identifying Energy Load*

In 2020, an energy meter was installed at Kgora's property. The meter uses PowerStar software to provide hourly load data for the entire property across every hour of the year. As such, the energy load for every hour of the year 2021 was drawn from the meter data and input into HOMER Pro. The energy load data also provided information on load shedding and outages. The load data is visualized in Figure 5 below.

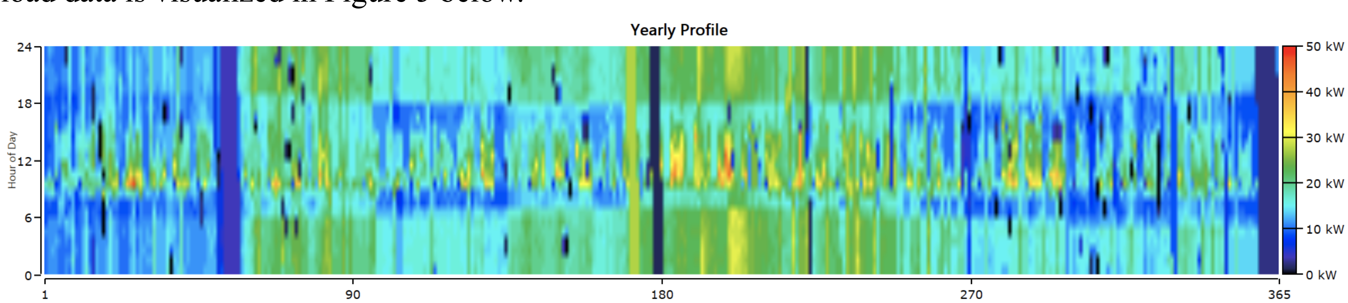



Fig. 5. Kgora's energy load data for every hour of the year 2021. Days of the year are on the x-axis while hours of the day are on the y-axis. Average energy load was 17.29 kW, with an average demand of 415.06 kWh/day and a peak load of 48.9 kW.

*3.2.2.2 Electricity Grid*

The electricity grid portion of the model requires grid power prices (including time-of-use rates), grid sellback prices, reliability estimates, and emissions factors.

Electricity at Kgora is provided by the South African national public utility, Eskom. Grid power prices are determined by Eskom's rate case updates which are published every year. As load data in the model was from the year 2021, 2021 rates were used. Specifically, the electricity rates used correspond to the "RURAFLEX- Local Authority Charges" tariff.[14] The tariff amounts are shown below in Table 2.

Table 2. Eskom 2021 "Ruraflex - Non-local Authority" charges for electricity used in the HOMER Pro model.[15]

**Ruraflex - Non-local Authority**

| Transmission zone | Voltage | Active energy charge [c/kWh] | | | | | | | | | | | | Network capacity charges [R/kVA/m] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | High demand season [Jun - Aug] | | | | | | Low demand season [Sep - May] | | | | | | | |
| | | Peak | | Standard | | Off Peak | | Peak | | Standard | | Off Peak | | | |
| | | | VAT incl | | VAT incl | | VAT incl | | VAT incl | | VAT incl | | VAT incl | | VAT incl |
| ≤ 300km | < 500V | 375.58 | 431.92 | 113.78 | 130.85 | 61.80 | 71.07 | 122.52 | 140.90 | 84.31 | 96.96 | 53.49 | 61.51 | R 21.69 | R 24.94 |
| | ≥ 500V & ≤ 22kV | 371.87 | 427.65 | 112.66 | 129.56 | 61.17 | 70.35 | 121.32 | 139.52 | 83.48 | 96.00 | 52.94 | 60.88 | R 19.88 | R 22.86 |
| > 300km and ≤ 600km | < 500V | 379.35 | 436.25 | 114.92 | 132.16 | 62.41 | 71.77 | 123.74 | 142.30 | 85.17 | 97.95 | 54.04 | 62.15 | R 21.75 | R 25.01 |
| | ≥ 500V & ≤ 22kV | 375.57 | 431.91 | 113.77 | 130.84 | 61.80 | 71.07 | 122.52 | 140.90 | 84.30 | 96.95 | 53.49 | 61.51 | R 20.00 | R 23.00 |
| > 600km and ≤ 900km | < 500V | 383.15 | 440.62 | 116.08 | 133.49 | 63.03 | 72.48 | 124.99 | 143.74 | 86.01 | 98.91 | 54.58 | 62.77 | R 21.87 | R 25.15 |
| | ≥ 500V & ≤ 22kV | 379.33 | 436.23 | 114.90 | 132.14 | 62.41 | 71.77 | 123.74 | 142.30 | 85.17 | 97.95 | 54.04 | 62.15 | R 20.09 | R 23.10 |
| > 900km | < 500V | 386.97 | 445.02 | 117.23 | 134.81 | 63.65 | 73.20 | 126.19 | 145.12 | 86.87 | 99.90 | 55.12 | 63.39 | R 21.96 | R 25.25 |
| | ≥ 500V & ≤ 22kV | 383.14 | 440.61 | 116.08 | 133.49 | 63.03 | 72.48 | 124.99 | 143.74 | 86.01 | 98.91 | 54.58 | 62.77 | R 20.10 | R 23.12 |

| Customer categories | Service charge [R/account/day] | | Administration charge [R/POD/day] | |
|---|---|---|---|---|
| | | VAT incl | | VAT incl |
| ≤ 100 kVA | R 21.34 | R 24.54 | R 6.06 | R 6.97 |
| > 100 kVA & ≤ 500 kVA | R 72.76 | R 83.67 | R 33.74 | R 38.80 |
| > 500 kVA & ≤ 1 MVA | R 223.85 | R 257.43 | R 51.78 | R 59.55 |
| > 1 MVA | R 223.85 | R 257.43 | R 96.08 | R 110.49 |
| Key customers | R 4 387.25 | R 5 045.34 | R 96.08 | R 110.49 |

| Voltage | Ancillary service charge [c/kWh] | | Network demand charge [c/kWh] in all time-of-use periods | |
|---|---|---|---|---|
| | | VAT incl | | VAT incl |
| < 500V | 0.48 | 0.55 | 30.88 | 35.51 |
| ≥ 500V & < 22kV | 0.48 | 0.55 | 27.07 | 31.13 |

| Reactive energy charge [c/kVArh] | | | |
|---|---|---|---|
| High season | | Low season | |
| | VAT incl | | VAT incl |
| 10.43 | 11.99 | 0.00 | 0.00 |

Power that is sold back to the grid (by, for instance, a renewable energy generator on a property that cannot consume all the produced electricity) is compensated according to the feed-in tariff set by Eskom. Customers obtain a rate of $0.049/kWh for sell-back electricity.[15] Emissions factors were determined by a study on Eskom power production in 2017; values are not available for the year 2021, but are believed to not have changed dramatically since 2017. Emissions intensities are as follows: 1,088.25 grams of $CO_2$/kWh, 0.38 grams of particulate matter/kWh, 4.22 grams of $NO_x$/kWh, and 7.84 grams of $SO_2$/kWh.[16] Finally, load data collected from the PowerStar meter provided information on load shedding and blackouts, which was entered into the *reliability* section of HOMER Pro's grid electricity inputs. Load outage data is represented in Figure 6 on page 13.

14 ("Tariffs")
15 ("You can sell")
16 ("Cairncross")

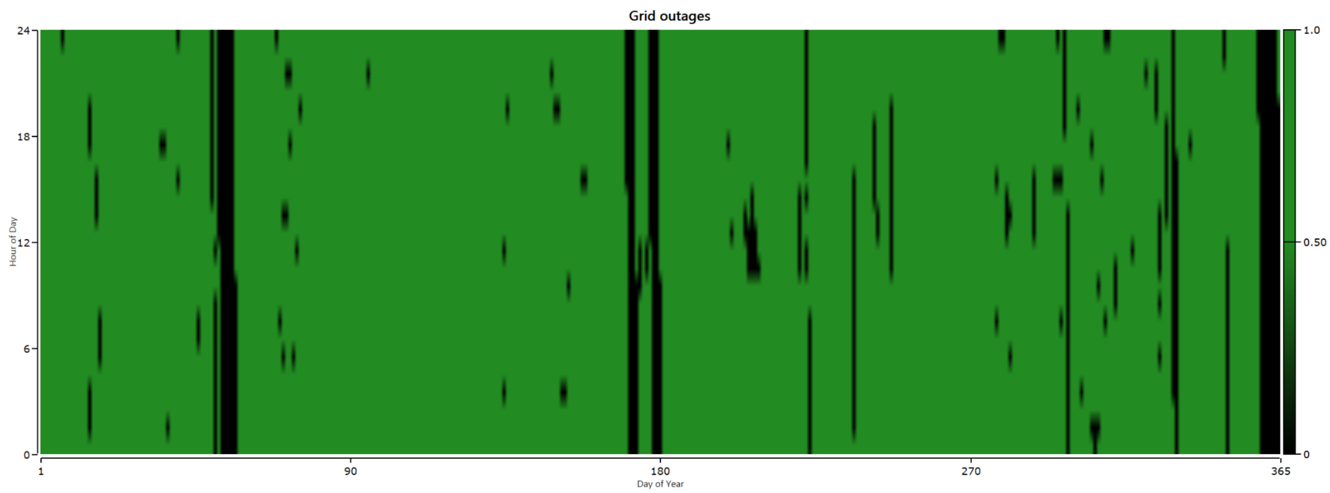


Fig. 6. Grid outages during the year 2021 at Kgora. This information was entered into the reliability input section of the HOMER Pro model.

### *3.2.2.3 Photovoltaics*

Financial parameters were input into the photovoltaic system information section of HOMER Pro. All of the information was drawn from the IRENA Power Generation Costs report for the year 2020 (2021 information has not been published at the time of this report).[17]

Table 3. PV components financial information.

| | |
|---|---|
| PV Replacement Cost | $845.75/kW |
| PV Capital Cost | $995/kW |
| PV Lifetime | 25 years |
| PV O&M | $9.95/yr |
| PV Derating Factor | 80% |

### *3.2.2.4 Battery*

Financial parameters were input into the battery information section. All of the information was drawn from the US Department of Energy energy storage costs report for the year 2018 (2021 information has not been published at the time of this report).[18]

[17] ("Irena")
[18] ("Mongrid")

Table 4. Battery components information.

| | |
|---|---|
| Battery Capital Cost | $271/kWh |
| Battery voltage | 6 V |
| String voltage | 6 V |
| Nominal capacity | 1 kWh |
| Minimum state of charge | 40% |
| Battery O&M | $5.42/yr |

*3.2.2.5 Gasifier System*

Gasifier system information was taken from laboratory experiments and data collected by the project Microgrids from Biomass for an Agricultural Circular Economy, led by Dr. Jose Alfaro. Biomass feedstocks were initially assumed to cost $10/tonne.

Table 5. Gasifier and generator system cost information.

| | |
|---|---|
| Capital Cost | $2500/kW |
| Replacement Cost | $450 |
| O&M | $0.020 |

*3.2.2.6 Converter*

The converter is used for translating between AC/DC power within the renewable energy system. Financial information was entered into HOMER Pro in accordance with U.S. solar converter cost benchmarking estimates.[19]

Table 6. Converter financial parameters.

| | |
|---|---|
| Converter Capital Cost | $183/kW |
| Converter Lifetime | 15 |

## *3.3 Survey*

Beyond a financial optimization model, factors such as perceptions around renewable energy, resource availability, and labor inputs will inform the success of any renewable energy project. A survey was developed for the purposes of assessing farmer experiences and interest, supplementing the resource assessment, and understanding gender in the agriculture industry.

[19] (“Fu”)

#### 3.3.1 Survey Design

All survey participants were individuals whose primary livelihoods are in the agriculture sector. The surveys were conducted in the English Language. While recognizing that many small scale farmers in this informal sector diversify their income through the dry season and other periods of low revenue, the focus was on those who depend on farming practices for their income. Special consideration was given to unique challenges faced by different individuals within the sample, such as women. Thus, the survey gathered the participant's sex, income level, education level, and other demographics. A total of 33 surveys were administered and enabled participants to provide their contact information should they be interested in participating in longer, semi-structured interviews in the future. This survey takes approximately 20 minutes. The survey covers basic demographics and then asks questions about the following topics: farming practices, financial aspects, water needs, energy needs, challenges and opportunities, and future engagement with the team.

To be included in this study, the survey participant must be 18 years of age and have an affiliation with farming. Study participants were excluded from the study if they were not 18 years of age. Participants were guided through a consent process prior to participating in this study. They were reminded participation within the study is optional and that they could opt out or skip questions at any time. The team members and the PI are the only people with access to the data. IRB approval was completed for implementation of the study in February 2022. The final survey instrument and collected results can be seen in Appendix A.

#### 3.3.2 Survey Implementation & Analysis

The survey was administered through interviews conducted by project members with farmers within 40 kilometers of Kgora in South Africa. Project partner Wisdom Nsokolo, president of the Young Farmers Association, supported the recruitment of survey participants.  Through in-person interviews, paper documents, and online links a total of 33 surveys were completed. All survey responses were recorded in Qualtrics. The data was analyzed using the built-in Qualtrics analysis tools to draw conclusions around general trends and insights. Ultimately, analysis is expected to be completed using an open coding method in excel using the Rapid and Rigorous Qualitative Data Analysis ("RADaR") Technique. This method will ensure the codes created are driven by the data collected. At this point, a code book will be created by the researcher in partnership with experts in the field.This analysis will be completed by the next project team, likely another round of Master's students from SEAS, in the 2022-2023 school year.

# 4. Results

## *4.1 Resource Assessment & Supply Chain*

The results of the BEFS Gasification Tool approach offer insight into labor costs and storage options that will be needed upon operating the gasifier on Kgora's property. While the tool provides further insights, including cost of electricity produced and overall investment costs, the scope of these insights fall outside the scope of this project and are more relevant for the pursuit of large-scale gasification technology. Additionally, the HOMER Pro model already provides the framework to assess cost and investment decisions on a scale that matches this project.

With that in mind, carrying out the Gasification Tool approach provided the following information for project implementation. The estimated cost of storing the biomass, assuming the use of an enclosed structure to maintain dryness, is $13/ton of residue. The estimated cost of collecting the biomass, including labor payments and cost of fuel for mechanization, is $4.5/ton. Biomass should be collected upon harvesting in May and stored for use throughout the year, replenished if necessary with other biomass residues such as hay bales. Supplementing the BEFS tool results with field experience at Kgora provided an even clearer picture of resource availability. First, it was determined that biomass collection is already a part of their operations. Figures 7 & 8 below display two such resources. Grass is abundant on the property and must be mechanically collected to prevent overgrowth. These grass bales are currently used for various farming purposes and Kgora staff expressed interest in diverting the use for energy instead. Kgora uses three chicken layer houses to raise chickens and the sunflower husks are used as bedding which is replaced after the chickens are raised and disposed.


Figs. 7 & 8. Biomass resources already collected at Kgora. On the left, grass bales that are collected through mechanized means and baled for various assorted purposes. On the right, a chicken layer house that uses sunflower seed husks as bedding- once a month, the bedding is discarded and could instead be diverted to gasification.

Grass & leftover sunflower seeds are two biomass resources already integrated into the daily operations at Kgora and would provide reliable supply chains for gasification.

### *4.2 Model*

Figure 9 below shows the financially optimal system size for Kgora's energy load.

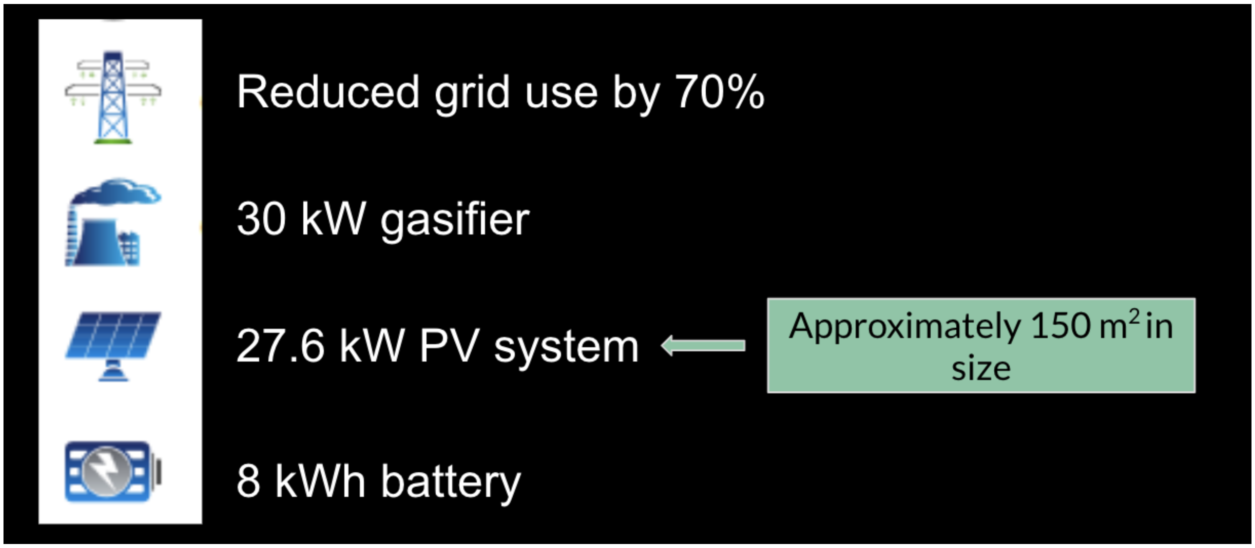



Fig. 9. The financially optimal system size for renewable energy at Kgora based on the parameters and load discussed in the Methods section.

While the proposed system will not reach 100% renewable energy penetration, the financial case is clearly beneficial in the long-run. The financial outlook is shown in Figures 10 and 11 below. This case assumes a price-per-ton of feedstock of $10/ton; according to the resource assessment carried out, maize cob feedstock would cost around $17.5/ton. Thus, sensitivity scenarios were carried out with varying feedstock costs, the results of which remain financially beneficial across the lifespan of the project. Sensitivity scenario results are shown in Appendix B.

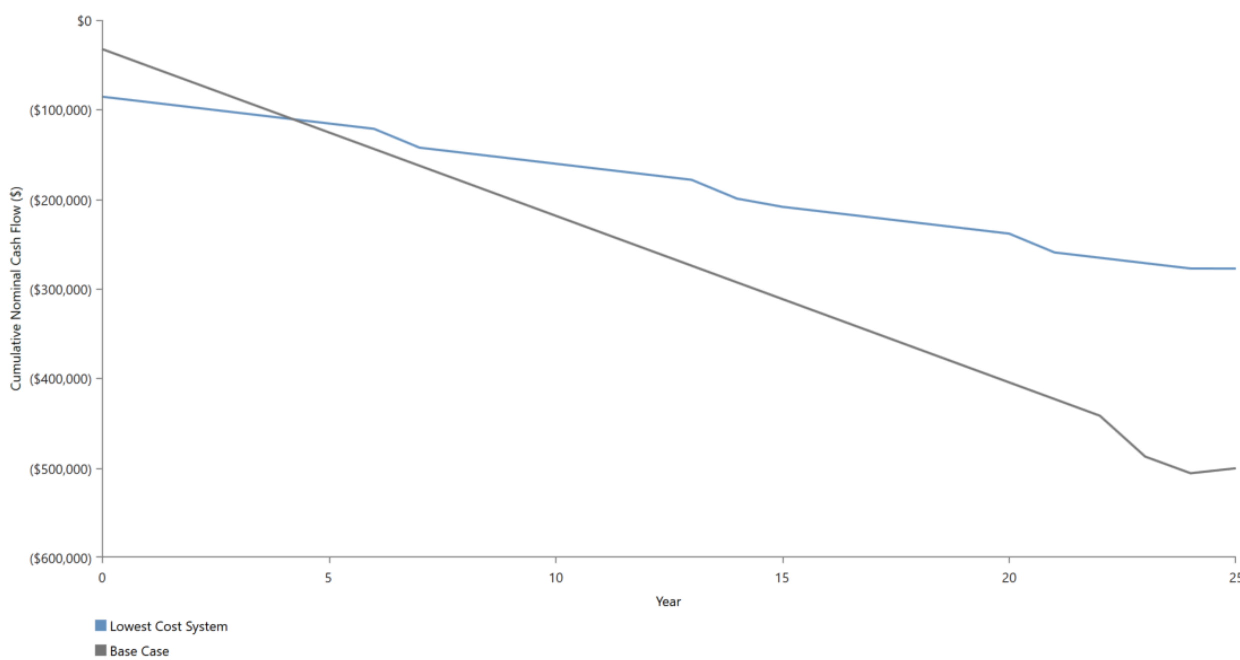



Fig. 10. The financial case for the proposed renewable energy system. The black line is the base case scenario, representing grid purchased electricity along with a diesel generator, while the blue line is the proposed system.

