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LEAP-RE
Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Joint EU-AU report on agreed project vision

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Summary

This report is the first scientific deliverable of the RE4AFAGRI project (or WP12 of LEAP-RE). The RE4AFAGRI project seeks to support sub-Saharan Africa (SSA) smallholder farmers and communities to grant community-wide access to energy services and water for crop irrigation and human use with the ultimate goal of fostering rural development. It will provide African research institutions and public and private decision makers with the tools and expertise necessary to operate a multi-scale modelling platform that can support the design and implementation of integrated solutions for the energy and water nexus in rural areas. In parallel, RE4AFAGRI will set the ground for a multi-stakeholder discussion platform about the business models and enabling environment (policy and regulation) to promote the involvement of the private sector in water-energy-agriculture integrated solutions.

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LEAP-RE

Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Joint EU-AU report on agreed project vision in the African continent:

"Tailoring research and methods to improve the climate-energy-water-agriculture nexus"

Deliverable D12.2

WP12 of LEAP-RE (RE4AFAGRI)

www.leap-re.eu

https://www.leap-re.eu/re4afagri/

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Acronym

AIF	Africa Improved Foods
FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation Statistics
FRA	Food Reserve Agency
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IAPRI	Indaba Agricultural Policy Research Institute
kWh	Kilowatt hour
PAYGO	Pay as you go
PPP	Purchasing Power Parity
PwC	PriceWaterhouseCoopers
RALS	Rural Agricultural Livelihood Survey
REEEP	Renewable energy and Energy Efficiency Partnership
RE4AFAGRI	Long-term EU-AU Research and Innovation Partnership on Renewable Energy
UNIDO	United Nations Industrial Development Organisation
USAID	US Agency for International Development
WFP	World Food Programme
WP	Work Package
SSA	Sub-Saharan Africa

Executive Summary

This report is the first scientific deliverable of the RE4AFAGRI project (or WP12 of LEAP-RE). The RE4AFAGRI project seeks to support sub-Saharan Africa (SSA) smallholder farmers and communities to grant community-wide access to energy services and water for crop irrigation and human use with the ultimate goal of fostering rural development. It will provide African research institutions and public and private decision makers with the tools and expertise necessary to operate a multi-scale modelling platform that can support the design and implementation of integrated solutions for the energy and water nexus in rural areas. In parallel, RE4AFAGRI will set the ground for a multi-stakeholder discussion platform about the business models and enabling environment (policy and regulation) to promote the involvement of the private sector in water-energy-agriculture integrated solutions.

In order to ensure a fruitful implementation and effective impact of the RE4AFAGRI activities, it is of utmost importance that African realities are properly identified and integrated in the modelling and business development activities, and this is the main aim of the present report which is based on Task 12.1 of the project. The outcome of this report serves as an input for the follow-up research activities of the RE4AFAGRI project and more precisely for Tasks 12.2-3 (modelling integration; data collection, calibration and validation) and Task 12.4 (business model research). Moreover, such insights are also fundamental for the capacity building activities planned as part of Tasks 12.5 (modelling training) and 12.6 (policymakers and stakeholders capacity building).

The report focuses on the agriculture-energy-water and development nexus in the SSA region. The literature review and analysis of international databases allowed to highlight strengths and weaknesses of the sub-Saharan area region in this respect, with specific attention to heterogeneities across countries and their specific and also challenges and opportunities. The analysis then focused on Nigeria, Rwanda, Zambia and Zimbabwe where a series of focus groups discussions with national stakeholders (representing farmers associations, renewable energy developers, irrigation experts and policy makers) were organised.

The first important conclusion is that there are both cross-country similarities and notable country (or sub-national) specificities with regards to the agriculture-energy-water-development nexus issues and challenges analysed in RE4AFAGRI. These characteristics pertain the environmental (climate, land, ground and surface water availability), agricultural (dominant crops, irrigation practices and infrastructure, crop processing machinery availability), market (sale and purchase of crops, market structure), infrastructure (power grid, roads), energy (rural electricity access, diffusion of diesel vs. solar pumping systems), socio-economic development (GDP per-capita, farmer disposable income), and market conditions (regulatory framework for decentralised energy access, risk and interest rates).

The most prominent similarity between different countries in SSA pertains to the relevance and typology of agriculture: about 80% of agricultural land in SSA is cultivated by smallholder farmers, i.e. farmers owning and/or managing only few hectares of land (in general, 0.5 – 2 hectares per household), part of which is used for subsistence and part for yield sale to market. This picture is confirmed both by literature and data-driven insights, and by stakeholder engagement activities, where the salient characteristics of smallholder farming in SSA were discussed. In parallel, another crucial similarity refers to the availability of irrigation: more than 90% of cultivated cropland in SSA is rainfed, with irrigation covering mainly specific large-scale farms or limited pilot schemes. Erratic rainfall – exacerbated by climate change impacts – and the difficulty of cultivating water-intensive profitable crops (most prominently vegetables) outside of the rainy season was systematically listed by stakeholders from different countries and sectors as a key reason behind the persistent poverty of SSA smallholder farmers, together with the year-to-year variation in yields and revenues, in turn jeopardising food security and the possibility of the farmers to perform multi-year infrastructure investments to be paid in instalments.

Thus, a core result of the analysis is that the structural challenges of the agricultural production system are rather consistent across SSA. Irrespective of this apparent similarity, crucial differences are and will increasingly have an important impact on the design of infrastructure and policy (and on the investment implications) to foster agricultural development in different SSA countries. For instance, focus group discussions highlighted the heterogeneous situation in terms of the location of the smallholder farmer-owned agricultural land compared to the rural village core, ranging from a few hundred metres to up to 3-5 km. This range of variability depends on the geographical and morphological configuration of each country, as well as on the speed of communities clustering and urbanisation in rural areas: for instance, a small and relatively dense country like Rwanda shows a much closer proximity of cropland to villages than a vast and scarcely populated country like Zambia. These types of geographical differences play a key role in the economic trade-off between different electricity supply, water pumping, and irrigation systems. They thus must necessarily be factored into the modelling assumptions and business model design if realistic results are to be provided to stakeholder active in this domain.

Additional aspects that were found to be very variable depending on the socio-economic, policy, and business context in question include the degree of livelihood of the policies and market for solutions seeking to tackle the above-mentioned challenges. Historically more homogeneous, SSA is becoming increasingly polarised in terms of countries and systems capable of attracting private or development infrastructure financing (thanks to regulation, political and economic stability, and local entrepreneurial culture), and those who struggle to witness a surge in capital inflows into rural development projects.

Different levels of market development and value chain dynamics result in differentiating potential business models within a country's specific context, tailoring these to each individual need. For example, the more developed small-scale crop processing sector in Nigeria could probably adapt more easily to new and innovative business models than Rwanda which presents a nascent small-scale processing sector. At the same time, distinct levels of government intervention in some crop commodity prices, such as in the Zambia and Zimbabwe maize value chain, require the business model analysis to consider different approaches tailored to each case.

Nonetheless, similarities regarding business models and enabling environments between countries can also be found. Focus Group Discussion insights provide a high-level overview of relevant government support mechanisms, and some of them are replicated in many cases, such as the Rwandan and Zimbabwe government subsidies to access solar pumps and post-harvest processing machinery. In addition, the presence of cooperative-owned processing equipment rather than individual farmer ownership in Nigeria, Rwanda, and Zambia, for example, makes the case for business models to be properly adapted to this market segment.

1 Introduction

This report is the first scientific deliverable of the RE4AFAGRI[1] project (or WP12 of LEAP-RE).

The RE4AFAGRI project seeks to support sub-Saharan Africa (SSA) smallholder farmers and communities to grant community-wide access to energy services and water for crop irrigation and human use with the ultimate goal of fostering rural development. It will provide African research institutions and public and private decision makers with the tools and expertise necessary to operate a multi-scale modelling platform that can support the design and implementation of integrated solutions for the energy and water nexus in rural areas.

In parallel, RE4AFAGRI will set the ground for a multi-stakeholder discussion platform about the business models and enabling environment (policy and regulation) to promote the involvement of the private sector in water-energy-agriculture integrated solutions.

To achieve these overarching aims, the core actions that are pursued by the RE4AFAGRI project consist of:

- Advancing the state-of-the-art of energy-water nexus modelling in rural areas of developing countries to bridge the current gap between large-scale and local-scale frameworks and agricultural and electrification modelling.
- Delivering a set of open-source validated tools developed through both analytical and empirical approaches that can be exploited by African stakeholders in future applications.
- Designing business models allowing to implement integrated energy-water solutions in rural areas, based on identified best practices, regulatory hurdles and opportunities through the participation of African businesses, public authorities, and smallholder consortia.
- Providing capacity building activities for African research institutions to enable the use of the integrated water-energy assessment platform developed; African entrepreneurs to enable the implementation of technological solutions through the identified business models; African public administrations to establish the required policy frameworks needed for a successful replicability, scalability and transferability.
- Supporting policymakers in establishing policy frameworks that ensure that the business models identified can be successfully implemented by local entrepreneurs while also meeting the technical and environmental requirements to fulfil development objectives in rural areas.