**Economic Metrics**

| | |
|---|---|
| IRR | 21% |
| ROI | 17% |
| Simple Payback | 4.2 yr |

Fig. 11. The economic metrics associated with the financially optimal renewable energy system.

With the proposed system, Kgora would pay back its investment within 4.2 years with a 17% return on investment. HOMER Pro also reports that the optimal system size would require 48.4 tons of feedstock per year. The previously discussed biomass feedstocks, grass bales and sunflower husks, are estimated to provide 20 tons of feedstock, assuming they are completely diverted from current uses. Thus, an additional 28.4 tons of feedstock would be required for the full system size. The resource assessment, paired with discussions with Kgora staff, indicate that additional feedstocks such as maize stover are likely readily available to use in gasification.

The sensitivity scenarios show that the financial outlook still remains promising with varying system sizes and biomass feedstock availability/price. For instance, in the case where biomass costs $20 per metric ton (and thus a more conservative estimate than the BEFS approach reported value of $17.5/ton) the investment is predicted to pay back in 6.5 years with an 11% return on investment.

### *4.3 Survey*

There was a diverse range of experiences & demographics among surveyed farmers. Of those who gave their age, 10 were between the ages of 20 and 49, while 12 were 50 and up. The majority of the farmers completed high school, with 13 of them reporting some sort of university education. Household size was typically around 5 people.

A purposeful attempt was made to ensure female farmers' voices were heard within this survey and that any gaps between life as a female farmer instead of male were understood. Of those who disclosed their gender, 19 were male and 9 were female. While very few answered gender related questions, all of those who did said they did not feel as though male and female farmers have the same access to government assistance, machinery, and the such. Most replied that farming tasks are seen as a responsibility for males only. Females who responded claimed they did not feel their community was supportive of female farmers and felt like the biggest challenge facing them was lack of experience and training.

When asking about farming practices, 15 of respondents owned the farm they worked on and 11 did not. The majority of the farms were in North West, with 2 in Eastern Cape and 1 in Free State. A wide range of experience was found with some having less than a year of experience and others having over 25 years of experience. Farm sizes were widespread as well, ranging from 2 hectares up to 1000 hectares with an average at 309 hectares. The range of farming products reported was sunflower, maize, soy, beans, groundnuts, vegetables, and livestock. The majority of farmers reported sunflower and maize as the main crops they grow. Not many were able to provide the exact amount of each crop grown, but a total of 450 hectares of sunflower, 200 hectares of maize, and 250 hectares of groundnuts were reported. About 69% of farmers reported harvesting only once a year, followed by 23% of vegetable farmers who harvest once a week. Many had difficulty reporting how much product they get from each harvest. Most of their plant waste comes in the form of stalks or stems from sunflower and maize, with maize being reported as the crop that produces the most waste. When asked if they would be interested in collecting crop waste to turn it into energy for their farms, 81% said yes. Most farms produced enough food to feed their family and were able to sell products like vegetables and livestock at markets. When looking to stay updated on farming practices, the majority of farmers look to farmers association and their peers, with most saying they talk to other farmers about practices once a week on average.

The financial section looked to gain insight on respondents' major farming related costs. In terms of needed labor, 9 respondents reported working over 60 hours each week. In terms of employees, 4 respondents said they employ 2 others with 8 employees being the most reported. About 33% of respondents claimed fuel/electricity was the most costly thing on their farm, followed by fertilizer at 21%. Most farmers' highest portion of their revenue comes from their livestock. Of those who knew the approximate annual cost of operating their farm, a minimum of 5,000 South African Rand was reported ranging up to a maximum of 750,000 Rand for an average at 258,933 Rand. 11 out of 15 responses reported spending over 60% of that income on their energy needs with one person claiming as high as 90%. This led 22 out of 24 respondents to agree or strongly agree with the statement, "I spend too much of my income on energy." When asked if they would be willing to invest in renewable energy if over the long term it lowered their overall farming costs, 23 respondents answered yes with only 2 with no. If they had unrestricted access to energy, most farmers said they would use it for irrigation or to grow their farm in value and size. About 80% of respondents said their current energy availability keeps them from doing an income activity they want to do, suggesting they would be able to achieve irrigation and growth goals if they had better, cheaper access to energy.

Looking into South African farmers' energy needs, 20 out of 25 said they had access to electricity with only 10 of those stating they use electricity from the grid. Most people choose not to use the grid because they find it to be costly and unreliable. Because of this, 8 of those who do not use grid electricity report having their own generator. Only one person reported solar, but it should be noted that others had attempted solar as well only to have their panels stolen. There was a mixture of responses when farmers were asked to indicate how much they agreed with the statement, "I am satisfied with my current electricity source." Two strongly agreed, 2 agreed, 7 were neutral, 6 disagreed, and 8 strongly disagreed. Only 9 out of 25 respondents claimed they had access to electricity 24 hours a day for 7 days a week, with 12 farmers stating their electricity source to be unreliable. Most farmers said they experience electricity outages on a weekly basis, with a couple reporting daily.

Out of 27 responses, 15 claimed they were familiar with renewable technologies. The majority of those were familiar with solar panels, with only a few answering biomass, wind, or microgrids. There was a pretty even mixture in terms of their sources for this knowledge with a third claiming they learned from the media, another third from the internet, and the other third from other farmers. When asked to indicate their agreement with the statement, "Renewable energy technologies would be feasible within my farming operation," all 27 respondents either agreed or were neutral. When asked of their agreement with the statement, "I would like to learn more about renewable energy," 21 out of 26 strongly agreed with the other five either agreeing or neutral. All 27 respondents said they would be more interested in incorporating renewable energy if they could see an example of it in practice, suggesting a successful demonstration site would have a big impact on farmers. Most farmers reported cost as renewable energy's most attractive attribute.

Most farmers need pumps for irrigation and 82% have to rely on generators fueled by costly diesel or petrol to power these pumps. A little over half of farmers need cold storage for their products, but only 2 of 25 respondents reported having an abattoir. Farmers have anywhere between 1 and 11 buildings on their farms that need energy. Many claimed their energy needs change throughout the year with a tie between those who felt they used more energy in the summer and those who felt they used more energy in the winter. When asked if their farm generates more waste than they can use, 16 respondents said yes and 10 said no. Of those who have excess waste, 42% reported it came in the form of crop waste and 33% said grass, which are both capable of being fuel for gasification. In addition, it is important to note that many farmers who said they did not have excess waste said they would be willing to divert some of their waste to renewable energy if it proved to be a better usage for the residues.

Small-scale farmers in South Africa are faced with many challenges  including access to knowledge and resources, financing, water shortages, cost of energy, access to a market, access to land, safety and theft, infrastructure, and a lack of training. However, they continue to hold onto hope for their farms and their futures. Many reported they have future plans and hopes of expanding their farming and increasing their production. In addition to producing more, many hope to be commercialized in 5 years. When asked where they see themselves in 5 years, some focused farmers hoped to be successful and leading farmers in their area, others reported dreams of traveling and remaining healthy. The survey instrument and de-identified responses can be found in Appendix A.

# 6. Discussion: Contextualizing Survey Findings

The outcomes of the survey offer critical insights into local farmers' perceptions of renewable energy and provide a framework for how Kgora might disseminate renewable energy information and demonstrations to local farmers.

The surveys offer a better understanding of the most common crops (and therefore biomass feedstocks) that exist in the area beyond Kgora's borders. Sunflower and maize are the two most common crops both at Kgora and for local farmers, indicating that the work done on gasifier installation at Kgora will translate well into training for local farmers who have similar crops and crop waste. Additionally, with the majority of farmers reporting only one main harvest period across the year, biomass residue storage will be critical in order to provide gasification feedstocks across the entire year while keeping the residue dry. It was encouraging to find that most farmers rely on each other for sharing information, an indication that there are strong community ties and collaboration. For technologies like gasification, economies of scale are important, meaning that it is not likely economically feasible for a single farmer to use the technology on their own. Thus, a community-led arrangement to split the costs associated with a renewable energy system is advised, allowing for groups of farmers to share the produced electricity.

More information will be needed in the future to understand how a renewable energy system can go beyond Kgora's energy load and support the income activities of local farmers. For instance, tools such as the BEFS framework can be used to obtain a clearer resource assessment of the region and to formulate labor practices for feedstock collection and electricity sharing. A better understanding of the geographic locations of local farmers may also support the development of a central energy hub that farmers can collectively own and operate. An aggregate energy demand of local farmers would also be required to develop the financial system sizing as with Kgora's energy load. The survey clearly indicates a desire to pursue renewable energy and paints an optimistic picture of the enthusiasm around such projects.

## 5. Future Scope of Work

The installation of a 15 kW gasifier at Kgora Farmer Training Centre aims to be completed in August 2022. The gasifier will be manufactured in San Mateo, Costa Rica by Steel CMS under supervision of Dr. Jose Alfaro and shipped overseas to Mahikeng. Upon arrival, the gasifier will be installed behind the meter at Kgora and begin generating energy with collected and pelletized crop residues. Trials will be run to determine the energy efficiency of each different type of available crop residue. This will provide Kgora and farmers with a detailed idea of what to expect in terms of energy output with each type of crop. While running these trials, Kgora staff and visiting farmers will be trained on the operation of the gasifier and will see firsthand how the machine works. After this period of trials is over, the gasifier will be left with Kgora to run when they please. It should allow them to operate during periods of load shedding, while also lowering their expensive electricity bills. In addition, they will be able to demonstrate gasification to any farmers that come to visit their institution.

After installation is complete, new students assigned to the Kgora project will continue to maintain the partnership with Kgora and the Africa Business Group to help farmers find the resources to obtain their own gasifier. In addition, project work is expected to complete the installation of components that will fully realize the renewable energy system recommendations provided here. Students will have the opportunity to demonstrate the benefits of agrivoltaics at Kgora for farmers to see side-by-side with the gasifier. Both the University of Michigan and Kgora Farmer Training Centre are grateful for their partnership and look forward to accomplishments made throughout the future course of this project.

## 6. Conclusion

Kgora staff are positioned to integrate renewable energy into their energy supply for the purposes of reducing grid dependency, supporting critical income activities, and disseminating information, as evidenced by the financial outlook of energy modeling that indicated an optimistic outlook of the proposed microgrid system, as well as resource availability to be sourced from Kgora's operations. A 15 kW gasifier will be the first piece of technology implemented at Kgora, a first step on the road to implementing the financially optimal system size of 30 kW of gasification capacity, 27.6 kW of solar photovoltaic capacity, and 8 kWh of battery capacity. Moreover, the survey instrument offers insights on biomass feedstock availability in surrounding communities and answers indicate the increase in interest for renewable energy resources in this region. Those perceptions will be critical as Kgora establishes their own microgrid and disseminates information as a demonstration site for other farmers to consider implementing gasification and photovoltaics into their own practices.

## References

"Bioenergy | Energy | Food and Agriculture Organization of the United Nations." *Fao.org*, 2018, www.fao.org/energy/bioenergy/en/. Accessed 16 Mar. 2022.

"BIOENERGY and FOOD SECURITY RAPID APPRAISAL (BEFS RA) User Manual GASIFICATION." 2014.

"Biomass Explained - U.S. Energy Information Administration (EIA)." *Eia.gov*, 2018, www.eia.gov/energyexplained/biomass/. Accessed 29 Mar. 2022.

Boost, In. "In Boost for Renewables, Grid-Scale Battery Storage Is on the Rise." *Yale E360*, 2020, e360.yale.edu/features/in-boost-for-renewables-grid-scale-battery-storage-is-on-the-rise. Accessed 29 Mar. 2022.

Burkhardt, Paul. "South African Grid Collapse Concern Prompts Utility to Resume Power Cuts." *Bloomberg.com*, Bloomberg, 2 Feb. 2022, www.bloomberg.com/news/articles/2022-02-02/grid-collapse-concern-prompts-eskom-to-resume-rolling-power-cuts. Accessed 12 Apr. 2022.

Chel, A., and G. Kaushik. "Renewable Energy for Sustainable Agriculture." *Agronomy for Sustainable Development*, vol. 31, no. 1, Jan. 2011, pp. 91–118, link.springer.com/article/10.1051/agro/2010029?noAccess=true, 10.1051/agro/2010029. Accessed 29 Mar. 2022.

Cairncross, Eugene. *Assessment of Eskom Coal Fired Power Stations for Compliance with Their 1 April; and Ranking of Their Pollutant and CO 2 Emission Intensities*. 2015.

Fu, Ran, et al. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018*. 2018.

"Farmers Elated by the Launch of Kgora Farmer Training Centre | South African Government." *Www.gov.za*, 2012, www.gov.za/farmers-elated-launch-kgora-farmer-training-centre. Accessed 31 Mar. 2022.

"How Microgrids Work." *Energy.gov*, 2014, www.energy.gov/articles/how-microgrids-work. Accessed 14 Apr. 2022.

"IRENA Renewable Generation Power Costs 2019." *IRENA.org,* 2019, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf

Mongird, K, et al. *Energy Storage Technology and Cost Characterization Report*. 2019.

Mehta, Sahil, and Prasenjit Basak. "A Case Study on PV Assisted Microgrid Using HOMER pro for Variation of Solar Irradiance Affecting Cost Of..." *ResearchGate*, unknown, Feb. 2020, www.researchgate.net/publication/342104979_A_Case_Study_on_PV_Assisted_Microgrid_Using_HOMER_Pro_for_Variation_of_Solar_Irradiance_Affecting_Cost_of_Energy. Accessed 20 Mar. 2022.

"Power Africa in South Africa | Power Africa | U.S. Agency for International Development." *Usaid.gov*, 5 Oct. 2021, www.usaid.gov/powerafrica/south-africa#:~:text=According%20to%20the%20Ministry%20of of%20the%20country's%20energy%20mix.. Accessed 14 Apr. 2022.

"Rapid Appraisal | Energy | Food and Agriculture Organization of the United Nations." *Fao.org*, 2022, www.fao.org/energy/bioenergy/bioenergy-and-food-security/assessment/befs-ra/en/. Accessed 1 Apr. 2022.

"South Africa - Agricultural Sector." *International Trade Administration | Trade.gov*, 2019, www.trade.gov/country-commercial-guides/south-africa-agricultural-sector. Accessed 14 Apr. 2022.

"Tariffs and Charges - Distribution." *Distribution*, 30 Nov. 2021, www.eskom.co.za/distribution/tariffs-and-charges/#:~:text=On%205%20March%202021%2 %20the,implemented%20on%201%20July%202021.. Accessed 13 Mar. 2022.

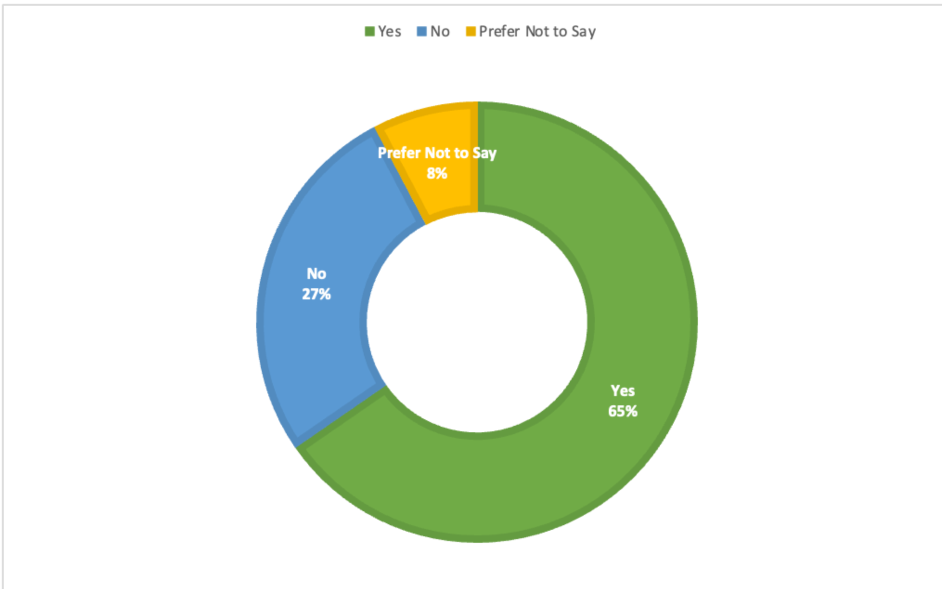
"You Can Sell Excess Solar Power back to Govt – but It May Take around 7 Years to Break Even." *Businessinsider.co.za*, 2021, www.businessinsider.co.za/you-can-sell-excess-solar-power-back-to-govt-but-it-can-take-around-7-years-to-break-even-2021-1. Accessed 20 Mar. 2022.

# Appendices

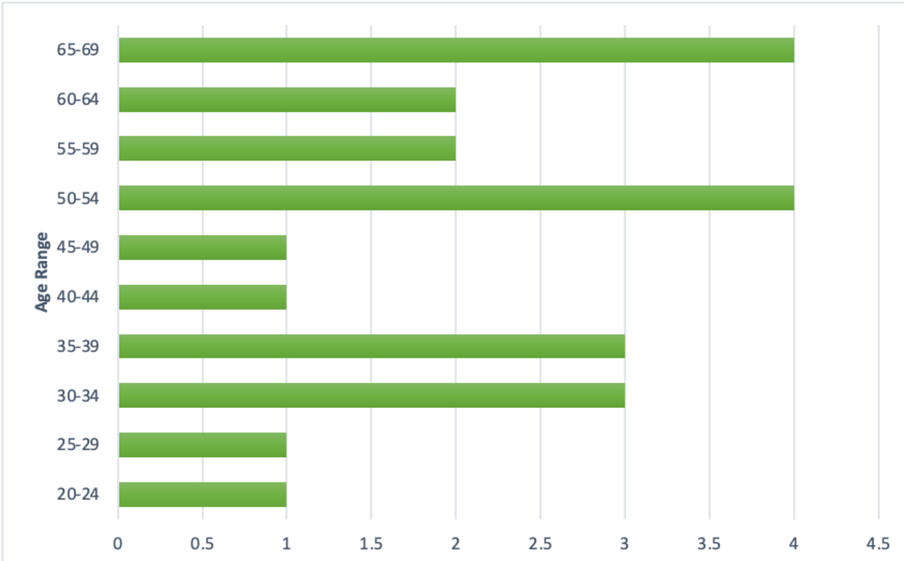
## Appendix A

<u>Household Demographics</u>

1. Are you the primary financial earner in your family?

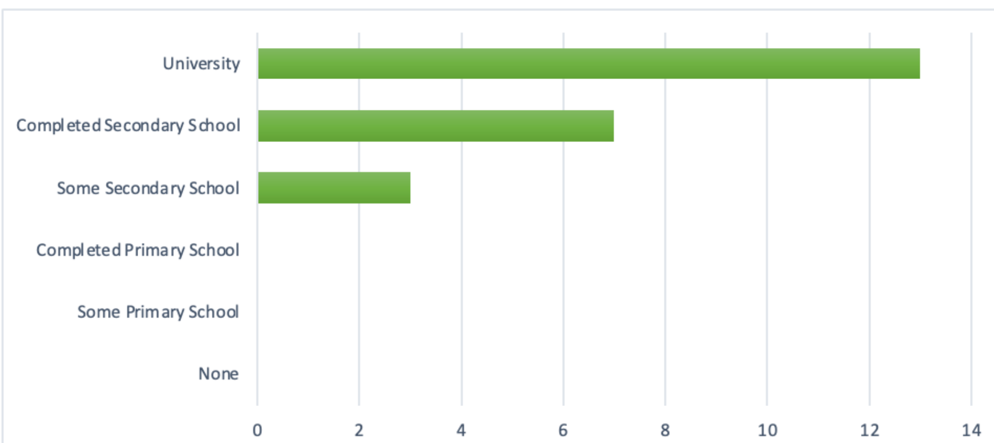


2. What is your age?



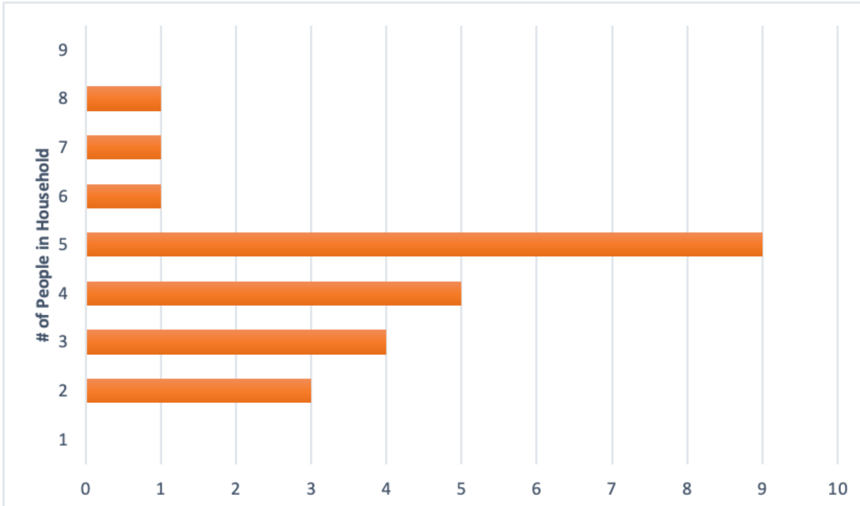

Average: 48 years

3. What is your highest level of education?

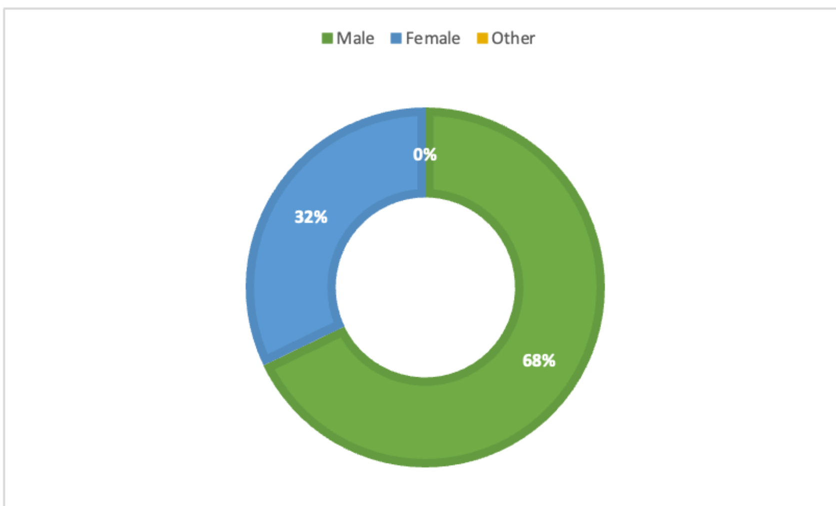



Disclosed Degrees: Public Finance, Education Management, Bachelor’s in Finances, Management, Agriculture Economics

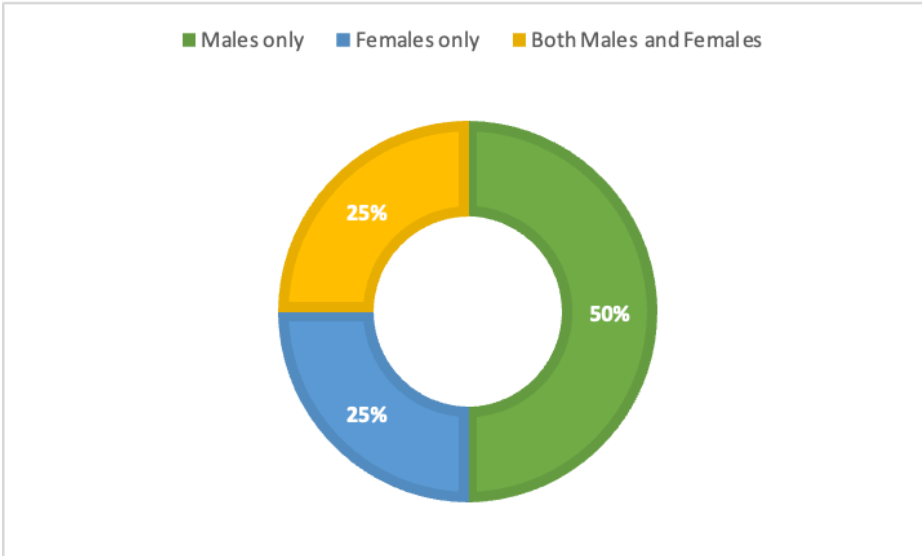
4. How many total people usually live in the household, including yourself:



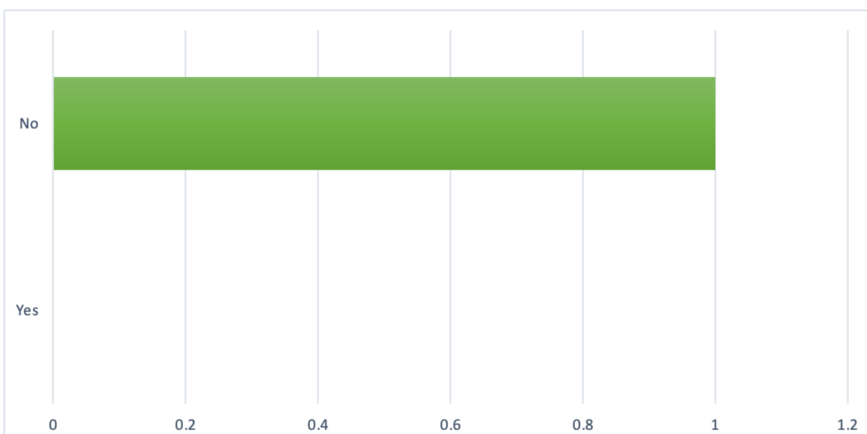

5. What is your gender?



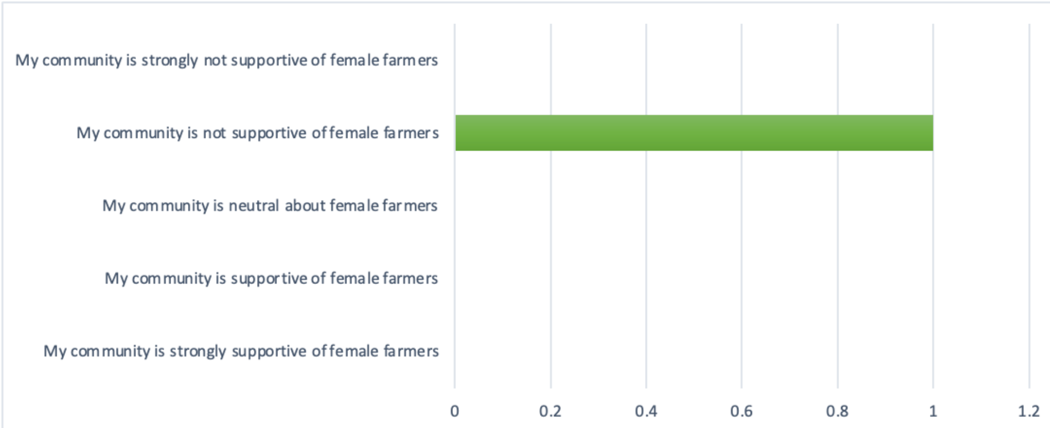
6. Are farming tasks seen as a responsibility for…




7. Do you feel that male and female farmers have the same access to government assistance, machinery, etc.?



8. Do you feel that your community is supportive of female farmers?

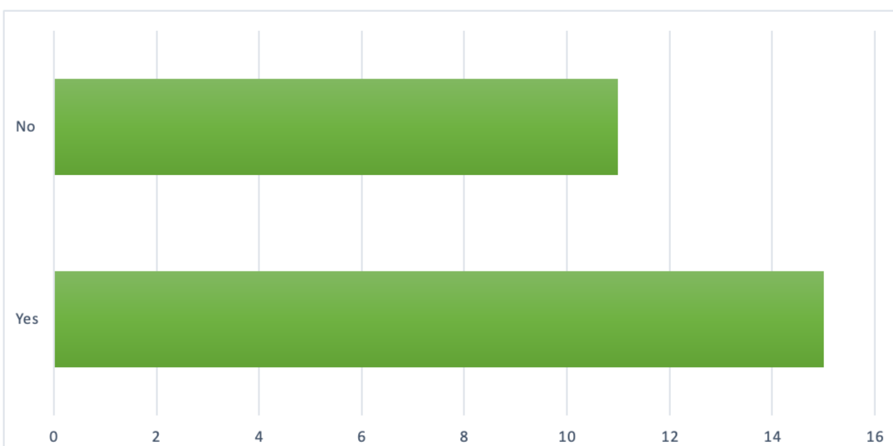



9. What are the largest challenges facing female farmers in your community?

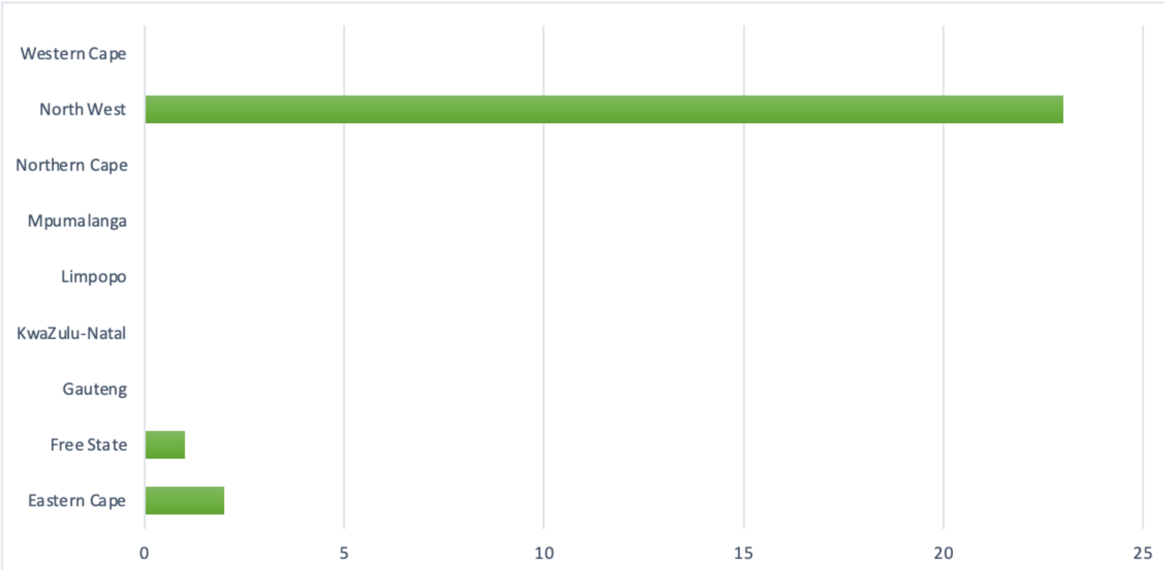
Responses include:
- Lack of experience
- Lack of training

<u>Farming Practices</u>

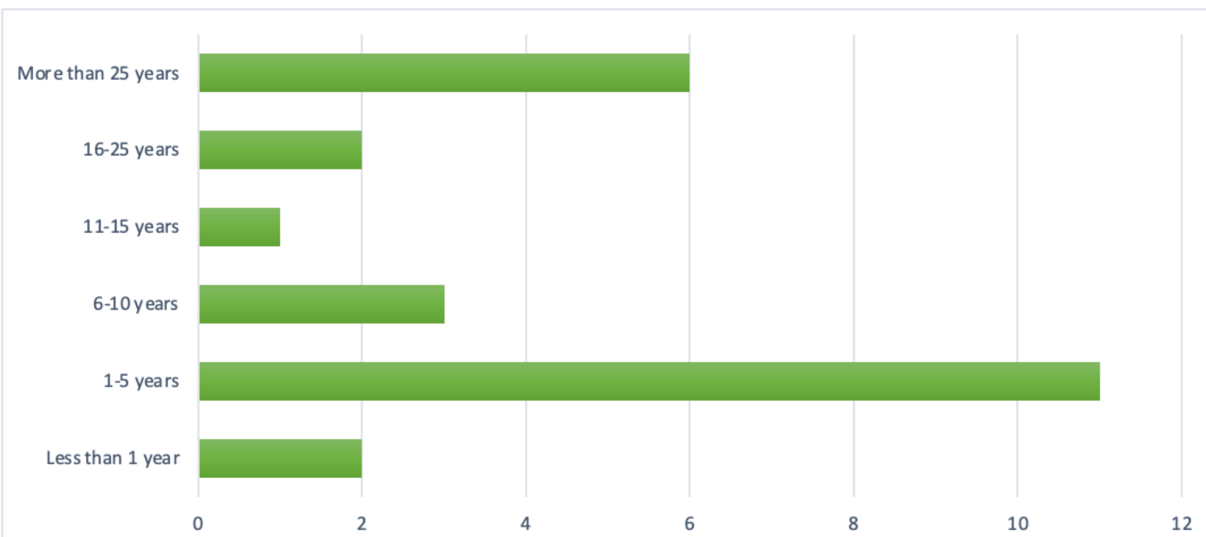
10. Do you own the farm you work on?



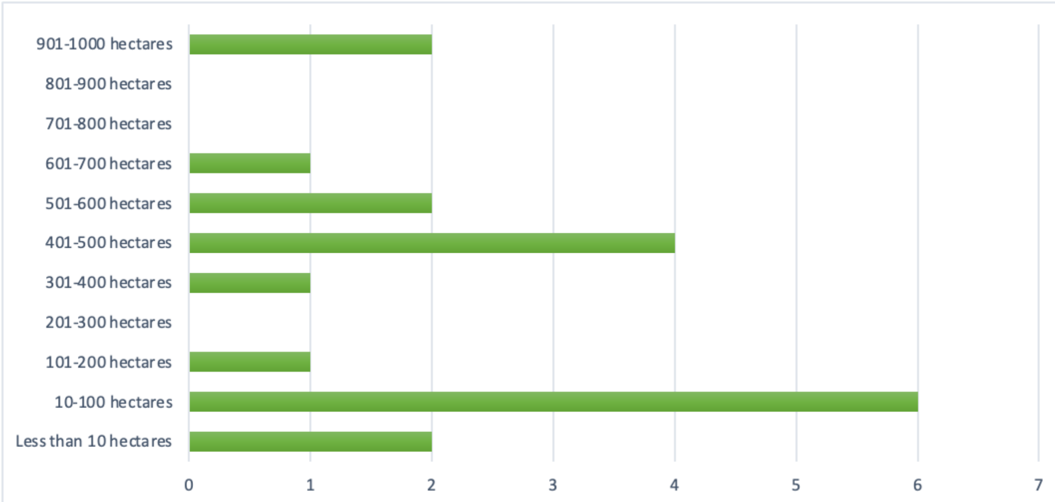
11. What province is your farm located in?




12. How many years of farming experience do you have?

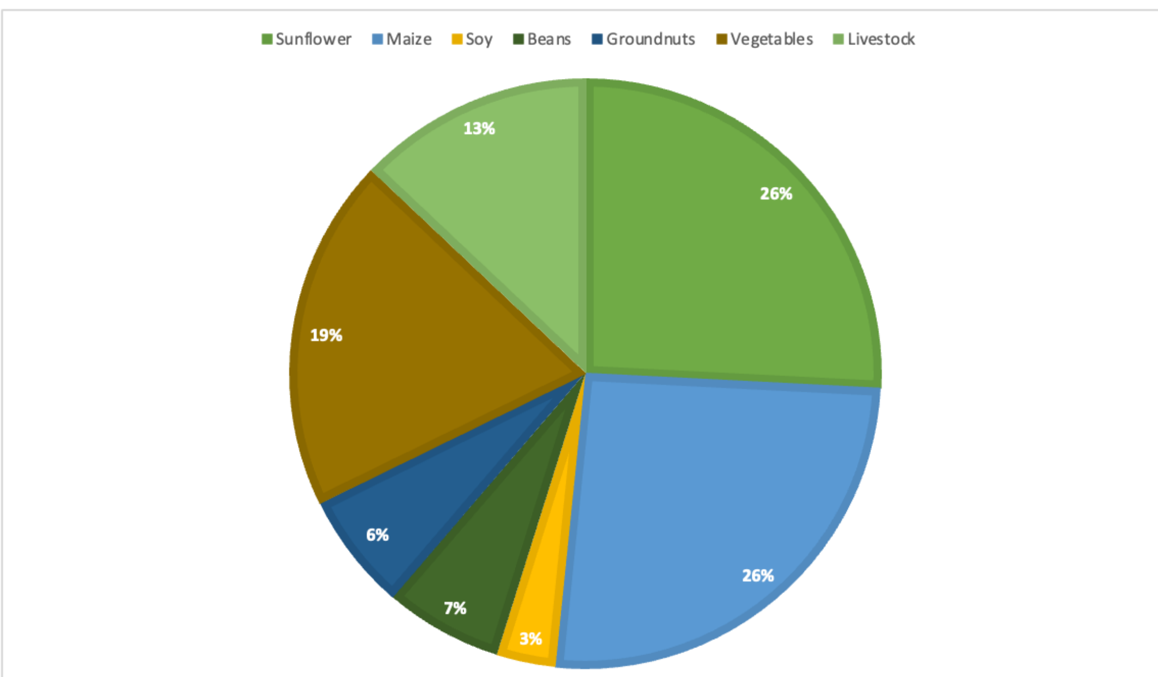


13. What is the size of the farm that you currently work on (in hectares)?

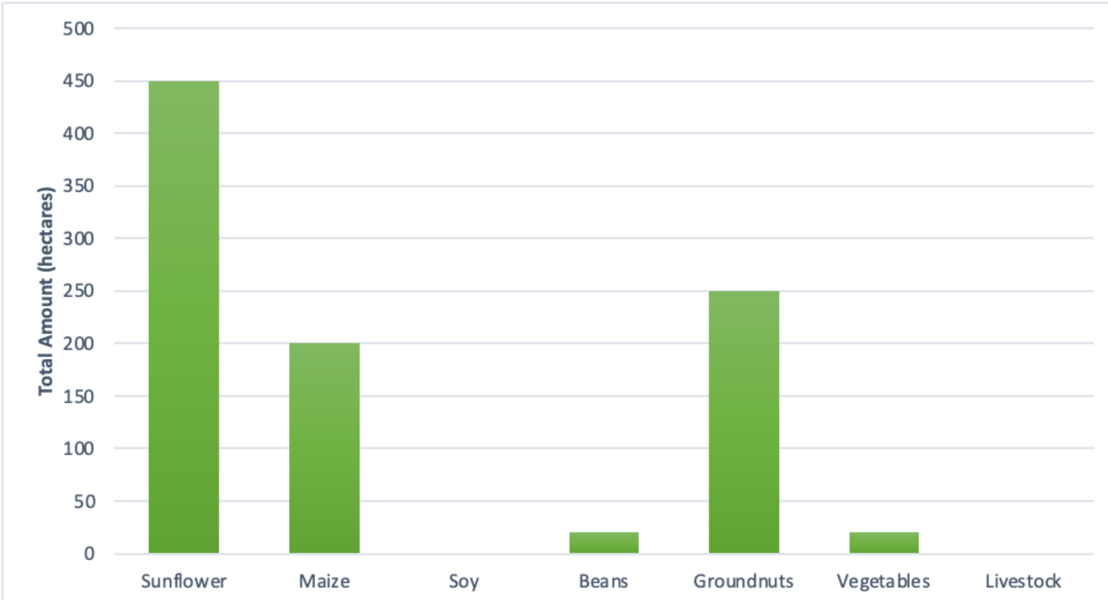



Minimum: 3 hectares
Maximum: 1000 hectares
Mean: 309.48

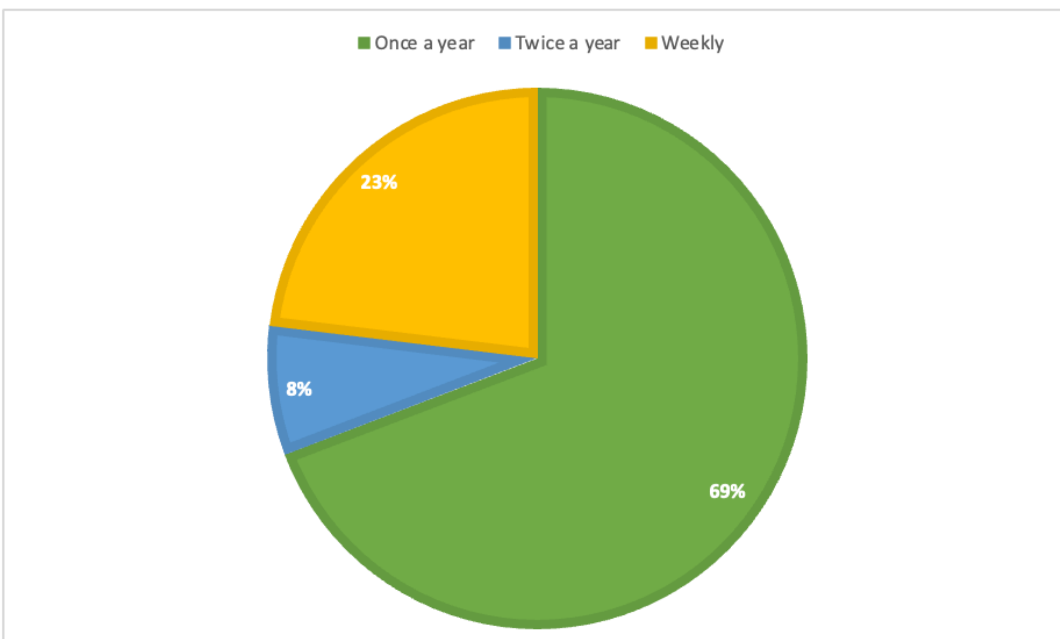
14. What are the three main crops you grow on your farm?