In order to ensure a fruitful implementation and effective impact of the RE4AFAGRI activities, it is of utmost importance that African realities are properly identified and integrated in the modelling and business development activities, and this is the main aim of the present report.

The present report represents the outcome of the first task (12.1) of the RE4AFAGRI project "Tailoring research and methods to African realities". Its objectives are to:

- set the right context, i.e. making sure that a clear understanding of the different African local contexts and of the real challenges involved is shared among all project partners;
- making sure that the right questions to be addressed are identified; and
- that the right solutions are considered, i.e. that only solutions that are truly implementable in the rural African context are selected.

[1] See the official project webpage: https://www.leap-re.eu/re4afagri/

The task which is on the basis of the present report was carried out with a tight collaboration among all RE4AFAGRI partners and actively involved many stakeholders in Sub-Saharan Africa. The present report combines a wide literature research on past experiences related to the climate-water-renewable energy-agriculture-development Nexus in sub-Saharan Africa with in-depth stakeholder engagement activities.

The final aim of the report is thus to get a better understanding of African realities in order to advance the local and expert-sourced knowledge on the climate-water-renewable energy-agriculture-development Nexus in sub-Saharan Africa. This is both an end in itself and instrumental for implementing the subsequent activities in the project.

In particular, the outcome of this report serves as an input for the follow-up research activities of the RE4AFAGRI project and more precisely for Tasks 12.2-3 (modelling integration; data collection, calibration and validation) and Task 12.4 (business model research). Moreover, such insights are also fundamental for the capacity building activities planned as part of Tasks 12.5 (modelling training) and 12.6 (policymakers and stakeholders capacity building).

This document is organized in 5 chapters.

Chapter 1 focuses on introduction to the activities of the RE4AFAGRI project. The core actions of this project are highlighted and a general introduction on Sub-Saharan Africa challenges and opportunities in agriculture are presented. The second part of this chapter contextualizes the project framework.

Chapter 2 focuses on the agriculture-energy-water and development nexus in the SSA region. The analysis of international databases allows to highlight strengths and weaknesses of the sub-Saharan area region, with specific attention to heterogeneities across countries and their specific challenges and opportunities. This analysis is preparatory to identifying the characteristics of the countries that have been defined as focus areas of the RE4AFAGRI project and that will support the development of the modelling and business model research activities in the next tasks.

Chapter 3 collects the results of literature analyses that provide detailed information for the target countries. Regarding the agriculture supply chain, the management of water for irrigation and the crop processing typical of each target country are described.

Chapter 4 presents the organisation and the results achieved through the survey with individual stakeholders and with focus groups discussion with experts. The goal is to bring out challenges, weaknesses and opportunities related to development of a sustainable agriculture.

Finally, chapter 5 summarizes the main conclusions related to the task “Tailoring research and methods to improve the climate-energy-water-agriculture nexus”, providing comparative insights on the countries under analysis.

1.1 Sub-Saharan Africa challenges in agriculture

About 80% of the agricultural production of sub-Saharan Africa comes from smallholder farmers (Harris & Consulting, 2014). These represent about 60% of the regional population (Goedde et al., 2019), against a global figure of 29% (Ricciardi et al., 2018).

Extensive rain-fed agriculture (>90% of cropland, Abrams, 2018), compared to e.g. about 60% in India, (The World Bank, 2019) under the unpredictable and erratic rainfall patterns exacerbated by climate change (Akinsanola & Zhou, 2019; Onyutha, 2020) has been the leading cause of the low agricultural productivity and food insecurity (Connolly-Boutin & Smit, 2016), together with a low degree of mechanisation (Gumbe, 2020). For instance, it is estimated that only 10% of farm power in rural SSA is mechanised (FAO, 2007). In addition, estimates suggest that 10-20% of grains are systematically lost after harvest because of the lack of storage, processing and cooling equipment (World Bank, 2011). Lack of access to transport means and a scarce road infrastructure are further crucial barriers to the marketability of local crops production (Berg et al., 2018; Porter, 2014). Finally, over 90% of forest loss in Africa is attributed to “shifting agriculture” or “slash and burn” practices, which are significantly driven by low agricultural productivity - requiring more land and fertilisation by forest burning (Curtis et al., 2018).

In this fragile context, most households (75% of rural SSA according to IEA & IRENA, 2019) and businesses (Blimpo & Cosgrove-Davies, 2019) lack reliable electricity access. In fact, about 470 out of 640 million rural dwellers contributing to the global electricity access gap are concentrated in SSA (IEA & IRENA, 2019). Not by chance, the share of agricultural output processed through electrified value chains is estimated to account for only about one tenth of the total (Banerjee et al., 2017). Lack of electricity also affects the capacity to pump water for irrigation purposes: in the few irrigated areas, small and medium-scale diesel-powered water pumps are prevalent and - because of the recurrent need for fuel - their operation largely relies on both farmers’ finances and public subsidies (Bertheau et al., 2015; Kojima et al., 2014), burdening national energy utilities with debt (Trimble et al., 2016), and continuing a reliance on fossil fuels and local pollution. This adds to the very low levels of access to clean drinking water and basic sanitation services (respectively 60% and 30%), which show strong linkages to energy access (Cloutier & Rowley, 2011), and in some cases also trade-offs with irrigation plans (Eberhard, 2019).

Few frameworks representing the Nexus have paid explicit attention to the question of local access to electricity, including the specific link between water needs, electricity demand, climate change, the local system configuration and investment costs, and the consequences for financing energy and water supply technologies (Falchetta et al., 2021). These analyses show that rural development and climate resilience are not possible without a transformation of the agricultural production system, which in turn relies on the provision of sustainable energy (Ramos et al., 2020; Sridharan et al., 2019). However, many of these intersections remain scarcely explored, modelled, and translated into technological, economic, and business model implications.

Moreover, whilst previous literature has investigated some of the interlinkages between agriculture, energy access, water supply, climate change, and socio-economic development, these studies have mostly been characterised by a descriptive approach, with few Nexus infrastructure and investment planning-oriented analysis.

1.2 State of the art of the knowledge

Broadly, the past literature can be divided into three main strands: (i) position papers highlighting the importance of energy for agricultural development and recommending actions to be taken at different levels; (ii) energy requirements assessments in the context of agricultural development and energy access planning; and (iii) research assessing specific technologies or value chain along the climate-water-energy-agriculture-development Nexus.

With regards to the first strand, Dubois et al. (2017) examine the intersection between energy access, food, and agriculture. They investigate the role of the energy input in the agricultural supply chain, while also highlighting that the agricultural sector can be a source of energy, e.g., through gasification of residuals. Relatively to business models for financing energy access, the authors discuss the concept of using the agri-food chain to support the anchor model, further discussed in Falchetta (2021). Shirley (2021) explores the interactions between agriculture, energy, economy, trade, climate resilience, and livelihoods across SSA, describing the opportunities for an intersectional approach to interventions at the food-energy Nexus. In addition, Shirley (2021) develops recommendations to support smallholder access to value-addition supply chains in Africa through a suite of reforms engaging smallholder farmer cooperatives to ensure increased bargaining power, encourage a rapid and targeted deployment of mini-grids in village communities involved in staple and cash crop farming, and foster the creation of incentives for increasing access to micro- and commercial finance for farmers and cooperatives.

Related to the second strand, Best (2014) investigates energy needs in smallholder agriculture, identifying two main types of direct energy requirements for raising productivity: (i) energy for transport to take goods to market and supply other key services that farmers need and (ii) energy for production, processing, and commercialization of products. In the second category, the author argues that the most pressing needs come from land preparation, irrigation, crop processing, and storage. The paper highlights how value chain analysis can help pinpoint energy needs and opportunities, while also attributing considerable importance to gender-related issues. Shirley et al. (2021) uses geospatial analysis to identify priority areas for serving on- and near-farm electricity demand, using maize and coffee farming in Uganda as a case study. The authors identify significant areas of underserved staple and cash crop farmlands that can be served through grid and mini-grid electricity access within the next ten years. In addition, Nilsson et al., (2021) develop a GIS-based approach to estimate electricity requirements for small-scale groundwater irrigation and apply it to the case study of Uganda.

With regards to the third strand, Guta et al (2017) assess the challenges and opportunities from the use of decentralised energy supply systems from a Nexus perspective based on different real-world case studies. The findings indicate that access to modern decentralized energy solutions has not resulted in complete energy transitions due to various trade-offs with the other domains of the Nexus. On the other hand, the case studies point at the potential for improvements in food security, incomes, health, the empowerment of women, and resource conservation with synergies between decentralized energy solutions and other components of the Nexus. Best (2014) also reviews empirical evidence on the impacts of energy inputs in smallholder agriculture and processing based on nine case studies in the rural Global South. These case studies regard different energy consuming infrastructure installations (e.g. dryers, cooking units, mills, storage facilities, treadle pumps and irrigation systems) and analyze their impact on an array of development indicators (e.g. crop yield, farmer income, post-harvest losses, food security, production costs, crop sale price, time saved by women). In all cases, a robust improvement of the development indicators inquired is reported. Parkinson and Hunt (2020) investigate the economic potential for rainfed agrivoltaics in groundwater-stressed regions, namely the potential to co-locate crops with solar photovoltaics to enable irrigation in currently rainfed only cropland, highlighting significant synergetic potential and co-benefits across land, energy, and water systems.