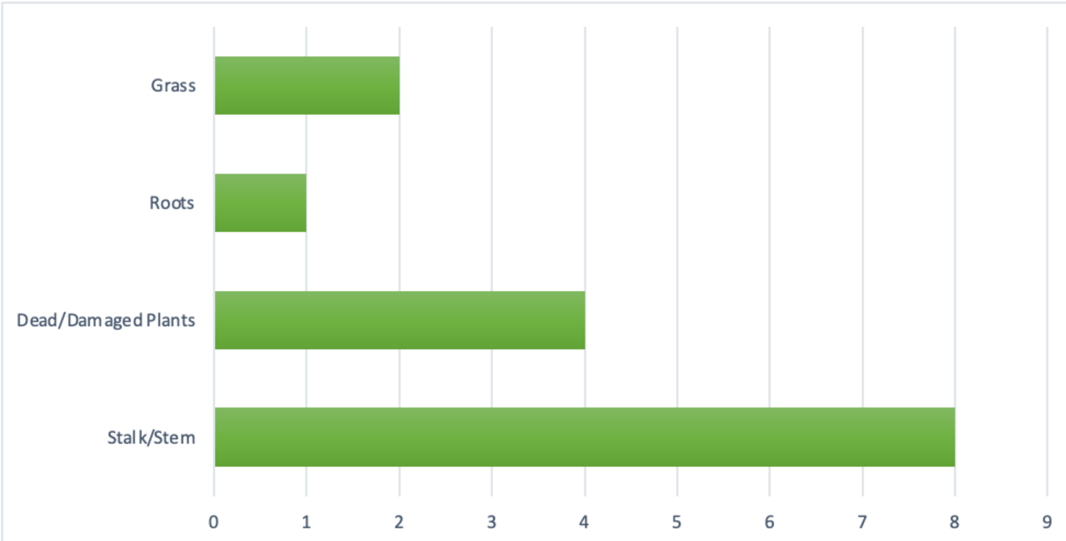
15. How much of each crop do you have on your farm?



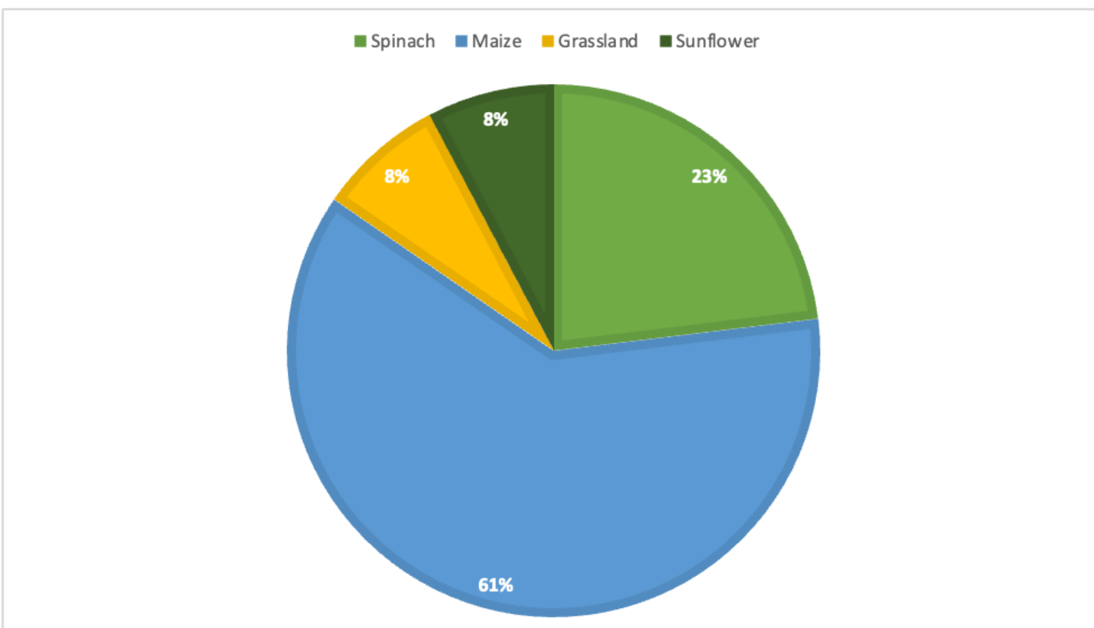

16. How often do you harvest?



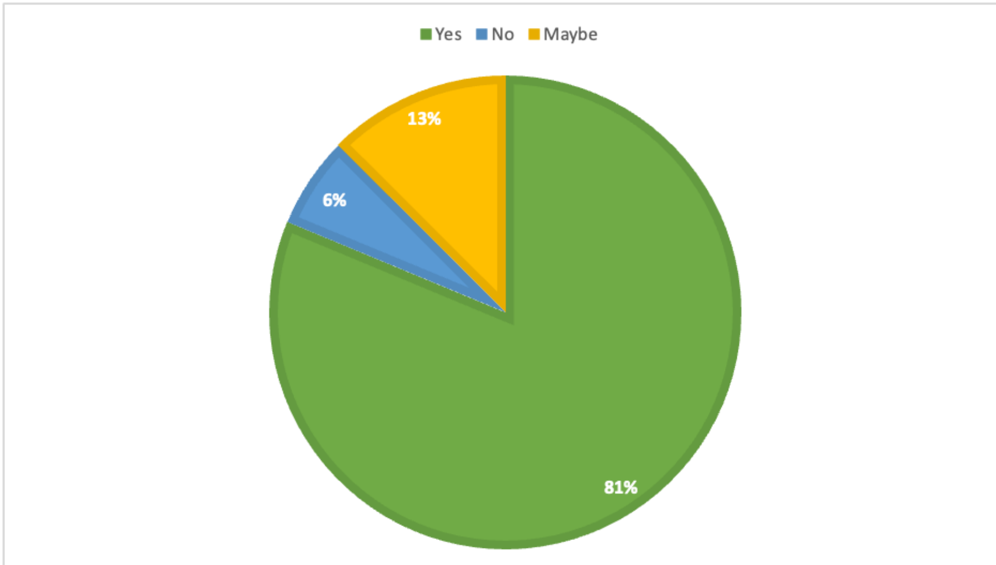
17. What form is the waste typically in, or what part of the plant is typically wasted?



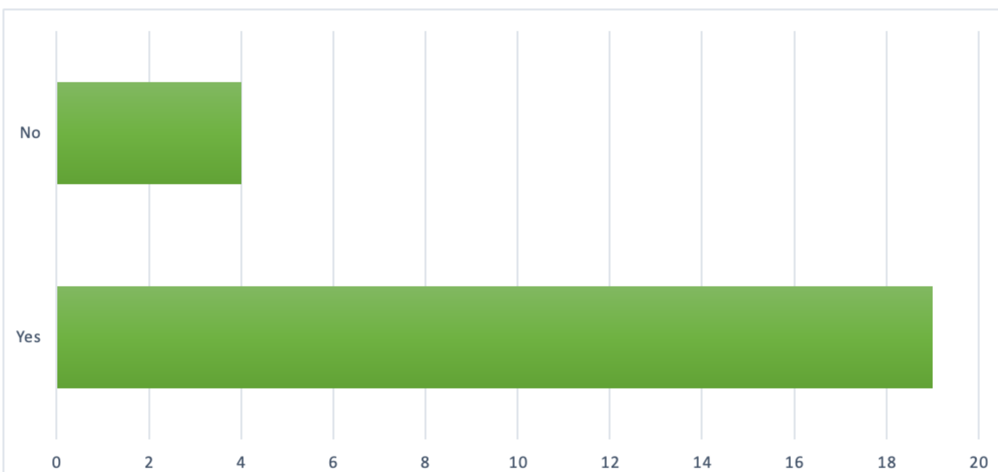

18. What crop typically produces the most waste?



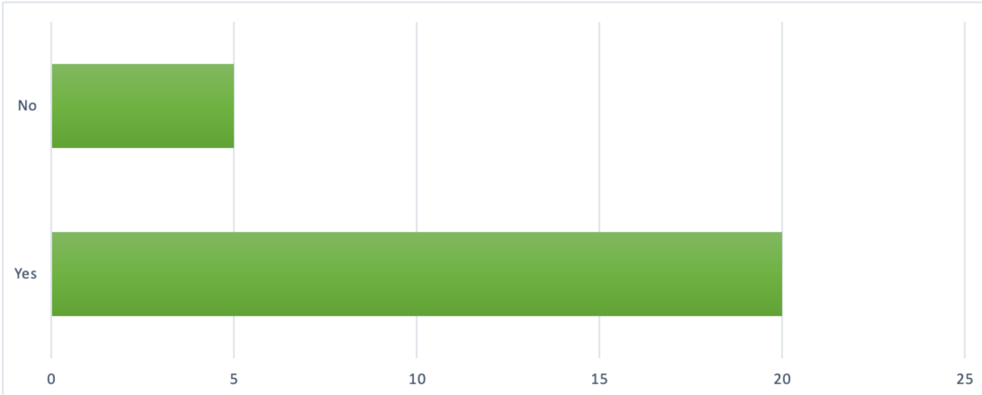
19. Would you be interested in collecting crop waste to turn it into energy for your farm?



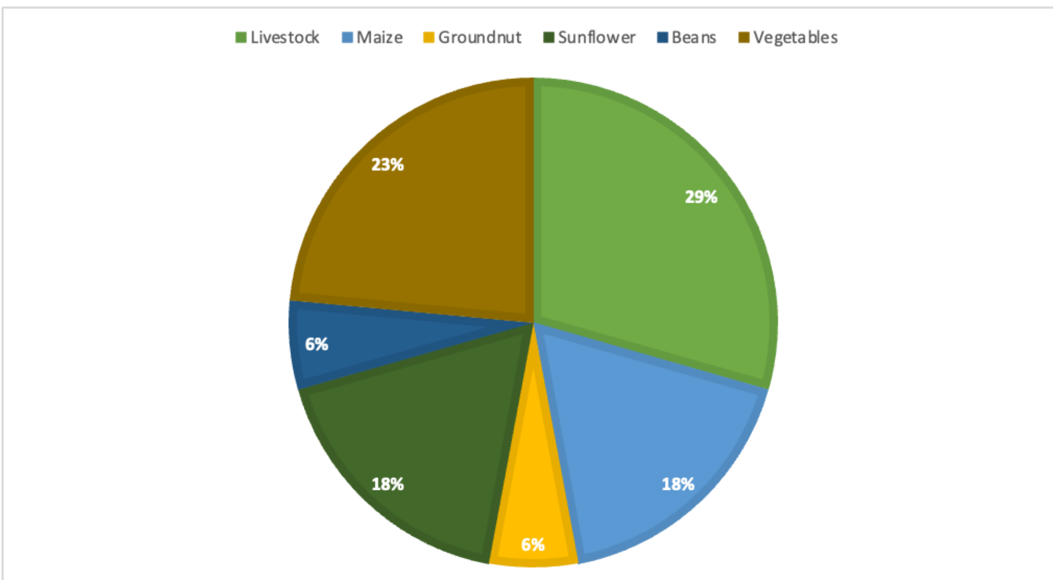

20. Does your farm provide enough food to feed your family?



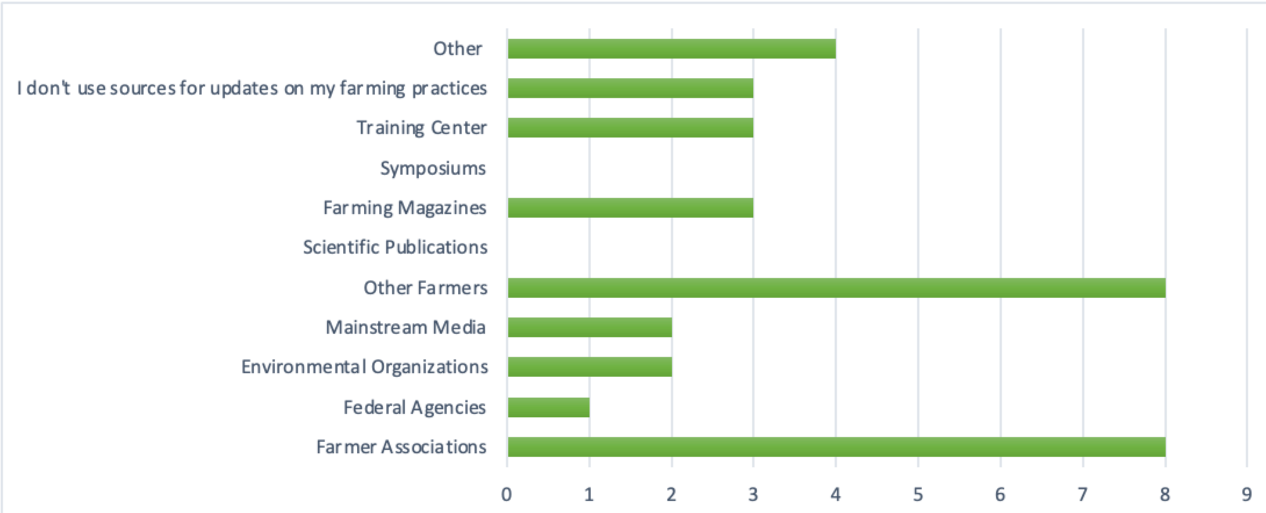
21. Does your farm sell any products at the market?



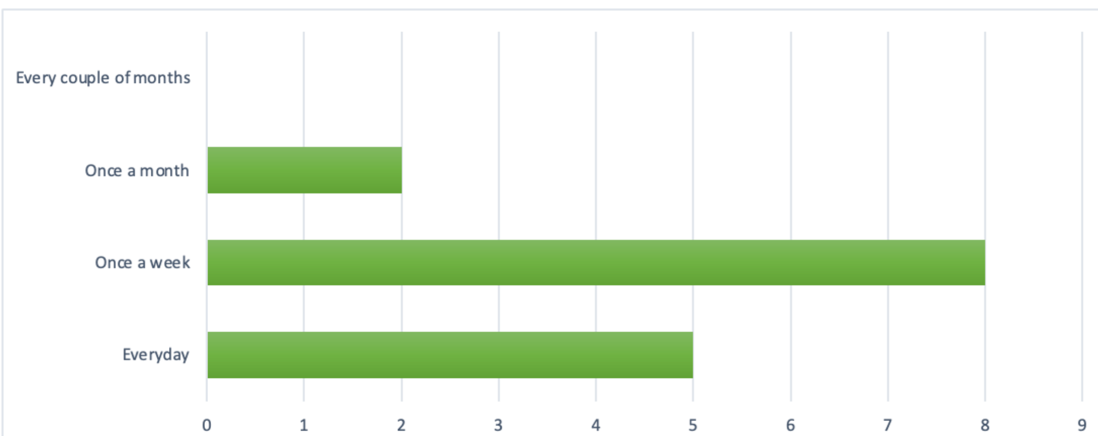

21b. If yes, please specify:



22. If you use sources for updates on farming practices, which do you use most? (select all that apply)

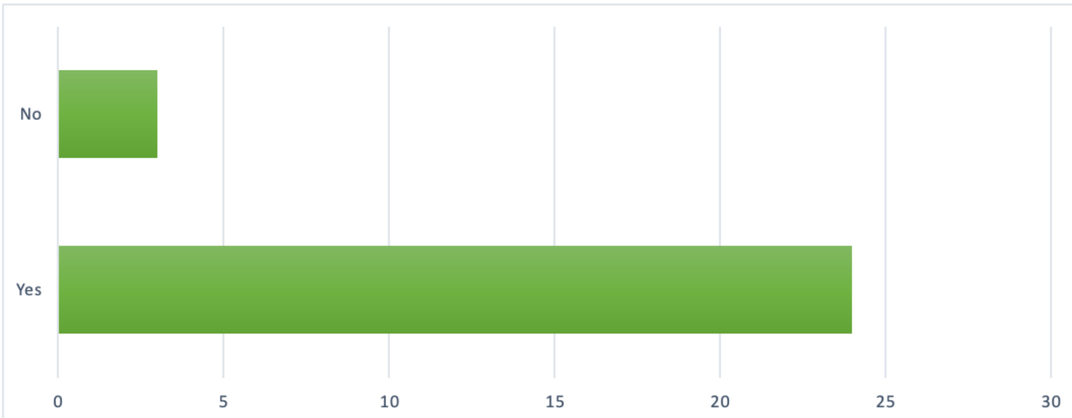



23. How often do you speak with other farmers about farming practices?

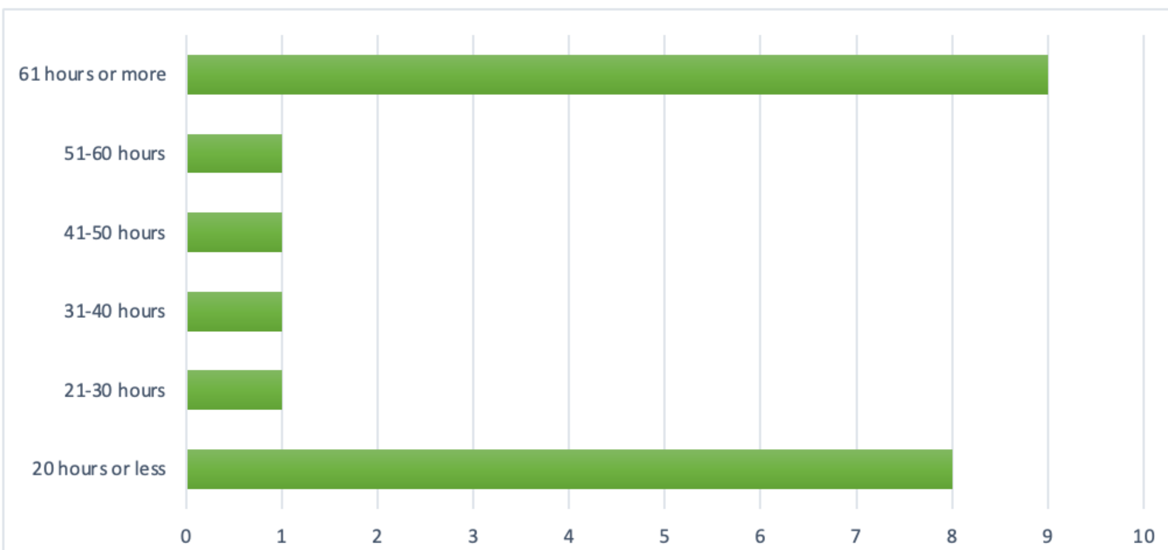


## Financial

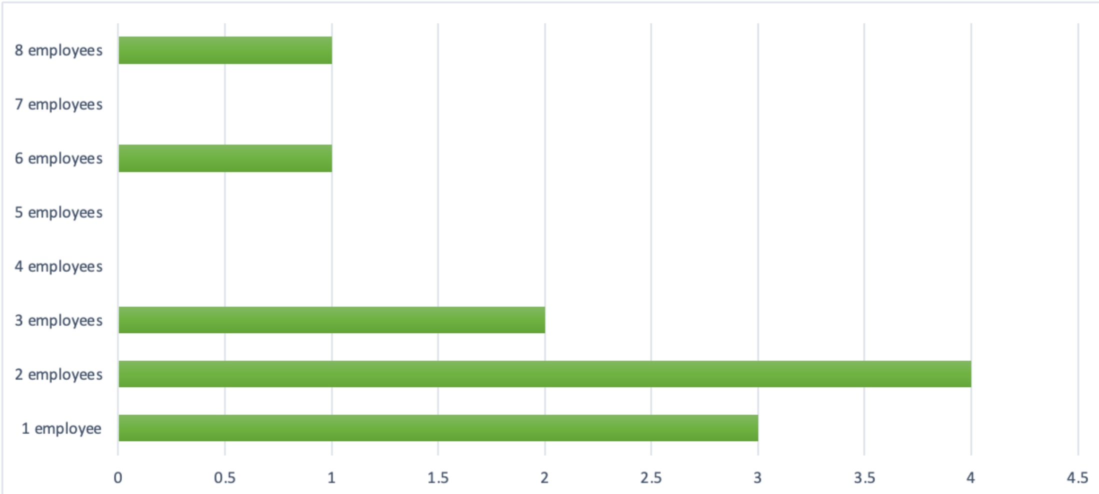
24. Are you comfortable answering some questions about your finances?