In addition, Gupta (2019) investigates the causal impact of solar water pumps on the consumption of water and energy in Rajasthan, India. This study shows that food security, cropping intensity and extension, and income security all benefit from the adoption of solar pumps, although with the side-effect of increasing resource consumption. Omoju et al. (2020) examine the impact of electricity access on agricultural productivity from a cross-country and macro perspective. Using panel data on 45 SSA countries (1980–2017), they find that promoting rural household electrification might not be sufficient for enhancing agricultural productivity. They argue that rather, policymakers should focus on electricity infrastructure intervention that supports the entire agricultural value chain.

As seen, most of the literature on rural water, electricity access and synergies with agriculture are empirical and data-driven studies reviewing historical developments and current situation (Candelise et al., 2021; de Strasser & Hafner, 2017; Mabhaudhi et al., 2018). There is a paucity of studies elaborating integrated models to plan and estimate impacts of possible future investments while elaborating on how to actually implement solutions given local financing and regulatory conditions. Current Nexus models mostly focus on centralized energy systems and their relations with water systems (e.g. hydropower, power plant cooling) (Joint Research Centre - European Commission et al., 2018; Welsch et al., 2014), which are not suitable for assessing the requirements for rural and decentralized systems. In addition, Nexus models that explore access to energy and water in rural areas require high spatial resolution given the high sparsity and heterogeneity of settings affected by these issues (Almulla et al., 2020).

1.3 The contribution of the RE4AFAGRI project and methodology for this report

In this context, Figure 1 presents a schematic framework of the paradigm proposed in the RE4AFAGRI project, which mutually integrates energy access and the Nexus dimension.

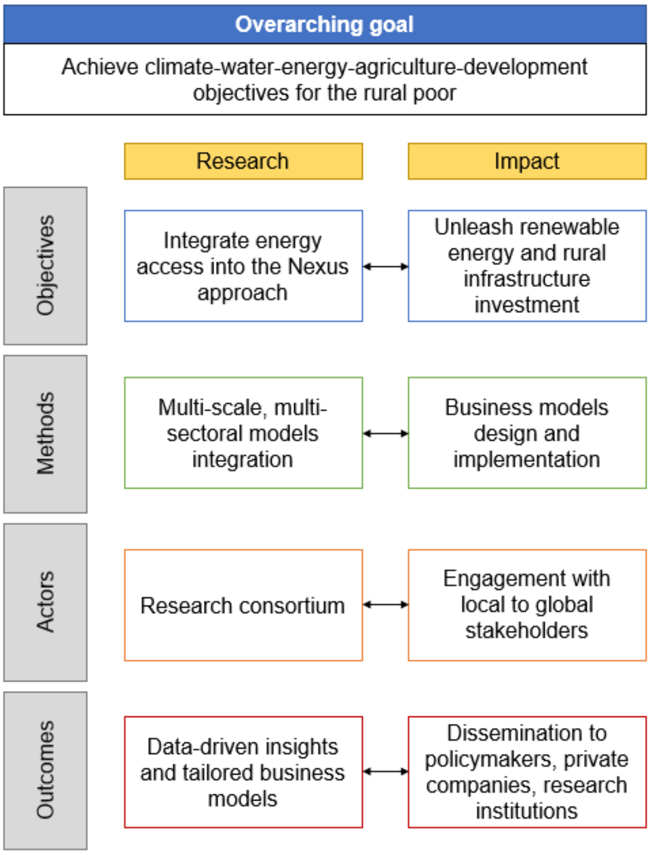

Figure 1 - Proposed framework for the energy access - Nexus research interlinkage proposed in this paper

Starting from an overarching Nexus development goal, the framework ("Objectives" row) seeks to integrate energy access explicitly into existing Nexus analytical instruments ("Research" column) in order to inform decision-making and promote cross-sectoral investment ("Impact" column). To achieve these aims, the framework proposes ("Methods" row) to operate a multi-scale (from local-level to basin and country-level) and multi-sectoral (encompassing water and energy demand assessment and water, energy, climate change, and land infrastructure supply planning) model integration exercise. In parallel and coordination with the above methods, it is further proposed to design and promote business models to achieve such desirable transformations. Concerning the actors involved ("Actors" row), the framework spans from the research consortium itself and the local stakeholders (e.g., Ministries, rural development agencies, crop value chain businesses, energy access system developers), up to global institutions (e.g., development banks and global research organisations). The interaction with stakeholders is crucial to the definition of the technological space to be considered, as well as the scope of the modelling work to ensure the relevance of the questions addressed and the underlying analytical assumptions. The desired result ("Outcomes" row) of the proposed research agenda is to supply policymakers, private companies, research institutions and individuals with data-driven insights to assess technological requirements and prioritise investment flows, as well as with suitable business models that are centred around both the technical and the social aspects relevant to the contexts inquired.

To achieve these overarching goals, the first Task (12.1: "Tailoring research and methods to African realities") of the RE4AFAGRI project carried out a literature review across sub-saharan African countries and subsequently focused its analysis on four countries (Nigeria, Rwanda, Zambia and Zimbabwe) where also a series of focus groups discussions with national stakeholders were organised:

- **Nigeria**
  - Value Seeds Limited
  - Kwara State University
  - Green Village Energy
  - MAX.NG
  - Ahmadu Bello University
  - FutuX Agri-Consult
- **Zambia**
  - Zambia Renewable Energy Association
  - Zambia Rural Electrification Authority
  - Ministry of Agriculture
  - Muhanya Solar
  - Musika
  - Zambia Agriculture Research Institute
  - ENGIE Power
- **Rwanda**
  - Rwanda Agriculture Board
  - ECM - Rwanda
- **Zimbabwe**
  - Samansco
  - Renewable Energy Association of Zimbabwe
  - Mobility for Africa
  - University of Zimbabwe
  - FAO consultants
  - Agricultural Research Trust
  - Farmers Association of Community Self-Help Investment Group.

In parallel, the RE4AFAGRI project organised discussions with four key international organisations and think tanks involved in the topics at the center of RE4AFAGRI:

- Bilateral focus group with the **Food and Agriculture Organisation** (FAO) of the United Nations
- Bilateral focus group with the **World Resources Institute**
- Bilateral focus group with **Practical Action**
- Bilateral focus group with the **United Nations Industrial Development Organisation** (UNIDO)

The purpose of this document is to combine the literature research with the contribution of these stakeholder engagement activities in order to identify the main parameters for advancing the locally and expert-sourced knowledge on the climate-water-renewable energy-agriculture-development Nexus in sub-Saharan Africa.

2 Agriculture-energy-water-development nexus in SSA

This Chapter analyses a broad range of indicators related to the climate-energy-water-agriculture-development nexus across sub-Saharan African countries and presents the methodology adopted in the selection of indicators (taxonomy) and target countries for the stakeholder engagement activities.

The analysis of the indicators allows clustering different countries by their degree of similarity to generalise part of the conclusions of the project, even in the absence of proper data collected and modelling carried out in all the countries. In any case, the methodology is developed coherently with the replicability and scalability principles underpinning RE4AFAGRI, and it thus bears the potential to be applied to other countries in the SSA region (Figure 2)

2.1 Sub-Saharan Africa: an overview

Given the objective of RE4AFAGRI to facilitate the impact of renewable energy access on agriculture, particularly smallholder farming, the study focuses on SSA where there is a wide deficit on energy access yet with agriculture as a predominant occupation.

Figure 2 – Africa map

According to the African Energy Portal managed by the African Development Bank, in 2019 the Northern Africa region has 97.6% electricity access (Urban: 98.7% and Rural: 96.1%); while the SSA electricity access rate stands at 48.4%. This data, among other factors, suggest SSA as a priority region for the analysis, hence the focus of the study only on SSA countries.

South Africa is within the SSA region, but its electricity access rate (85 %) differs widely from that of most sub-Saharan African countries (and chiefly their rural areas), as well as for other development indices. Also, Mauritius and Seychelles - small island states - differ significantly from the typical SSA country. Indeed, Mauritius and Seychelles have 100% rural electrification rates. Moreover, the two countries have the lowest agricultural area per capita, highest proportion of agricultural lands equipped for irrigation, highest life expectancy rates and the lowest rates of severe food insecurity. Mauritius is among the top 20 economies in terms of improved ease of doing business score, ranking 13th in the world. For all these reasons, South Africa, Mauritius and Seychelles are outside the scope of this project.

In conclusion, also based on language-related considerations, the focus of the study has been on continental anglophone countries in Northern, Western, Central, Eastern and Southern Africa (except South Africa).

Though sub-Saharan African countries, Somaliland and Eritrea are not considered due to paucity of data on the selected indicators for the study, leaving the study to cover 21 SSA countries.