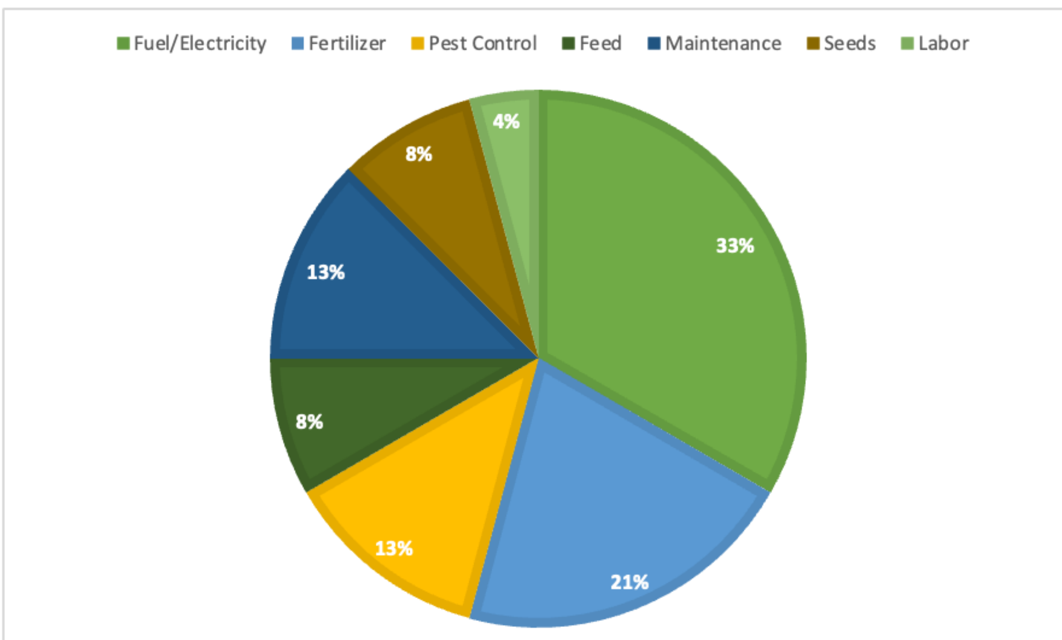

25. About how many hours do you work each week?



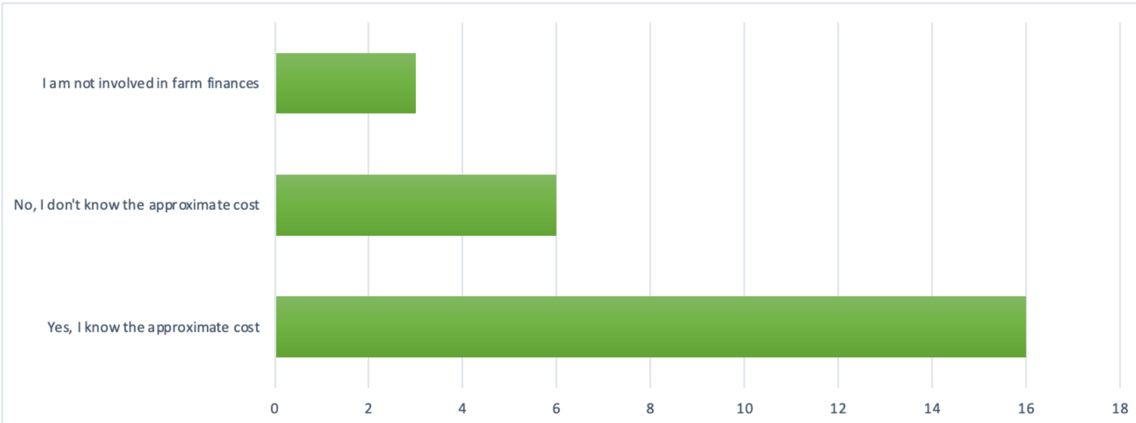
26. How many people does your farm employ?



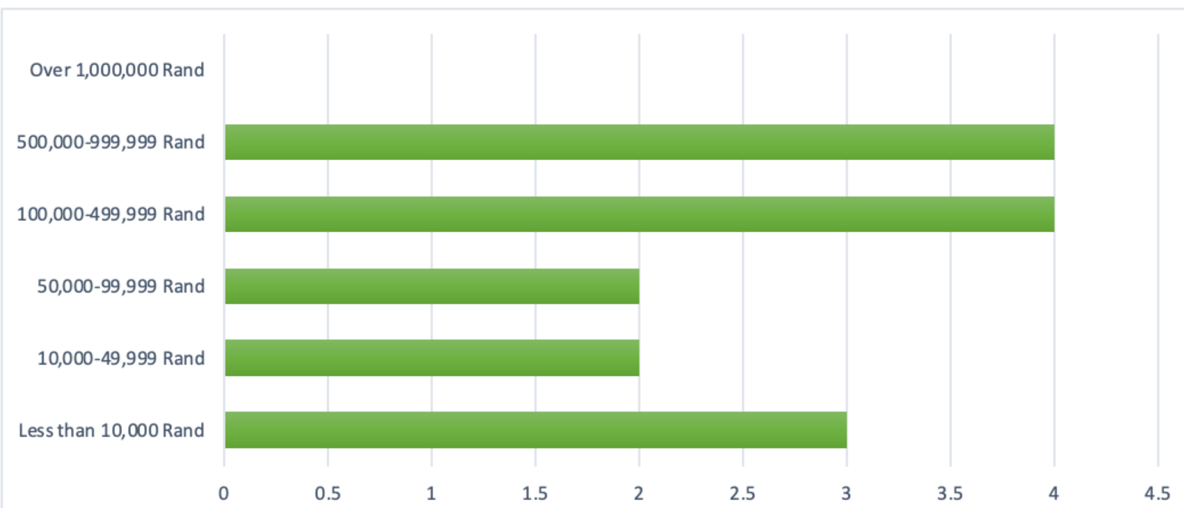

27. What are the most costly things on your farm?



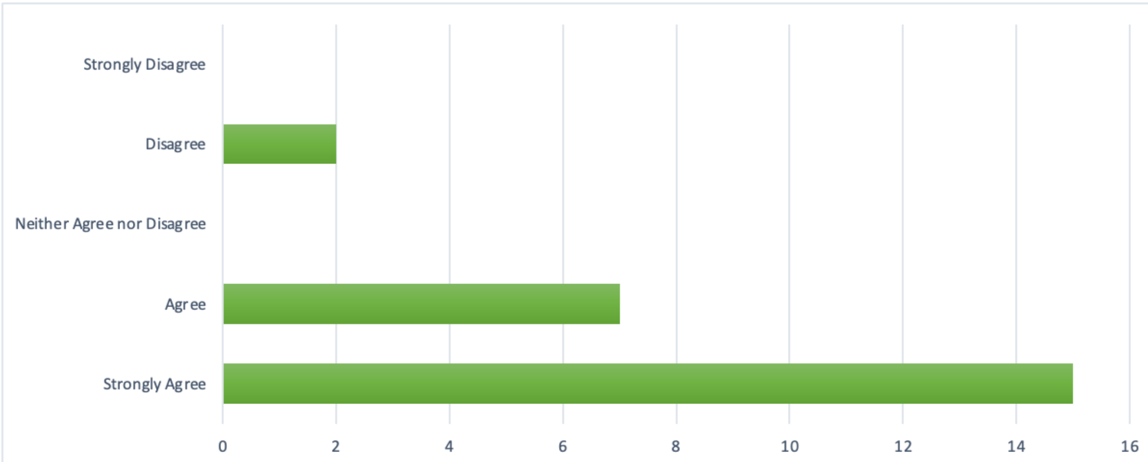
28. Do you know how much it costs to run the farm each year?



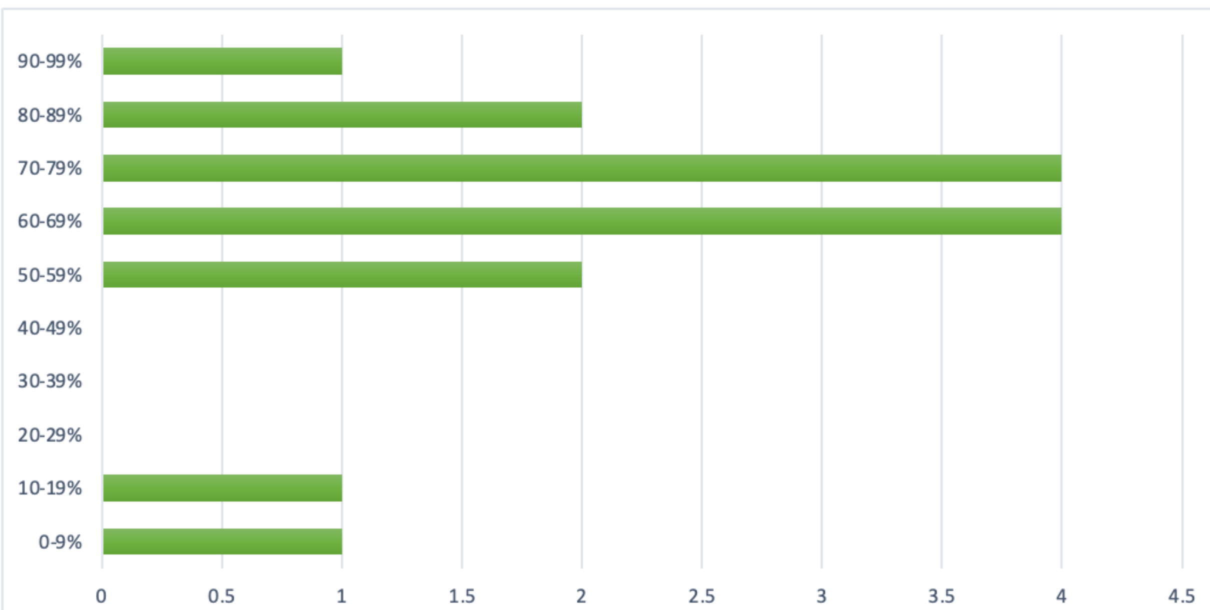

29. Approximately how much does it cost (in Rand) to run the farm each year?



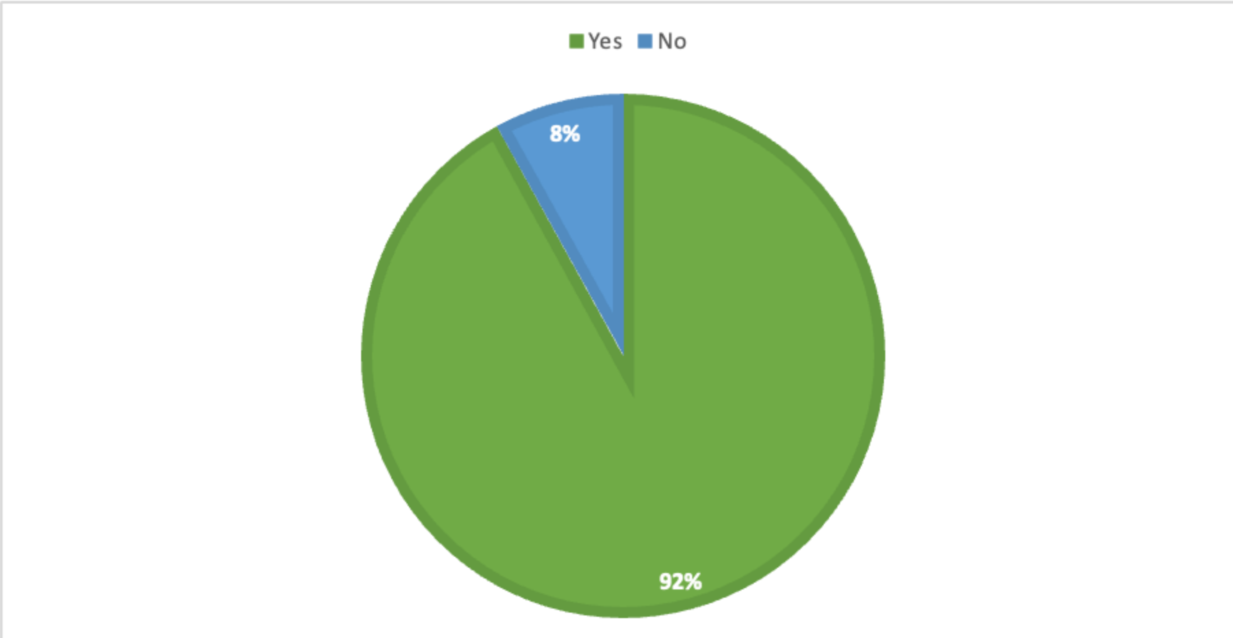
30. Please indicate how much you agree with the following statement: I spend too much of my income on energy.



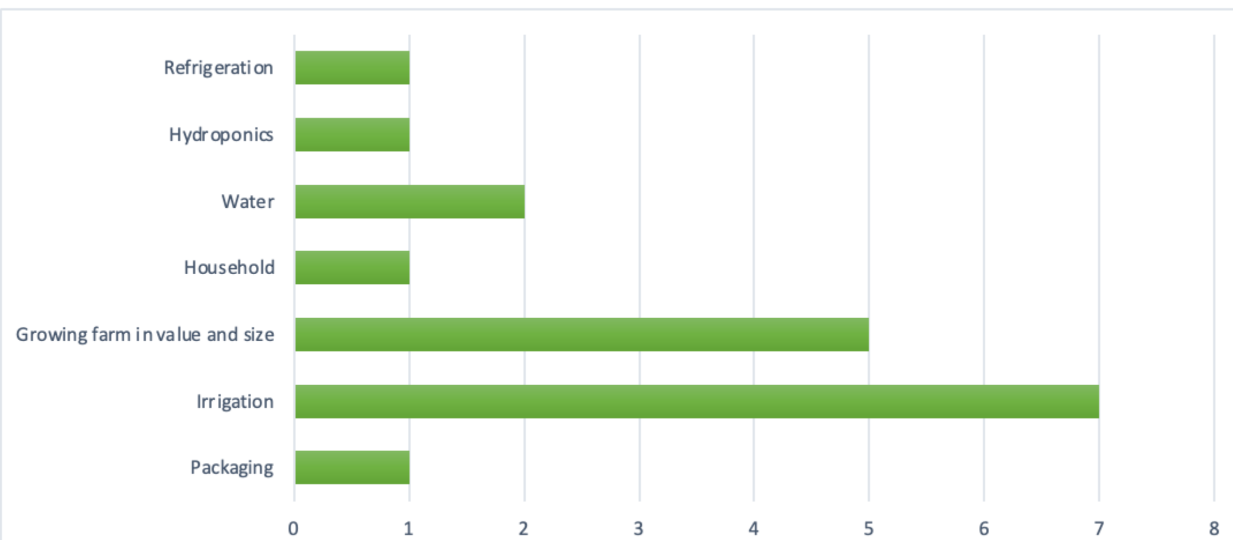

31. About what percent of your income is dedicated to your energy needs?



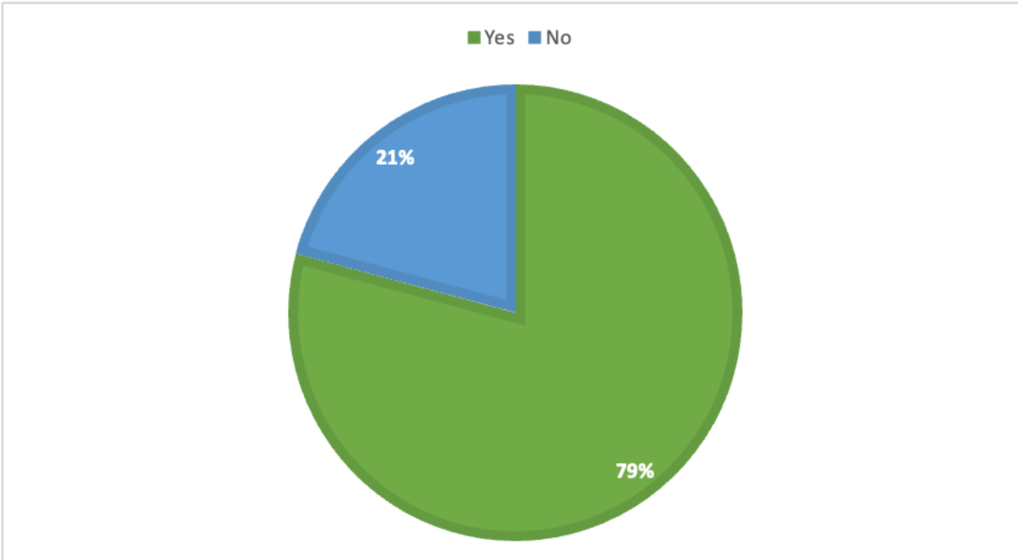
32. Would you be willing to invest in renewable energy if over the long term it lowered overall farming costs?