The complete list of selected countries (clustered in region and in alphabetical order) reads:

Northern Africa: Sudan
Western Africa: Gambia, Ghana, Liberia, Nigeria, Sierra Leone
Central Africa: Cameroon, Ethiopia
Eastern Africa: Burundi, Kenya, Malawi, Rwanda, South Sudan, Tanzania, Uganda, Zambia, Zimbabwe
Southern Africa: Botswana, Lesotho, Namibia, Swaziland

Figure 3 shows the share of the population with access to electricity. It is evident the large span between the SSA countries. Some of them have a share of population with very low access to electricity, as well as few of them have access to more than 70%. Notably, some countries with intermediate access rates such as Nigeria and Ethiopia, are those hosting the largest number of people without access to electricity due to their large population sizes (206 and 115 million, respectively).

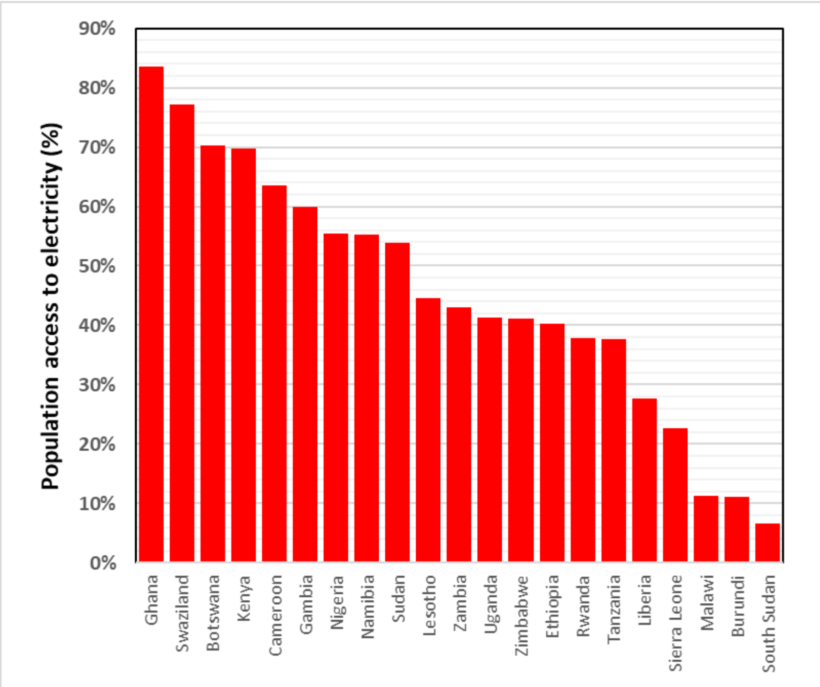

Figure 3 - Share of total population with access to electricity

More in detail Malawi, Burundi and South Sudan have a very low share of population with access to electricity (around 10 %); Sierra Leone and Liberia are between 20% and 25%; Cameroon, Kenya, Botswana Swaziland and Ghana have a share of population with access to electricity larger than 60 %. All other countries under consideration are in the middle, with a share of population with access to electricity in the range 35 – 60 %.

Low access to electricity represents a fundamental barrier to progress for a sizable proportion of the SSA countries' population and has impacts on a wide range of development indicators, including health, education, food security, gender equality, livelihoods, and poverty reduction. The investigation was conducted in two streams: taxonomy and stakeholder engagement.

2.1.1 Taxonomy

To develop the relevant context for the study, indicators related to agricultural development were selected. Extensive and intensive indicators that are relevant to agriculture such as energy and water management in the rural context, as well as market-based indicators that highlight countries' weaknesses and strengths economically and politically.

2.1.2 Stakeholder Engagement

Stakeholder interview activities play a role in deepening further aspects related to the energy, agriculture and water nexus in SSA. To facilitate a holistic perspective of the relevant issues, two sets of questionnaires were developed. One to gather individual stakeholder perspectives of relevant experts with competence in agriculture, water and access to energy in the rural context of the SSA and the other for direct Focus Group discussions with representatives of national and institutional bodies.

2.2 Taxonomy from Sub-Saharan Africa countries

The following presents the analysis of data retrieved based on the indicators on the selected SSA countries based on indicators, including statistics on agricultural contests, demographic indicators, climatic indicators, environmental indicators and economic indicators.

Given the focus of the study on Agriculture-Energy-Water-Development nexus, the indicators are categorized within the four main thematic areas of the study. Indicators within the **agriculture dimension** include share of rural population, agricultural land area, use of water for irrigation and severe food insecurity in the population. The indicators within the **energy dimension** of the taxonomy include rural electrification rate and renewable resources availability (i.e. solar radiation). The annual rainfall and total annual freshwater withdrawals are the two indicators covered within the **water dimension**. The indicators captured within the **development dimension** include economical (ease of doing business, unemployment rate and GDP per capita) as well human aspects (fertility rate per woman, life expectancy and HDI value).

Not all the indicators have the same significance and importance in this analysis, but it is interesting to have a general overview about single countries.

The collected data are representing international databases. The main institutional databases are World Bank Open Database, Food and Agriculture Organisation Statistics (FAOSTAT), Our World in Data, Get.invest and UNDP's Human Development Insights.

2.2.1 Agriculture dimension: rural population

Life changes along a variety of dimensions, moving from the most remote forest outpost through fields and pastures, through small towns with weekly farm markets, into intensively cultivated areas near large towns and small cities, eventually reaching the center of a megacity. Along this way access to infrastructure, social services, and nonfarm employment increase, and with them population density and income.

This picture represents areas along which economic behaviour and development interventions vary substantially. Where population densities are low, markets of all kinds are thin, and the unit cost of delivering most social services and many types of infrastructure is high. Where large urban areas are distant, farm-gate or factory-gate prices of outputs will be low and input prices will be high, and it will be difficult to recruit skilled people to public service or private enterprises.

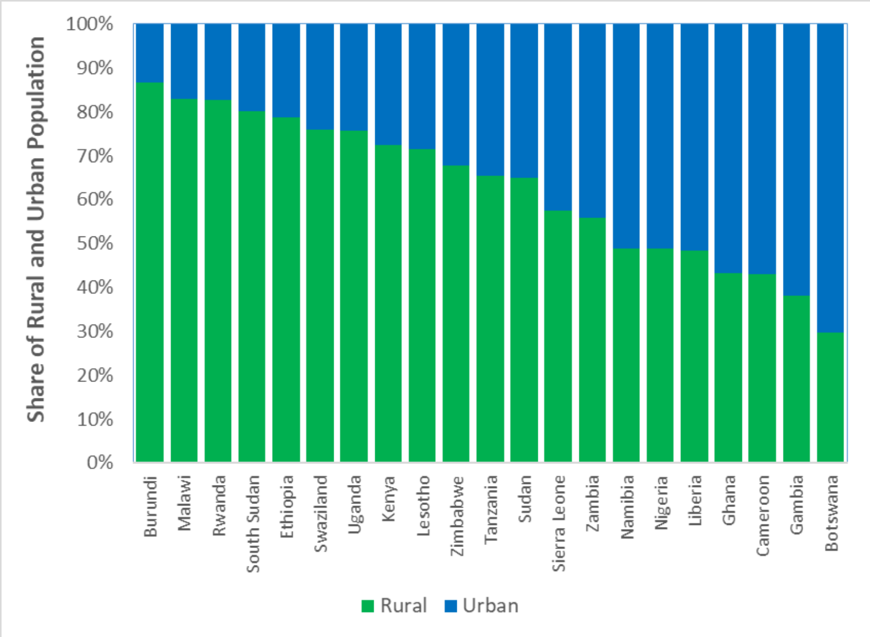

Figure 4 - Share of national rural and urban population

Figure 4 shows the large prevalence of rural areas in many countries of SSA. More than 50 % of SSA countries under consideration have more than 60 % of the share of the rural population. They are Burundi, Malawi, Rwanda, South Sudan, Ethiopia, Swaziland, Uganda, Kenya, Lesotho, Zimbabwe, Tanzania and Sudan.

These data confirm the importance of agriculture in many countries of the SSA region. The economies of these countries are based on the sustainability of this sector.

2.2.2 Agriculture dimension: land use and food security

With an estimated 1.1 billion hectares as of 2019, Africa has the second-largest area of agricultural land compared to other continents (Figure 5).

Nigeria has the largest agricultural land - with approximately 69 million hectares (Figure 5 based on data collected from the Food and Agriculture Organisation database – FAOSTAT). Sudan comes in second with 68 million hectares, while Tanzania has about 40 million hectares of agricultural land. However, only Namibia and Botswana have agricultural land area per capita that is above 1000 hectares per capita, with Namibia having the highest (1,556 hectares per capita) while South Sudan, Sudan, Zambia, Zimbabwe, Swaziland and Lesotho have 100-300 hectares per capita. The remaining 13 countries have less than 100 hectares per capita with Rwanda having the lowest (14.25 hectares per capita). Nigeria, despite having the highest total agricultural land, has 34.40 hectares per capita largely due to its high population – the most populous African country.