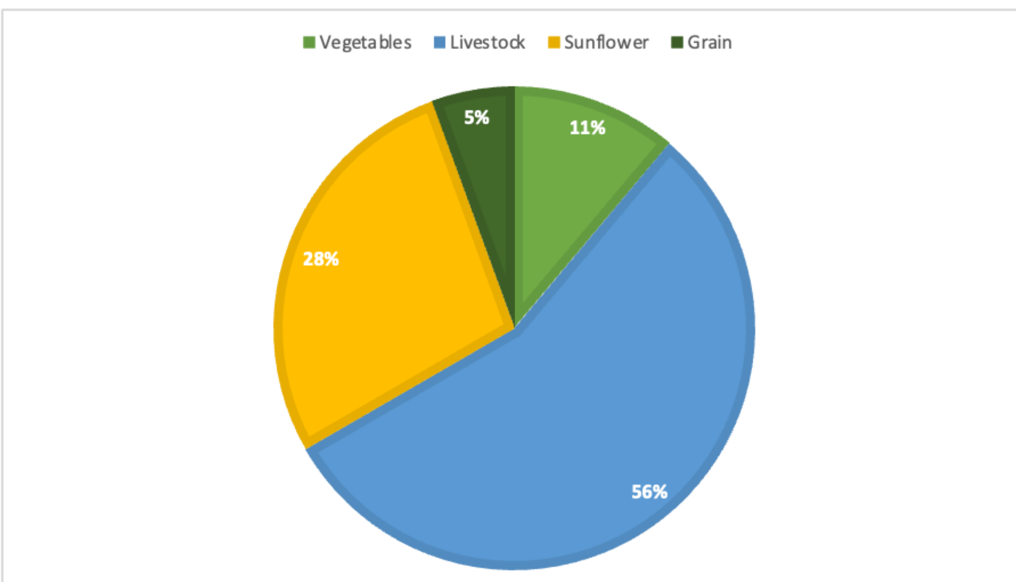

33. If you had unrestricted access to energy, what would you use it for?



34. Does your energy availability keep you from doing an income activity you want to do?

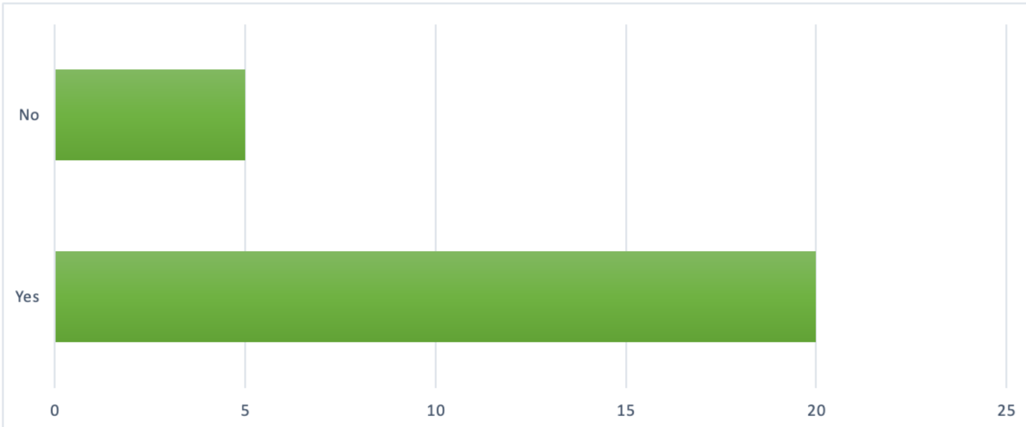



35. Which of your farming products contributes to the highest portion of your farming revenue?

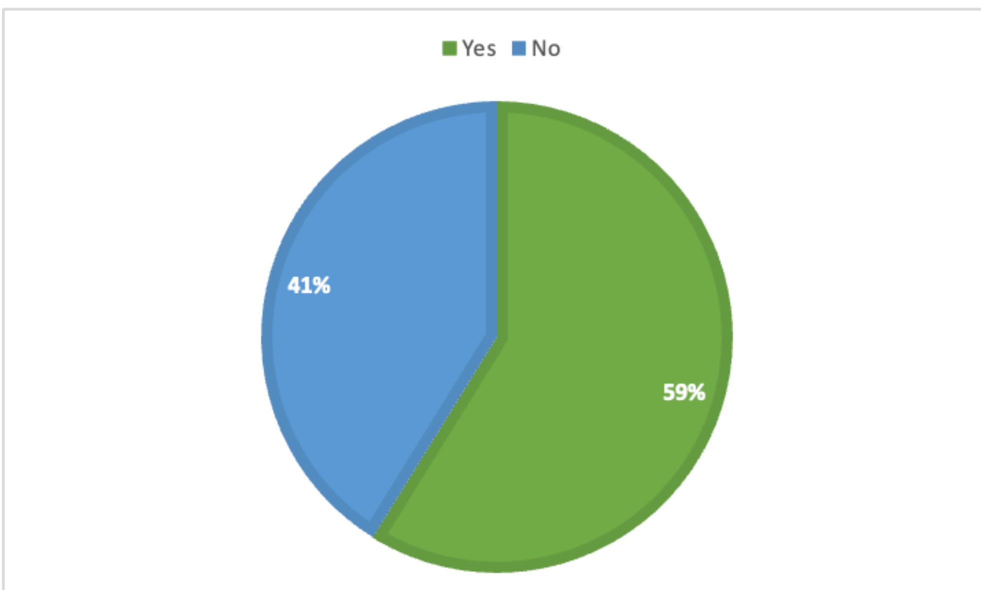


Energy Needs

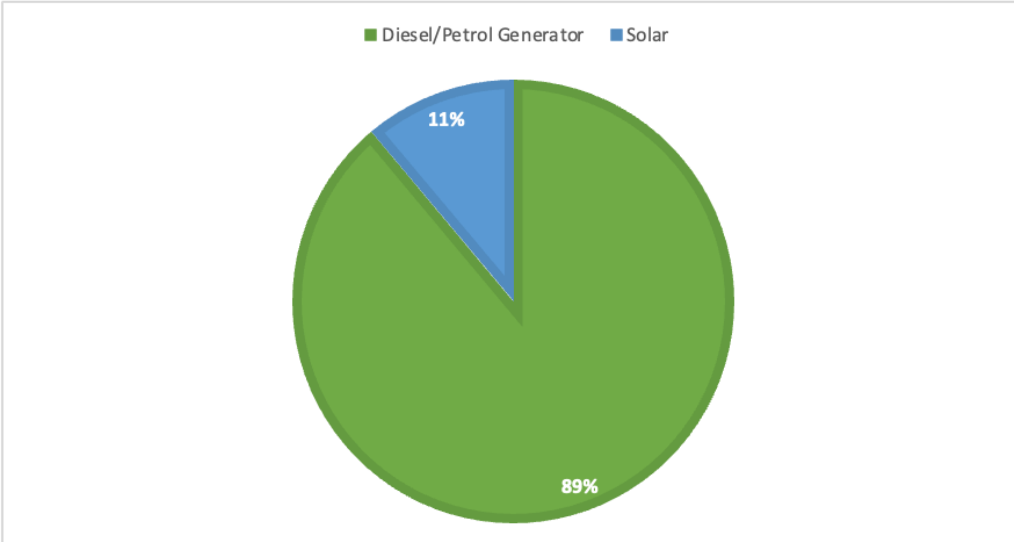
36. Do you have access to electricity?



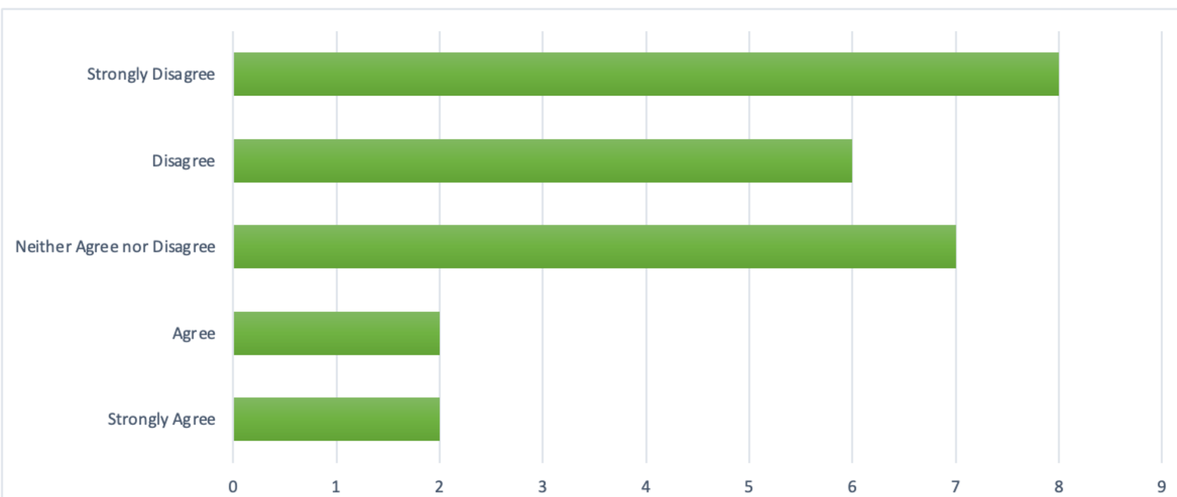

37. Do you use electricity from ESKOM?



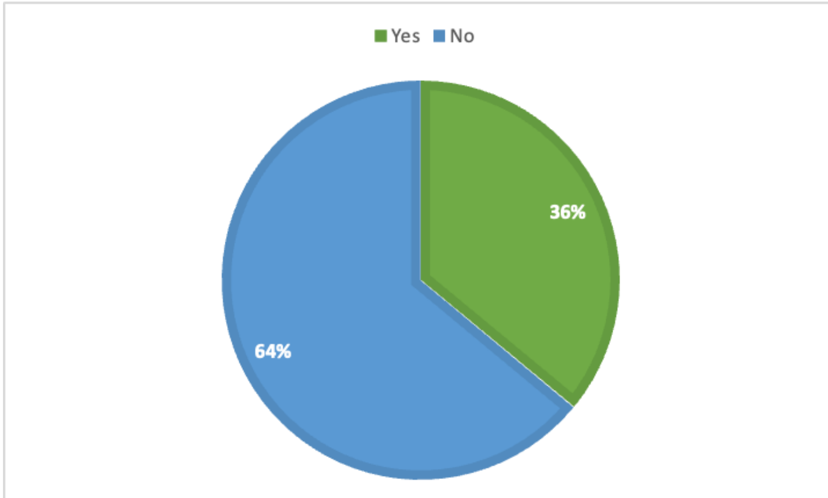
38. Do you get electricity from other sources, and if so, what are they?



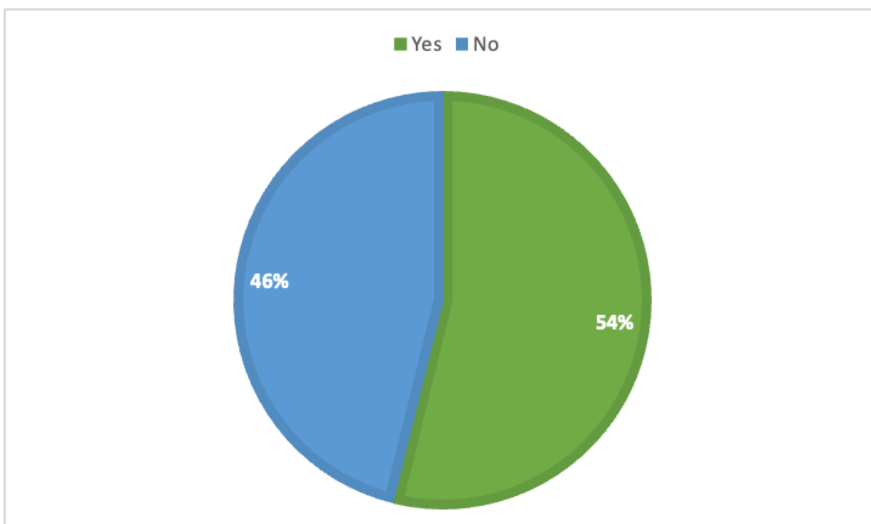

39. Please indicate how much you agree with the following statement: I am satisfied with my current electricity source.



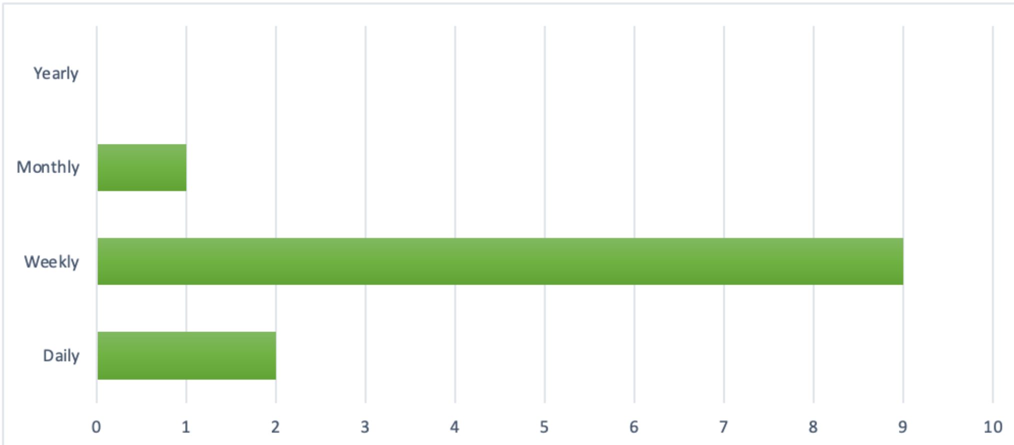
40. Do you have electricity 24 hours a day for 7 days a week?



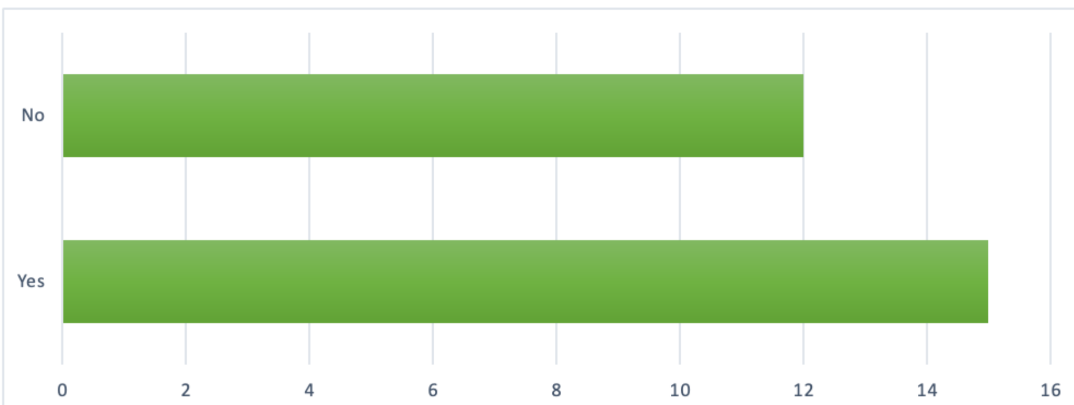

41. Is your electricity source reliable?



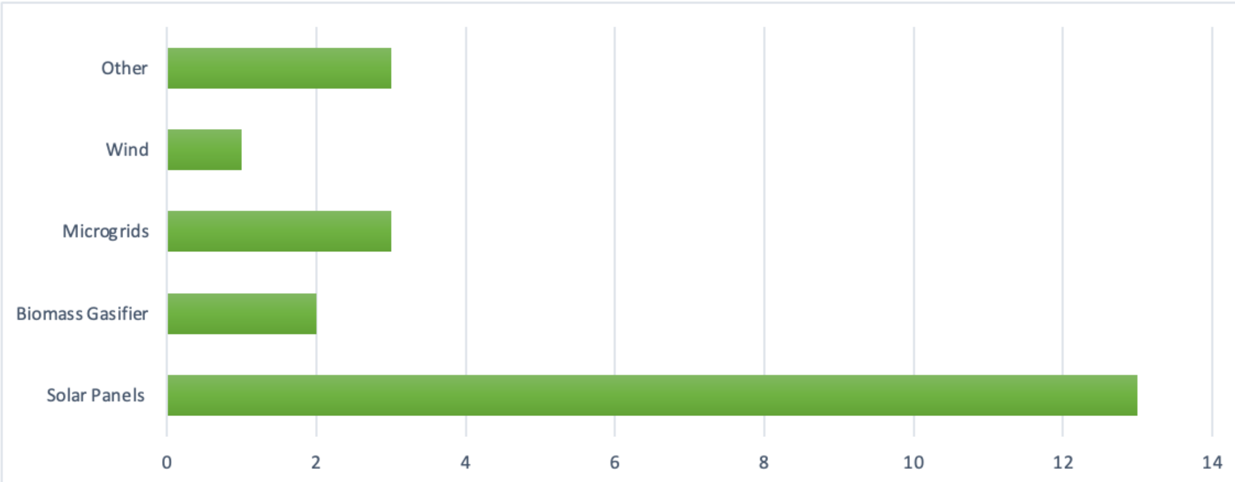
42. How often do you experience electricity outages?



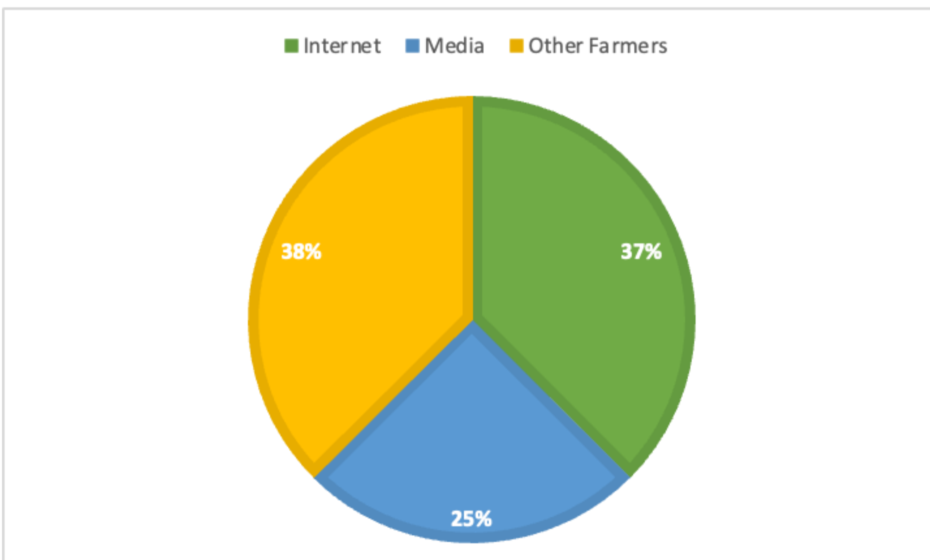

43. Are you familiar with renewable energy technologies?



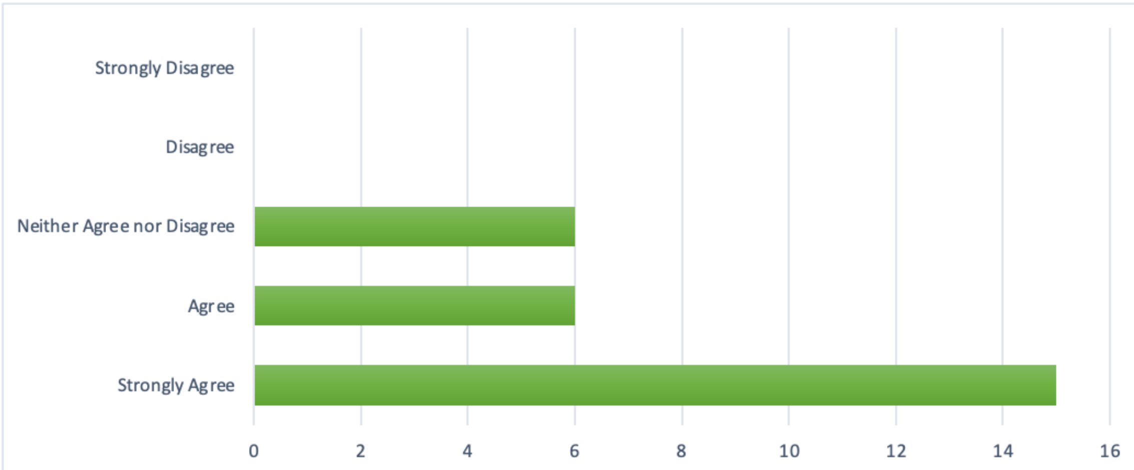
44. If so, what renewable energy technologies are you familiar with? (select all that apply)



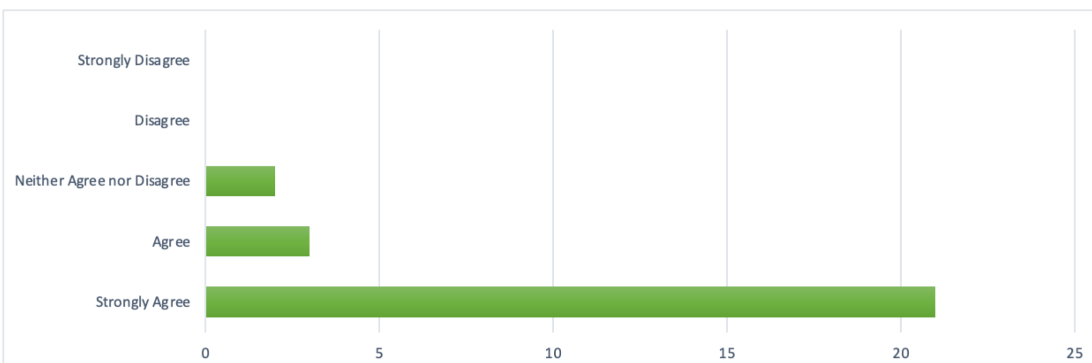

45. How did you learn about these technologies?



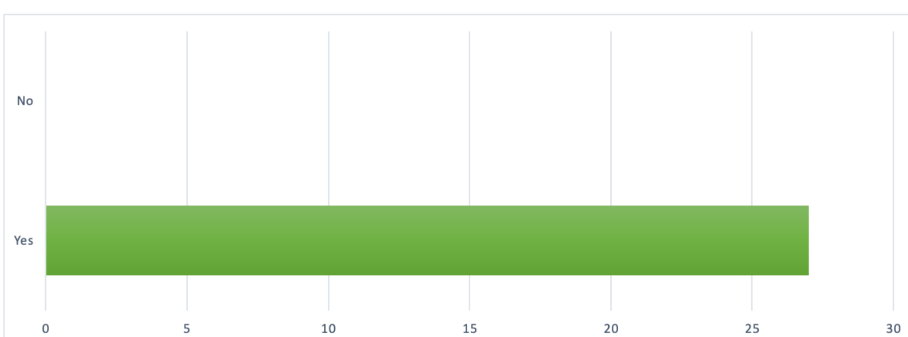
46. Please indicate how much you agree with the following statement: Renewable energy technologies would be feasible within my farming operation (or the farm I work on).



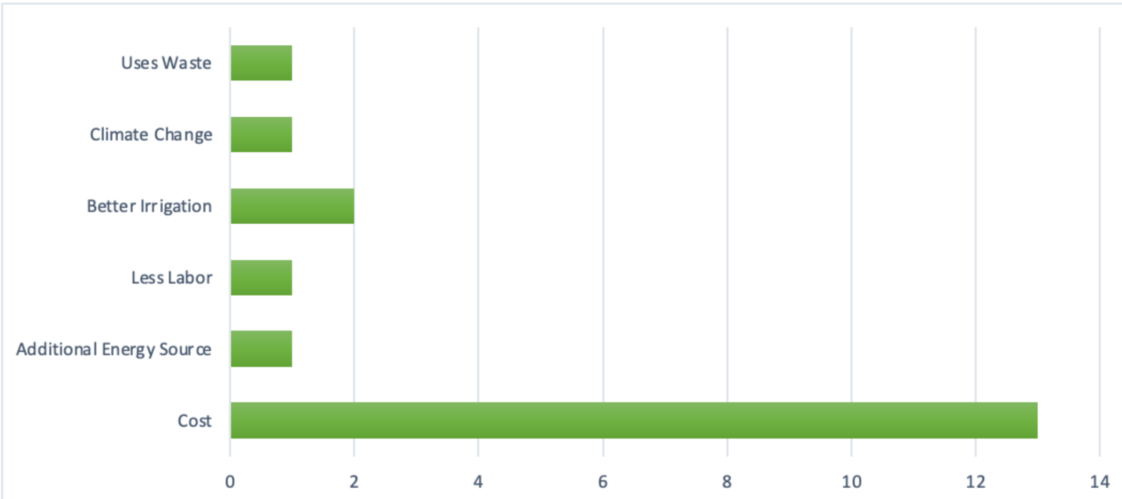

47. Please indicate how much you agree with the following statement: I would like to learn more about renewable energy.



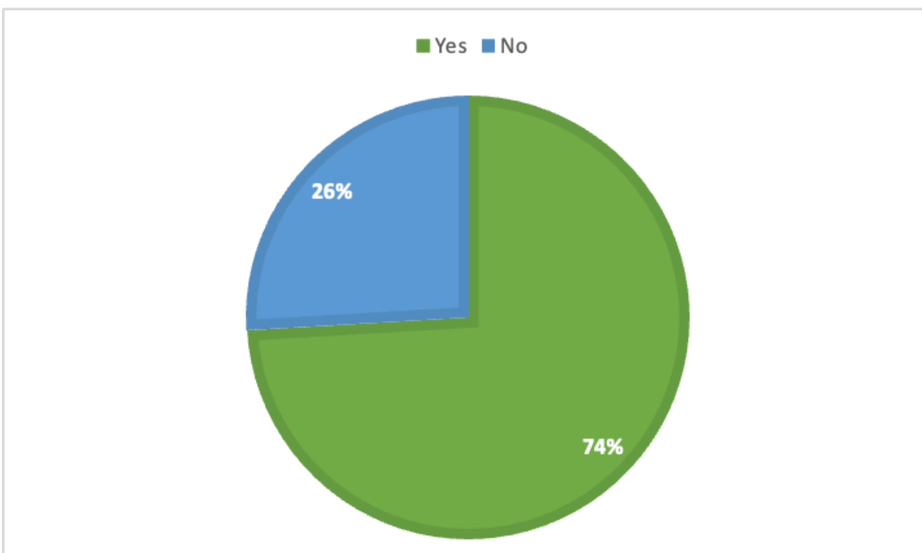

48. I would be more interested in incorporating renewable energy if I could see an example of it in practice.



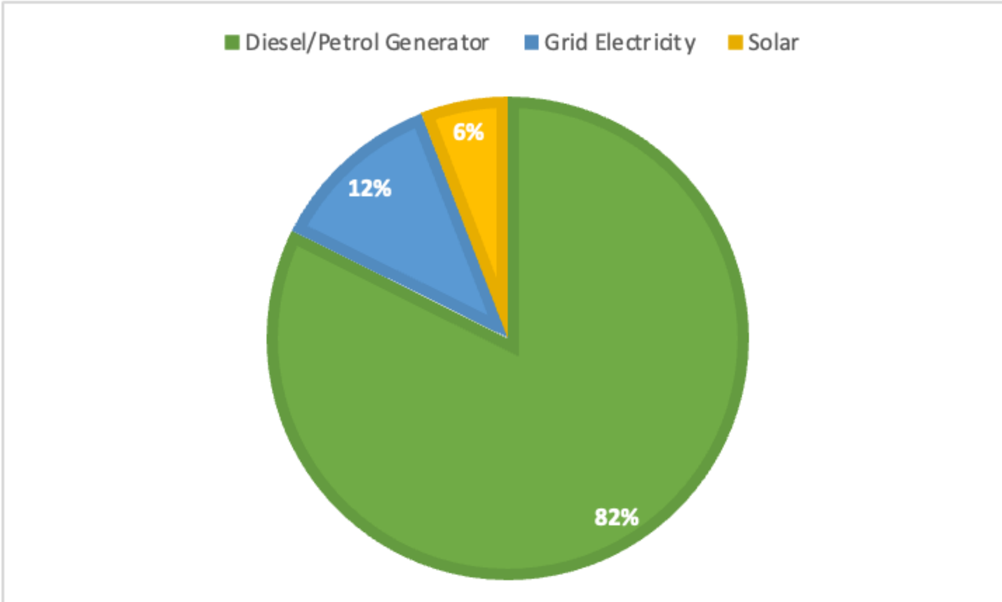
49. What, if anything, attracts you to renewable energy?



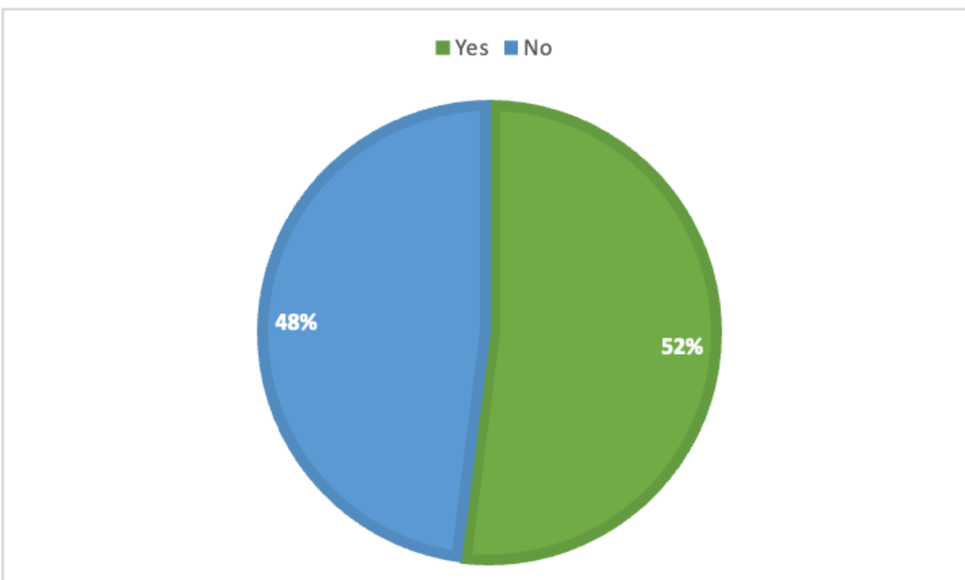

50. Do you need pumps for irrigation?



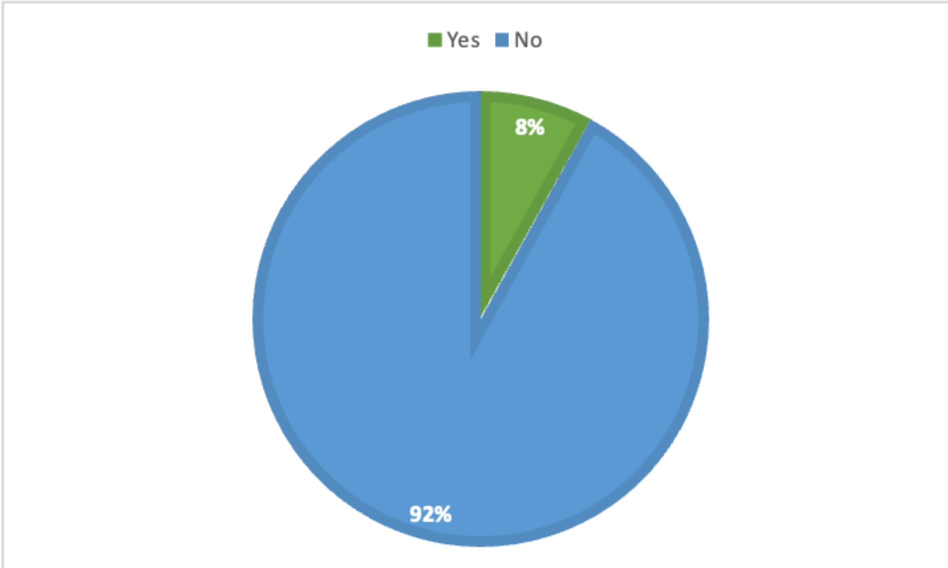
51. What fuel source do you use for these pumps?



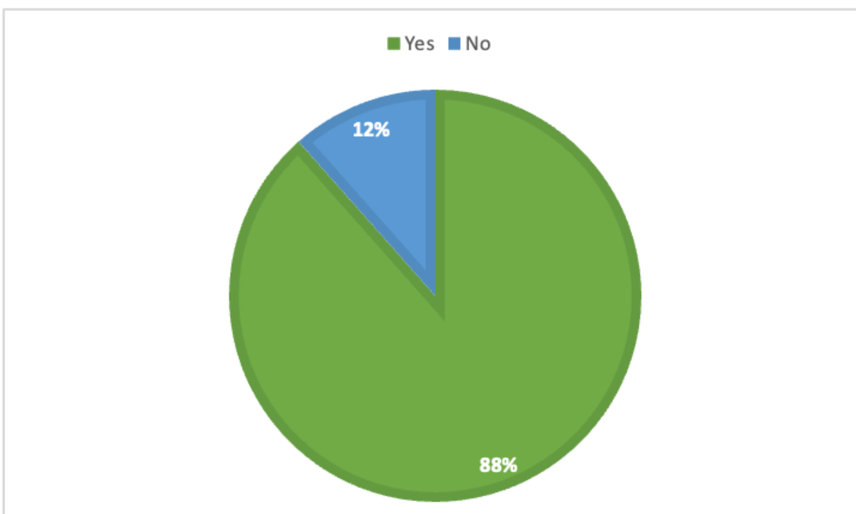

52. Do you need any cold storage for your products?



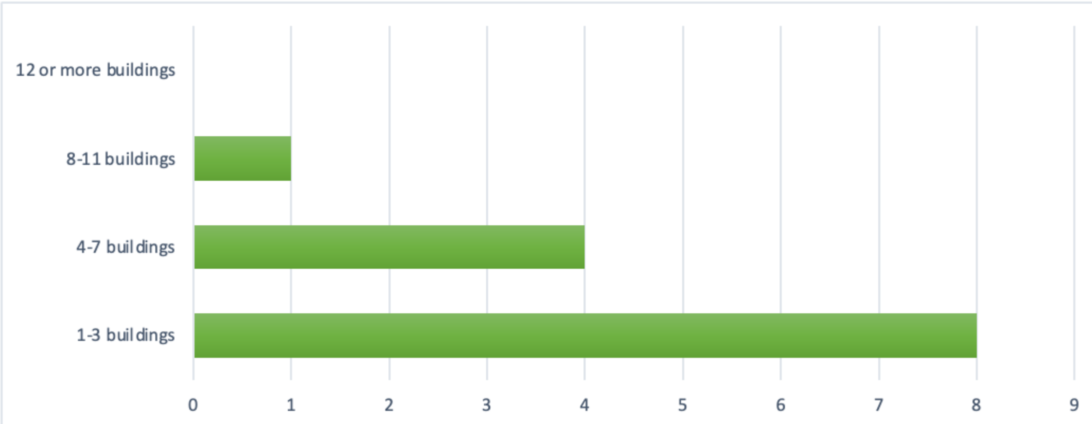
53. Do you have an Abattoir on your property?



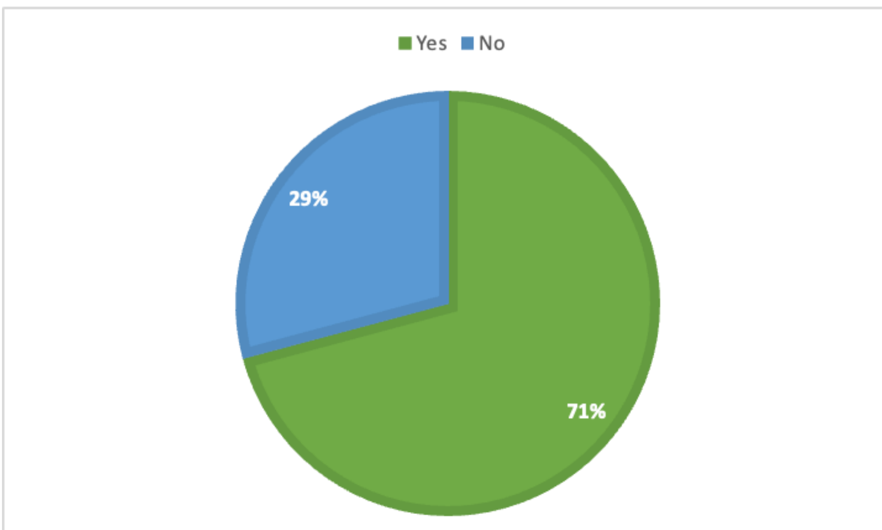

54. Do you need energy for any of the buildings on your property?



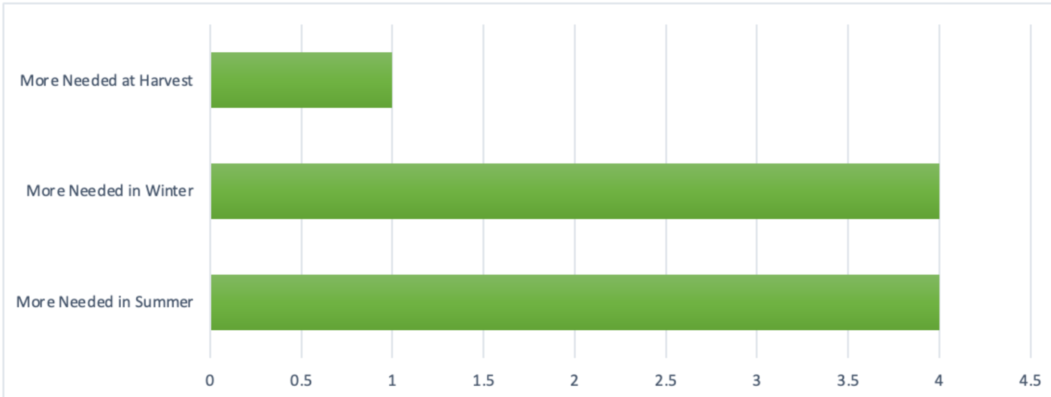
55. If so, how many buildings on your farm need energy?



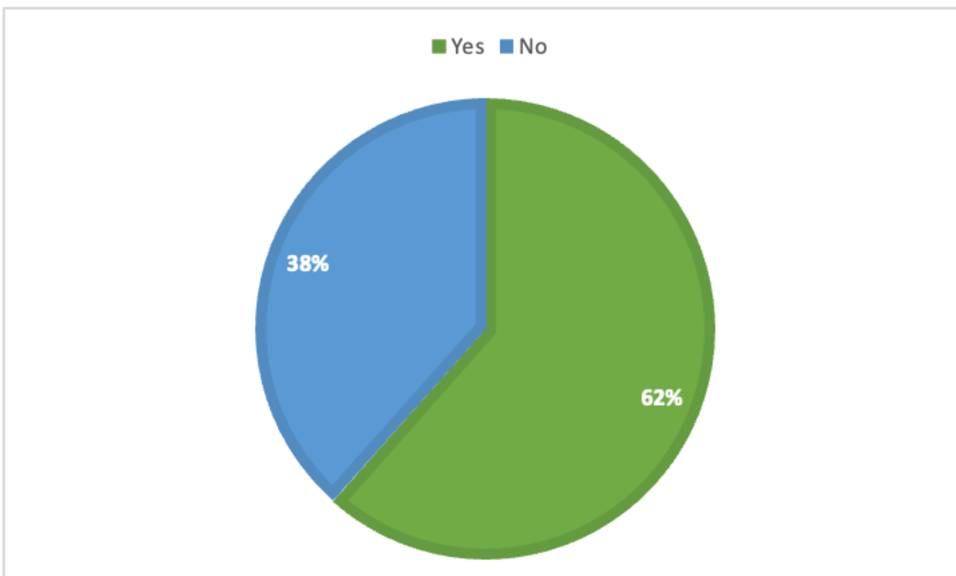

56. Do your energy needs vary during different times of the year?



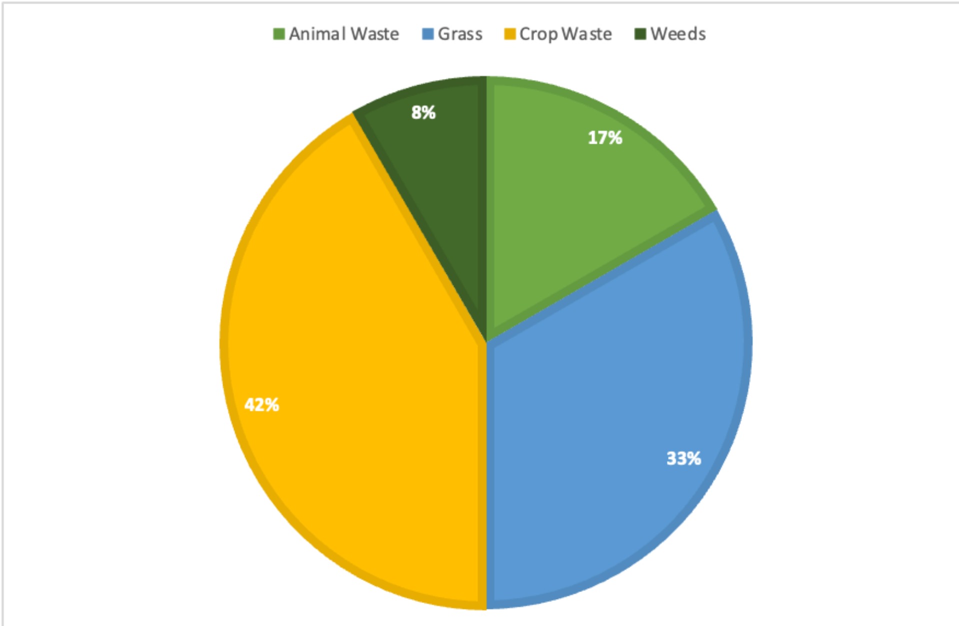
57. If so, how do your energy needs change during the year?