As presented in Figure 6 also developed from data from FAOSTAT, Sudan has the largest highest land equipped for irrigation among the selected African countries, with about 1.86 million hectares. Ethiopia came in second with 858,000 hectares of land equipped for irrigation while Tanzania came in third with 364,000 hectares of land equipped for irrigation.

However, all the three countries have less than 5% share of agricultural land equipped for irrigation, this partly explains the low productivity of agricultural productivity and the associated low income from agriculture in the region particularly for smallholder farmers. One-third of the 21 countries considered have between 1.0-5.0% of agricultural land equipped with irrigation facilities, with the highest being 4.09% (Swaziland); eight countries comprising Tanzania, Gambia, Sierra Leone, Zambia, Kenya, Nigeria, Rwanda, Cameroon, Ghana, Liberia, Lesotho and Uganda have between 0.1-1% while Uganda, South Sudan, Namibia and Botswana have between 0.01 – 0.1%.

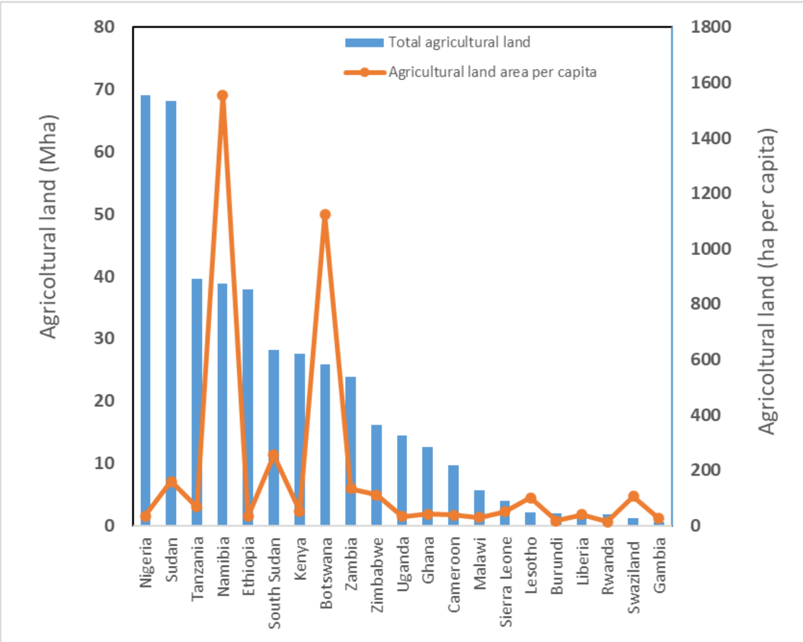

Figure 5 - Absolute and Per Capita values of agricultural land in Africa

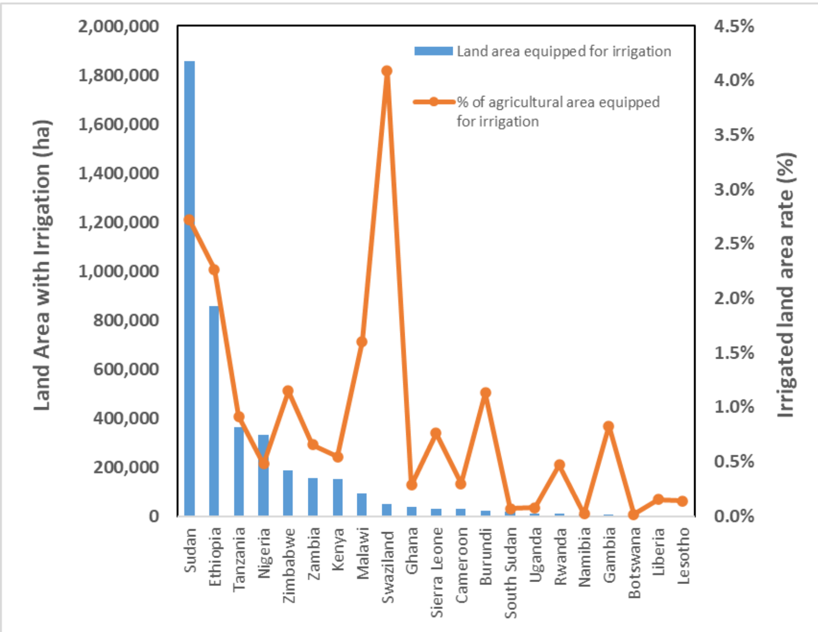

Figure 6 - Land Area equipped with Irrigation and Percent of Land equipped for Irrigation.

Figure 7 (developed from data collected from FAOSTAT) presents the prevalence rate of severe food insecurity by selected African countries. Ghana has the lowest (8.6%) share of its population experiencing severe insecurity while the highest severity is observed in South Sudan (62%). Ethiopia, Sudan, Nigeria, Uganda, Botswana, and Tanzania have 10-25% severity of insecurity, while Gambia, Kenya, Cameroon, Lesotho, Swaziland, Sierra Leone, Namibia, Zimbabwe and Liberia have 25-50%. Malawi, Zambia and South Sudan are the only three countries with more than 50% prevalence of food insecurity.

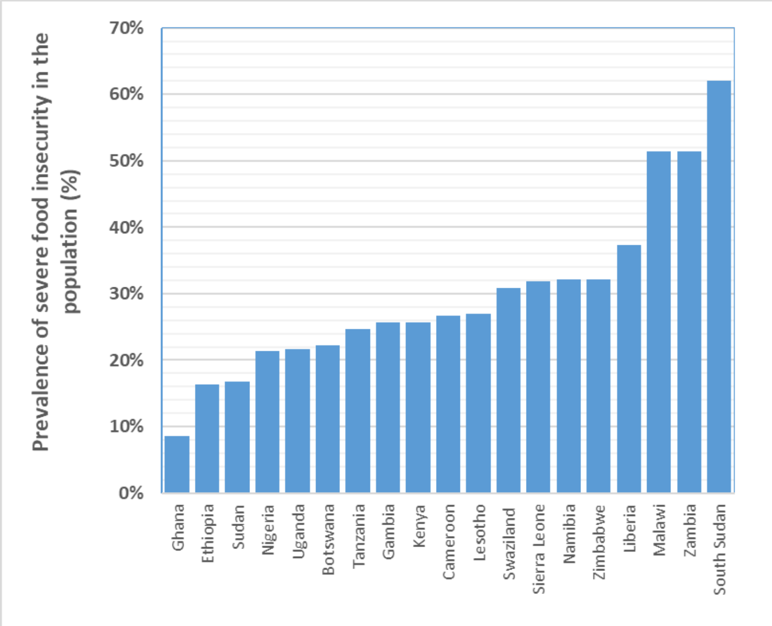

Figure 7 - Prevalence of Severe Food Insecurity in Total Population

2.2.3 Energy dimension: electrification and natural resources

Figure 8 (developed from the World Bank Open Database) depicts the rural electrification rate in the African countries covered in the study.

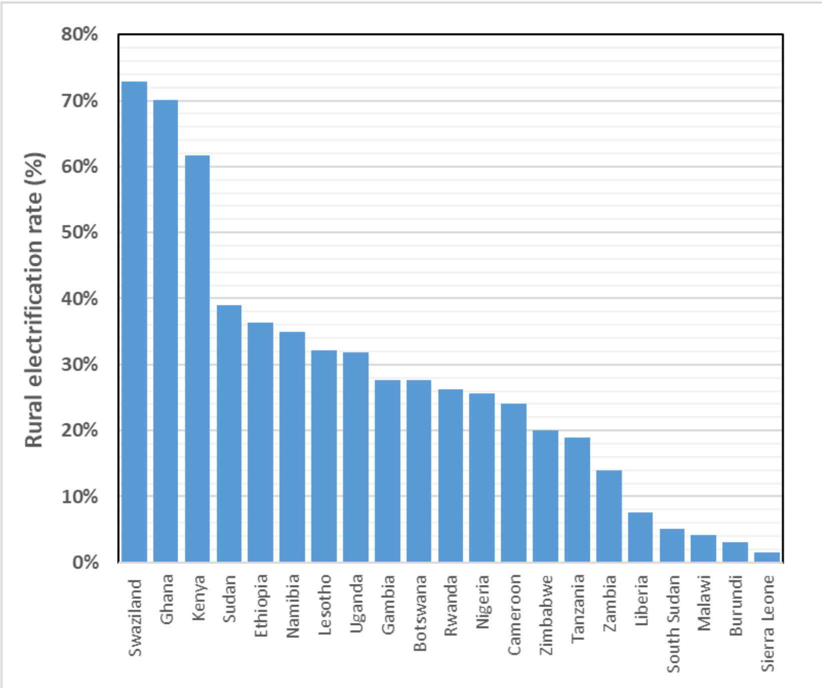

Figure 8 - Rural Electrification Rate

Only three countries (Kenya, Ghana and Swaziland) have more than 50% rural electrification rate. Sudan, Ethiopia, Namibia, Lesotho, Uganda, Gambia, Botswana, Rwanda, and Nigeria have between 25-50% while Cameroon, Zimbabwe, Tanzania, and Zambia have between 10-25%. Liberia, South Sudan, Malawi, Burundi and Sierra Leone have less than 10% rural electrification rate, with the lowest being Sierra Leone with 1.5%. Given the relevance of electricity access to agriculture, particularly, for irrigation, processing and value addition of farm produce, the majority of the countries having less than 40% rural electrification rate suggest that lack of electricity access largely explains the low agricultural productivity, low income and poor state of livelihood of smallholder farmers in rural SSA. This highlights that electricity access is crucial to enhancing agricultural productivity and improving rural livelihood. As expected, all the countries have lower share of access at electricity services in rural area compared with national data (Figure 3)

Looking at the energy dimension it is important to evaluate the renewable resources availability and specifically the mean solar irradiation depicted in Figure 9 developed based on data collected from the Global Solar Atlas that is being managed by the World Bank.

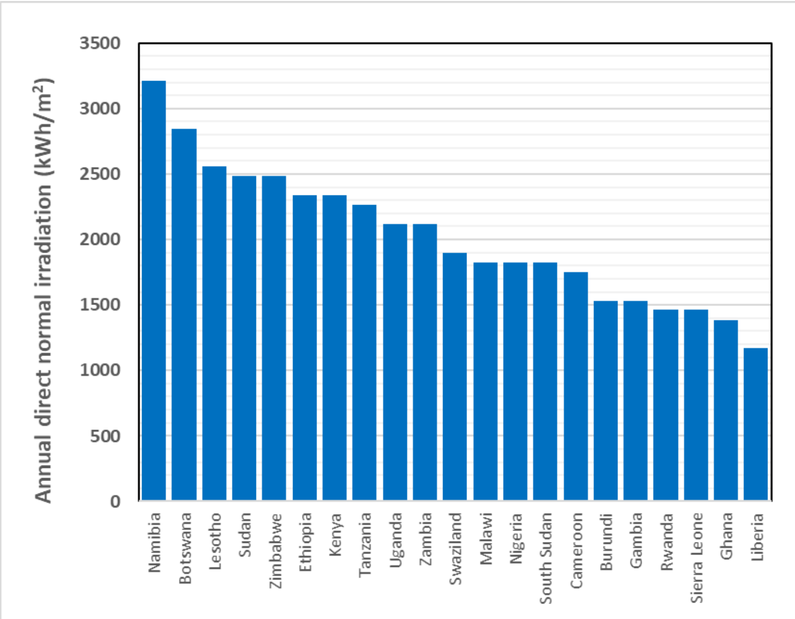

Figure 9 - Annual solar irradiation. Source: Global Solar Atlas

Annual direct normal irradiation also ranges widely from 1168 to 3214 kWh/m^2. Liberia, Ghana, Rwanda, and Sierra Leone have less than 1500 kWh/m^2 direct normal irradiation, while those of Burundi, Gambia, Cameroon, Malawi, Nigeria, South Sudan and Swaziland range from 1500–2000 kWh/m^2. Direct normal irradiation in Uganda, Zambia, Tanzania, Tanzania, Ethiopia, Kenya, Sudan, and Zimbabwe range between 2000 – 2500 kWh/m^2 while those of Lesotho, Botswana and Namibia are above 2500 kWh/m^2 with the highest (3214 kWh/m^2) in Namibia.

As a climatic indicator of SSA countries the mean annual temperature has a large variability (from 13.8 – 27.8 °C) as depicted in Figure 10 developed based on data retrieved from the Climate Knowledge Portal of the World Bank.

Only Lesotho and Rwanda have less than 20 °C while the variable ranges from 20 - 23 °C in Burundi, Namibia, Swaziland, Zimbabwe, Zambia, and Malawi. The indicator ranges from 23 - 25 °C in Ethiopia, Botswana, Tanzania, Uganda, and Cameroon. Kenya, Liberia, Sierra Leone, Nigeria, South Sudan, Ghana, Gambia and Sudan have their mean annual temperature ranging from 25 – 28 °C.

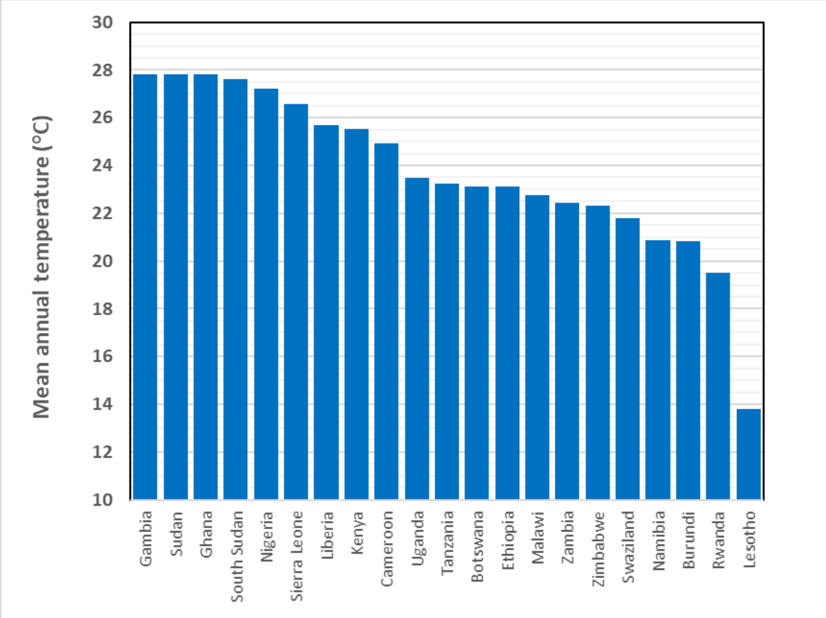

Figure 10 - Mean annual temperature

2.2.4 Water dimension: use and natural resources

The water dimension includes precipitation and water withdrawal as depicted in Figure 11 (based on data retrieved from the World Bank's Climate Knowledge Portal) and Figure 12, (developed from World Bank Open Database) respectively.

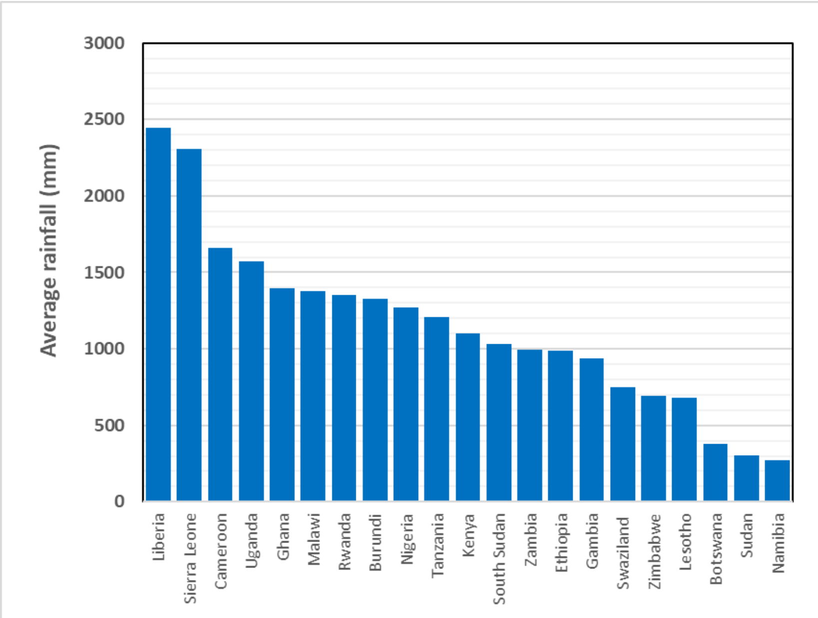

Figure 11 - Average rainfall

The annual mean rainfalls range widely across the countries covered in the study from 277 mm in Namibia to 2448 mm in Liberia. Namibia, Sudan and Botswana have less than 500 mm annual mean rainfall while those of Zimbabwe, Swaziland, Gambia, Ethiopia and Zambia range between 500 -1000 mm. On the other hand, South Sudan, Kenya, Tanzania, Nigeria, Burundi, Rwanda, Malawi and Ghana have 1000 – 1500 mm annual mean rainfall while those of Uganda, Cameroon, Sierra Leone and Liberia are above 1500 mm with the highest being in Liberia.