58. Does your farm generate more waste than you can use?

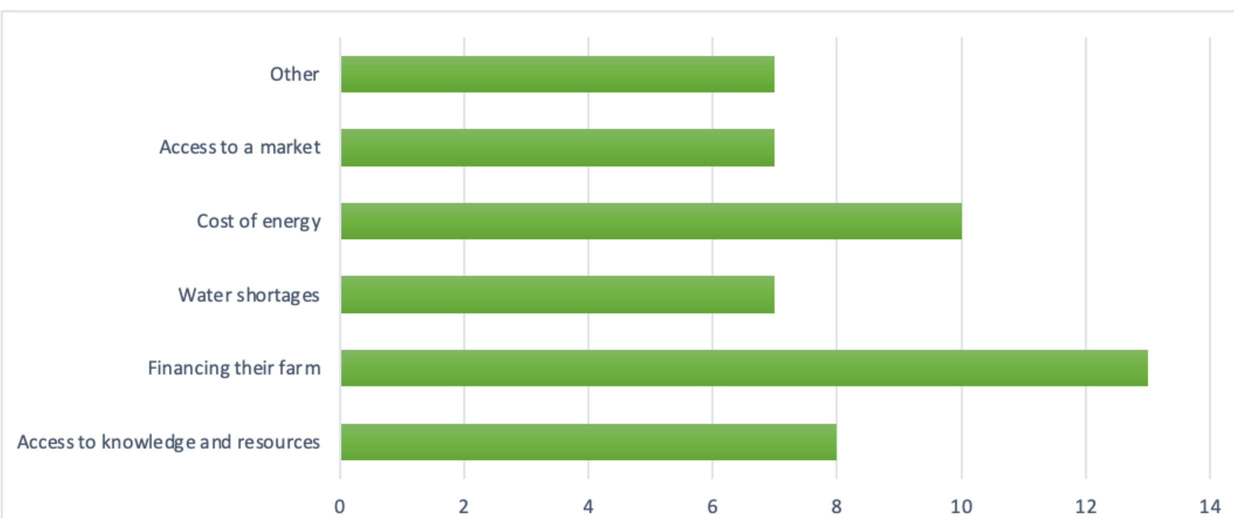


58b. If yes, what type of waste do you have?

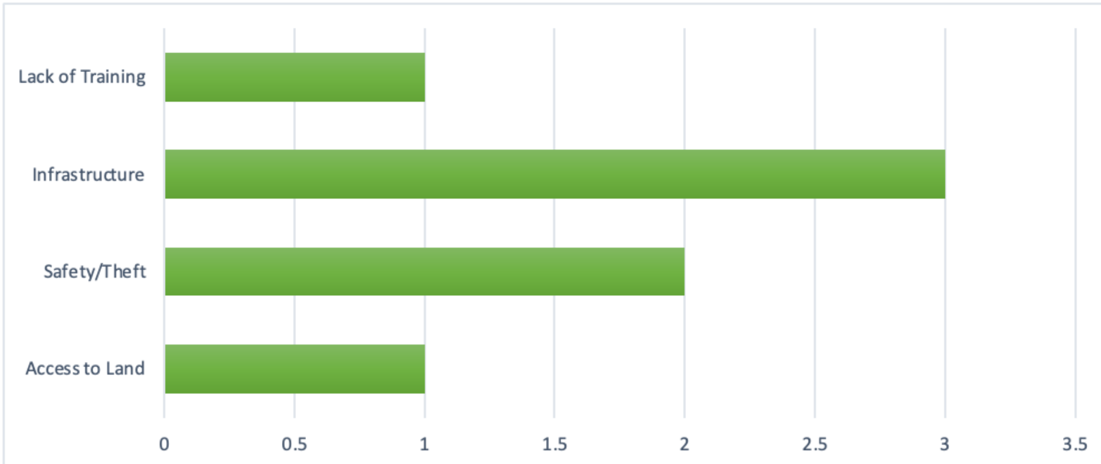



## Opportunities and Challenges

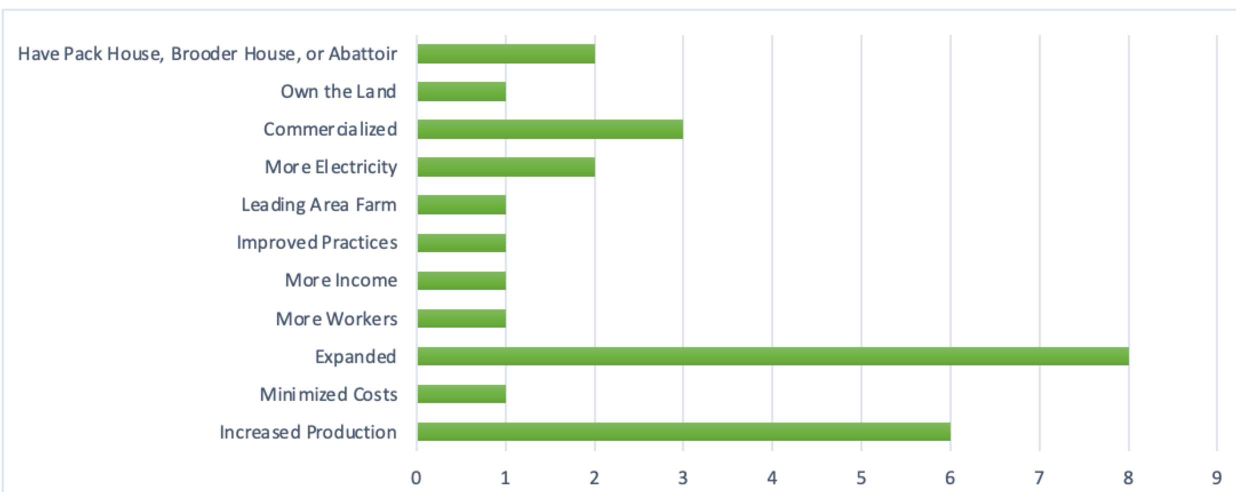
59. What do you see as the greatest challenge faced by small-scale farmers in your area? (Select all that apply)



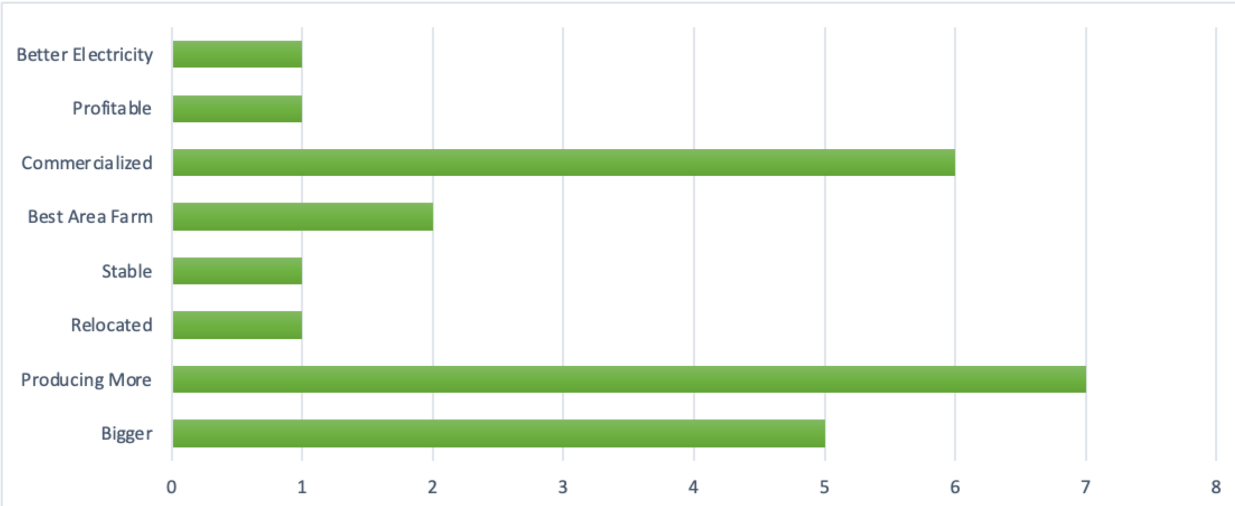
59b. "Other" Responses




60. What future plans and hopes do you have for your farm?



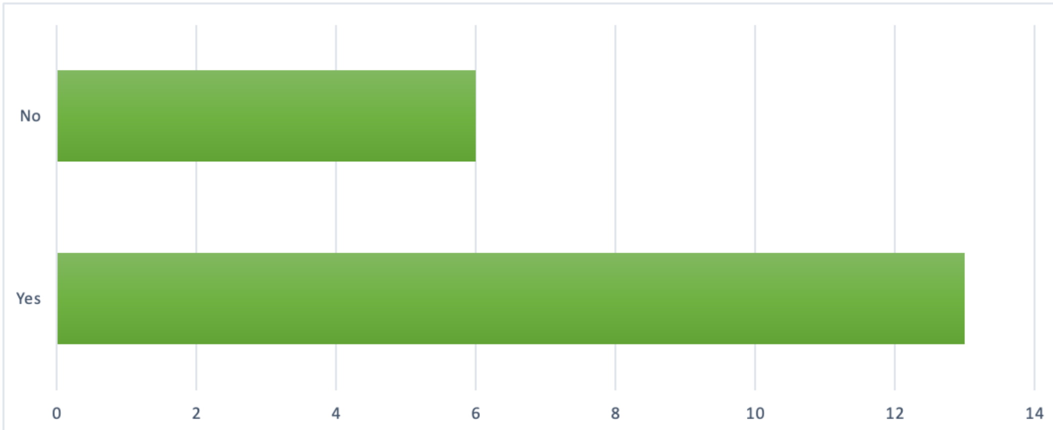
61. Where do you see your farm in 5 years?




62. Where do you see yourself in 5 years?

- “Changing other people’s life”
- “Exactly where I want myself to be”
- “Being the best farmer and a mentor to the up and coming ones”
- “Migrating to other countries”
- “Having another farm as well”
- “Commercialized”
- “As a leading farmer”
- “Making money”
- “Commercial farmer”
- With “too much rainfall”
- “Strong, big farmer”
- “Heading one of the biggest suppliers of veggies, selling at supermarkets”
- With “more cattle and more money”
- “Independent and commercial”
- “Healthy”
- “Successful commercial farmer”
- “Traveling to Ghana”
- “Well-off with a successful farmer”
- “Successful farmer with water and electricity and the ability to travel”
- With a “very big farm that I am in command of”

63. Would you be willing to participate in a group conversation about these topics?



# Appendix B

## Optimization results for varying system architectures

| Optimization Case | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Architecture/PV (kW) | 7.508678 | | 31.73599 | 11.16871 | 11.8551 | | | 53.94012 | | | 63.97917 | | 151.6969 |
| Architecture/Gen100 (kW) | 30 | 30 | 30 | 15 | 15 | 15 | 15 | | | 50 | | | |
| Architecture/Gen (kW) | | | | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | 54 | |
| Architecture/1kWh LI | 8 | 4 | | | 4 | | 4 | 48 | 20 | | | | 756 |
| Architecture/Grid (kW) | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 | 999999 |
| Architecture/Converter (kW) | 5.464179 | 2.092471 | 24.7056 | 8.509841 | 8.21262 | | 0.385417 | 38.48187 | 11.36979 | | 47.21354 | | 106.5898 |
| Architecture/Dispatch | CC | LF | CC | CC | LF | CC | LF | LF | CC | CC | CC | CC | LF |
| Cost/NPC ($) | 184698.8 | 185318.7 | 188779.1 | 193480.5 | 193796.8 | 195105.6 | 196542.3 | 200749.4 | 233630.2 | 239688.4 | 239911.2 | 274625.4 | 482083.8 |
| Cost/COE ($) | 0.069057 | 0.070425 | 0.074594 | 0.092354 | 0.092501 | 0.096725 | 0.097455 | 0.087031 | 0.119292 | 0.071852 | 0.09561 | 0.140224 | 0.117075 |
| Cost/Operating cost ($/yr) | 7662.706 | 8420.164 | 6008.937 | 8579.401 | 8471.389 | 9685.201 | 9707.03 | 7319.949 | 14985.83 | 8871.647 | 10459.23 | 18737.2 | 8258.621 |
| Cost/Initial capital ($) | 85639.08 | 76466.92 | 111098.4 | 82570.17 | 84282.73 | 69900 | 71054.53 | 106120.6 | 39900.67 | 125000 | 104699.4 | 32400 | 375320.3 |
| System/Ren Frac (%) | 66.25629 | 65.42332 | 66.22382 | 51.73079 | 52.00294 | 43.7443 | 43.76948 | 48.54095 | 0 | 69.57146 | 50.55934 | 0 | 75.19434 |
| Gen100/Hours | 4411 | 4871 | 3059 | 4797 | 4675 | 4942 | 4940 | | | 4140 | | | |
| Gen100/Production (kWh) | 125114.6 | 134750.3 | 79893.12 | 65960.88 | 65279.07 | 68646.85 | 68659.65 | | | 183886.8 | | | |
| Gen100/Fuel (tons) | 210.5828 | 226.857 | 134.5827 | 111.0541 | 109.8893 | 115.5646 | 115.5854 | | | 309.698 | | | |
| Gen100/O&M Cost ($/yr) | 2646.6 | 2922.6 | 1835.4 | 1439.1 | 1402.5 | 1482.6 | 1482 | | | 4140 | | | |
| Gen100/Fuel Cost ($/yr) | 2105.828 | 2268.57 | 1345.827 | 1110.541 | 1098.893 | 1155.646 | 1155.854 | | | 3096.98 | | | |
| Gen/Hours | | | | 112 | 111 | 113 | 111 | 143 | 293 | | 506 | 663 | |
| Gen/Production (kWh) | | | | 1572.371 | 1550.226 | 1633.7 | 1605.279 | 2625.321 | 5988.515 | | 7597.248 | 10577.4 | |
| Gen/Fuel (L) | | | | 672.8195 | 664.8992 | 689.9861 | 677.8904 | 1004.818 | 2202.617 | | 3156.156 | 4282.428 | |
| Gen/O&M Cost ($/yr) | | | | 181.44 | 179.82 | 183.06 | 179.82 | 231.66 | 474.66 | | 819.72 | 1074.06 | |
| Gen/Fuel Cost ($/yr) | | | | 1009.229 | 997.3488 | 1034.979 | 1016.836 | 1507.227 | 3303.925 | | 4734.234 | 6423.642 | |
| PV/Capital Cost ($) | 7471.135 | | 31577.31 | 11112.87 | 11795.83 | | | 53670.41 | | | 63659.27 | | 150938.4 |
| PV/Production (kWh/yr) | 13695.83 | | 57886.43 | 20371.72 | 21623.7 | | | 98386.76 | | | 116698 | | 276695.1 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1kWh LI/Autonomy (hr) | 0.277551 | 0.138775 | | | 0.138775 | | 0.138775 | 1.665303 | 0.693876 | | | | 26.22853 |
| 1kWh LI/Annual Throughput (kWh/yr) | 300.9869 | 79.68701 | | | 223.6841 | | 32.19358 | 2852.51 | 2396.263 | | | | 5956.895 |
| 1kWh LI/Nominal Capacity (kWh) | 8.000016 | 4.000008 | | | 4.000008 | | 4.000008 | 48.0001 | 20.00004 | | | | 756.0015 |
| 1kWh LI/Usable Nominal Capacity (kWh) | 4.80001 | 2.400005 | | | 2.400005 | | 2.400005 | 28.80006 | 12.00002 | | | | 453.6009 |
| Converter/Rectifier Mean Output (kW) | 0.029188 | 0.009589 | 0 | 0 | 0.002965 | | 0.003874 | 0.041112 | 0.287942 | | 0 | | 0 |
| Converter/Inverter Mean Output (kW) | 1.446191 | 0.008198 | 5.851609 | 2.082618 | 2.191758 | | 0.003312 | 9.930337 | 0.246533 | | 11.57774 | | 27.34166 |
| Grid/Energy Purchased (kWh) | 69812.73 | 70381.85 | 66121.49 | 76651.41 | 76235.47 | 86143.71 | 86116.52 | 89192.04 | 146062.6 | 78518.71 | 88368.56 | 145822.8 | 79012.27 |
| Grid/Energy Sold (kWh) | 55421.98 | 52106.75 | 44266.69 | 10560.28 | 10566.44 | 4535.898 | 4506.871 | 26931 | -2.49E-14 | 106545.9 | 42606 | 0 | 167062 |

Sensitivity cases for varying cost of biomass resource

| | | | |
|---|---|---|---|
| Sensitivity/Biomass Price ($/tonne) | 10 | 17.5 | 20 |
| Architecture/PV (kW) | 7.508678 | 28.96956 | 27.61309 |
| Architecture/Gen100 (kW) | 30 | 30 | 30 |
| Architecture/Gen (kW) | | | |
| Architecture/1kWh LI | 8 | 8 | 8 |
| Architecture/Grid (kW) | 999999 | 999999 | 999999 |
| Architecture/Converter (kW) | 5.464179 | 21.68095 | 20.7629 |
| Architecture/Dispatch | CC | LF | LF |
| Cost/NPC ($) | 184698.8 | 197896.9 | 199595 |
| Cost/COE ($) | 0.069057 | 0.091418 | 0.094254 |
| Cost/Operating cost ($/yr) | 7662.706 | 6802.277 | 7051.033 |
| Cost/Initial capital ($) | 85639.08 | 109960.3 | 108442.6 |
| System/Ren Frac (%) | 66.25629 | 48.0499 | 44.7823 |
| Gen100/Hours | 4411 | 1347 | 1181 |
| Gen100/Production (kWh) | 125114.6 | 33685.45 | 28711.07 |
| Gen100/Fuel (tons) | 210.5828 | 56.77101 | 48.40292 |
| Gen100/O&M Cost ($/yr) | 2646.6 | 808.2 | 708.6 |
| Gen100/Fuel Cost ($/yr) | 2105.828 | 993.4926 | 968.0583 |
| Gen/Hours | | | |
| Gen/Production (kWh) | | | |
| Gen/Fuel (L) | | | |

| | | | |
|---|---|---|---|
| Gen/O&M Cost ($/yr) | | | |
| Gen/Fuel Cost ($/yr) | | | |
| PV/Capital Cost ($) | 7471.135 | 28824.71 | 27475.02 |
| PV/Production (kWh/yr) | 13695.83 | 52840.48 | 50366.27 |
| 1kWh LI/Autonomy (hr) | 0.277551 | 0.277551 | 0.277551 |
| 1kWh LI/Annual Throughput (kWh/yr) | 300.9869 | 303.9866 | 306.2884 |
| 1kWh LI/Nominal Capacity (kWh) | 8.000016 | 8.000016 | 8.000016 |
| 1kWh LI/Usable Nominal Capacity (kWh) | 4.80001 | 4.80001 | 4.80001 |
| Converter/Rectifier Mean Output (kW) | 0.029188 | 0.022392 | 0.022619 |
| Converter/Inverter Mean Output (kW) | 1.446191 | 5.399722 | 5.157092 |
| Grid/Energy Purchased (kWh) | 69812.73 | 86992.1 | 90451.05 |
| Grid/Energy Sold (kWh) | 55421.98 | 15956.18 | 12311.04 |