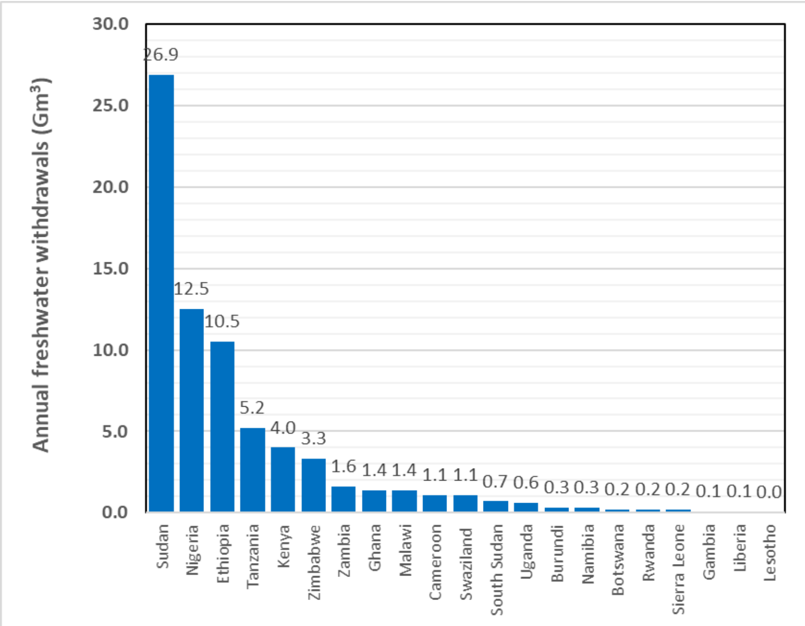

Figure 12 - Freshwater withdrawals

The total annual freshwater withdrawal (Figure 12, data 2017) range widely from 0 – 26.9 Gm^3 across the 21 countries considered in the study with almost half of the countries (Lesotho, Gambia, Liberia, Botswana, Rwanda, Sierra Leone, Burundi, Namibia, Uganda and South Sudan) having less than 1 Gm^3 freshwater withdrawal. Cameroon, Swaziland, Ghana, Malawi, Zambia, Zimbabwe, and Kenya have 1-5 Gm^3 in annual freshwater withdrawals; Tanzania had 5.2 Gm^3, while Ethiopia, Nigeria and Sudan had 10-25 Gm^3 freshwater withdrawal.

2.2.5 Development dimension: economic and human

Figure 13 (developed from data retrieved from the World Bank Open Database) presents the economic indicator useful to understand the opportunity and the potential of national markets.

Rwanda ranks 38th in the world Ease of doing Business and it is the only country covered in the study among the Top 50 countries on the same indicator. Botswana, Zambia, and Kenya rank between 50th -100th positions, while Tanzania, Zimbabwe, Nigeria, Lesotho, Swaziland, Ghana, Uganda, Malawi and Namibia are rated between 100th – 150th.

South Sudan (185th), Liberia, Sudan, Cameroon, Burundi, Sierra Leone, Ethiopia, and Gambia (155th) rank all above 150th in the global Ease of Doing Business ranking. In addition, the region performed best in the security of loans but performed poorly on electricity access. The poor electricity access rate partly explains the region's low performance in the ease of doing business.

Energy intensity measures the quality of the industrial processes (Figure 14). Lower values refer to efficient use. In SSA countries range widely between 0.3-7.22 kWh/$2011 PPP GDP in 2015 (developed based on data retrieved from Our World in Data).

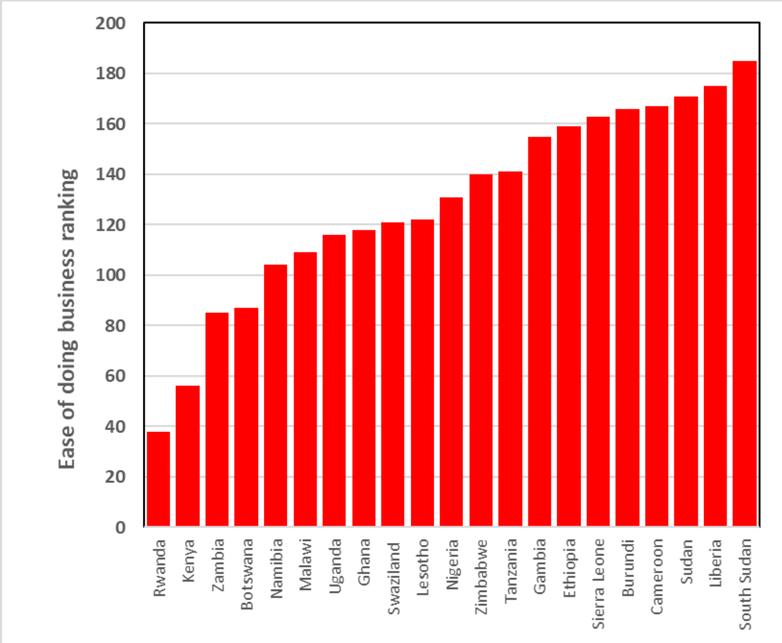

Figure 13 - Global ranking on ease of doing business

South Sudan, Namibia and Botswana use 0-1 kWh/$2011 PPP GDP while most of the countries (Ghana, Sudan, Malawi, Gambia, Swaziland, Cameroon, Rwanda, Nigeria, Sierra Leone, Zambia, Burundi, Kenya, Tanzania, Uganda, and Lesotho) use 1-3 kWh/$2011 PPP GDP. Ethiopia, Zimbabwe, and Liberia use 3.8 kWh/$2011 PPP GDP, 4.39 kWh/$2011 PPP GDP and 7.22 kWh/$2011 PPP GDP respectively.

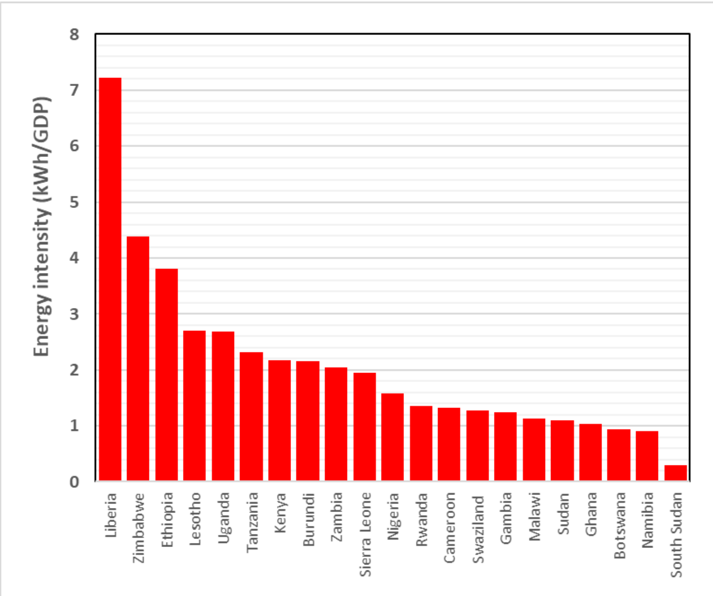

Figure 14 - Energy intensity.

More ambiguous is the analysis based on CO_2 emission per capita (Figure 15, developed based on data retrieved from the World Bank Open Database). In countries with equivalent economic development this indicator allows us to evaluate the environmental sustainability of energy processes and uses. But, at the same time, lower ***CO_2*** emissions could be linked to a reduced energy availability as well.

The CO_2 emissions in the countries understudied range quite wide from 0.1 – 3.6 tons per capita in 2018. Most of the countries namely, Burundi, Ethiopia, Malawi, Rwanda, Sierra Leone, South Sudan, Uganda, Gambia, Tanzania, Cameroon, Liberia, Kenya, Zambia, Ghana and Sudan emitted 0-0.5 tons per capita. CO_2 emissions per capita in Nigeria, Zimbabwe and Swaziland stood between 0.5 – 1 tons per capita, Lesotho, Namibia and Botswana had 1.2, 1.7 and 3.6 tons per capita respectively.

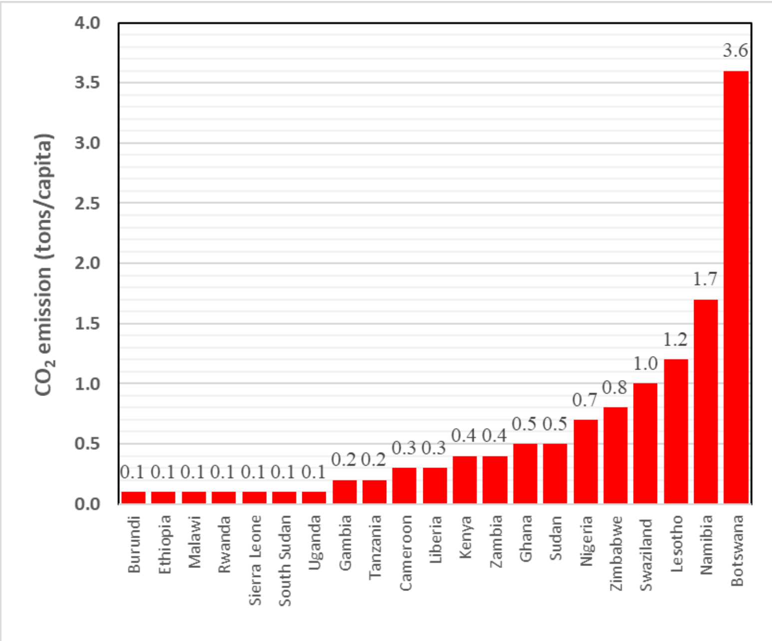

Figure 15 - CO_2 emission per capita

The economic indicators present an overview of the countries' GDP per capita, poverty rate and unemployment rate, as depicted in Figure 16 (developed from the World Bank Open Database), Figure 17 (developed based on data retrieved from Worlddata.info) and Figure 18 (developed from the World Bank Open Database) respectively.

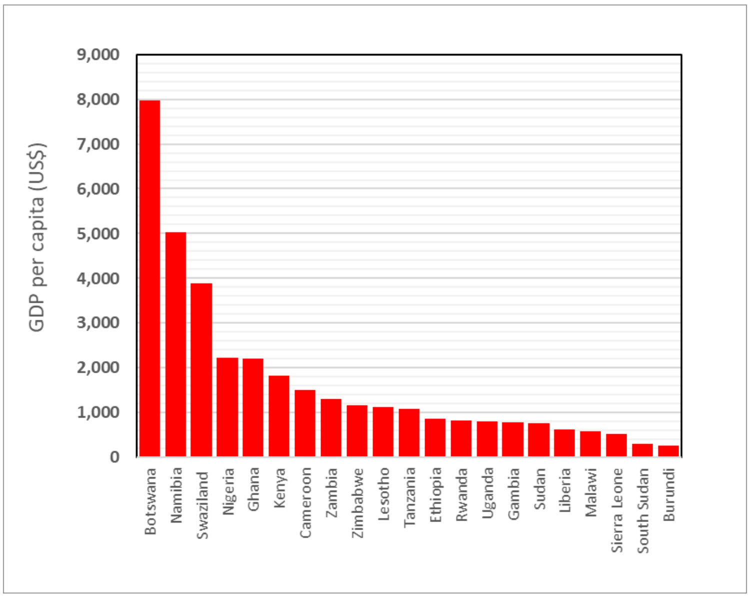

Figure 16 - National GDP per capita

GDP per capita ranges extensively in the countries considered in the study from USD 261 in Burundi to USD 7,970 in Botswana, with most of the countries having less than USD 1,500. Burundi, South Sudan, Sierra Leone, Malawi, Liberia, Sudan, Gambia, Uganda, Rwanda, and Ethiopia had between USD 250 – 1,000 GDP per capita, while Tanzania, Lesotho, Zimbabwe, Zambia and Kenya had between USD 1,000 – USD 2000. Ghana, Nigeria and Swaziland had between USD 2,000-4000 while Namibia and Botswana had between USD 5,000 – USD 8,000.

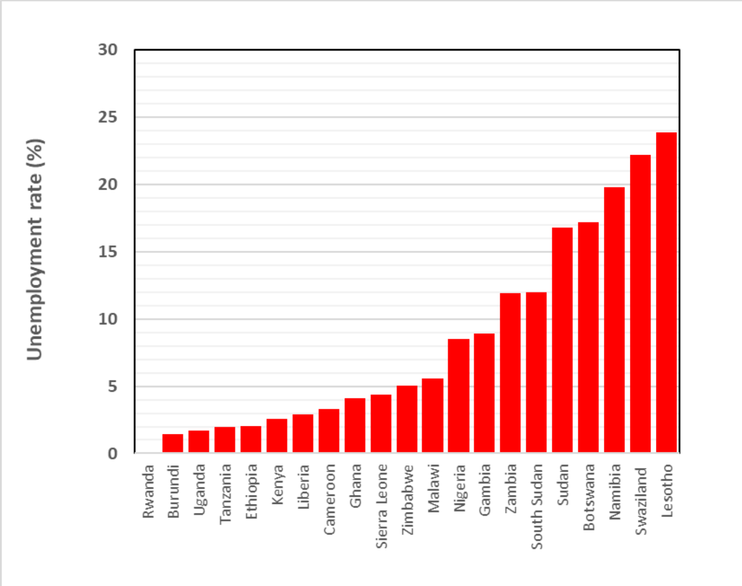

Figure 17 - Unemployment rate

Unemployment rate ranges from 0.09% in Rwanda to 23.90% in Lesotho as of 2019. Rwanda, Burundi, Uganda, Tanzania, Ethiopia, Kenya, Liberia, Cameroon, Ghana, and Sierra Leone had 0-5% unemployment rate while Zimbabwe, Malawi, Nigeria, and Gambia had 5-10%. South Sudan had 12.01%, meanwhile, Sudan, Botswana, Namibia, Swaziland and Lesotho had 20-25% unemployment rate.

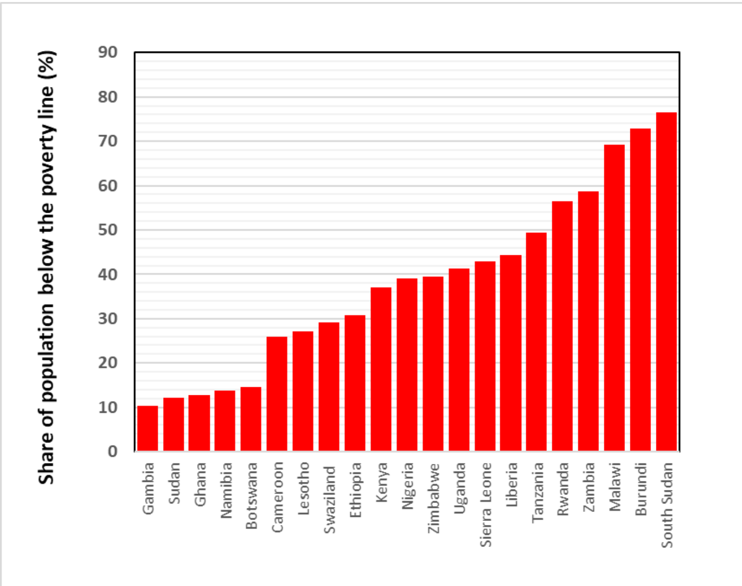

Figure 18 - Population below poverty line

The share of population living USD 1.90/day poverty line in 2019 ranged widely from 10.3% in Gambia to 76.4% in South Sudan. The Gambia, Sudan, Ghana, Namibia had from 10-25% poverty rate, while Cameroon, Lesotho, Swaziland, Ethiopia, Kenya, Nigeria and Zimbabwe had 25-40%. Poverty rage in Uganda, Sierra Leone, Liberia, Tanzania, Rwanda and Zambia range from 40-65% while Malawi, Burundi and South Sudan had 65-80% poverty rate.

The national fertility and mortality rates are major determinants of the population size, growth and structure. Figure 19 (developed based on data retrieved from the World Bank Open Database) presents the fertility and mortality rates as of 2019 for the countries considered in this study.

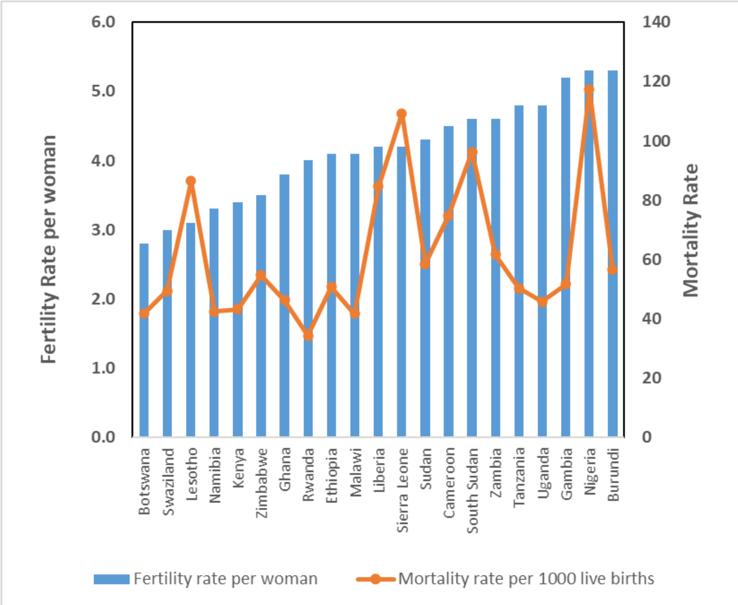

Figure 19 - Fertility and Mortality Rate

Botswana and Swaziland have fertility rates of 2.8 and 3.0, respectively. All the countries except Botswana have 3 and above fertility rate per woman. Swaziland, Lesotho, Namibia, Kenya, Zimbabwe and Ghana have between 3-4; Rwanda, Ethiopia, Malawi, Liberia, Sierra Leone, Sudan, Cameroon, South Sudan, Zambia, Tanzania, and Uganda have between 4-5 while Gambia, Nigeria and Burundi have above 5 fertility rate per woman.

On the other hand, South Sudan had the highest mortality rate of 96.2 per 1000 live births, followed by Sierra Leone at 109.2 per 1000 live births and Nigeria at 117.2 per 1000 live births. Seychelles had the lowest mortality rate at 14.2 per 1000 live births.

Life expectancy (Figure 20 developed based on data retrieved from the World Bank Open Database) in the countries considered in the study range from 54.3 (in Lesotho) and 69.6 (in Botswana) Lesotho, Nigeria, Sierra Leone, South Sudan and Cameroon have 50-60 years life expectancy. Majority of the countries have 60-70 years life expectancy with Swaziland, Zimbabwe, Burundi, Gambia, Uganda, Namibia, Zambia, Ghana, Liberia, and Malawi having between 60-65 while life expectancy in Sudan, Tanzania, Ethiopia, Kenya, Rwanda and Botswana range from 65-70 years.

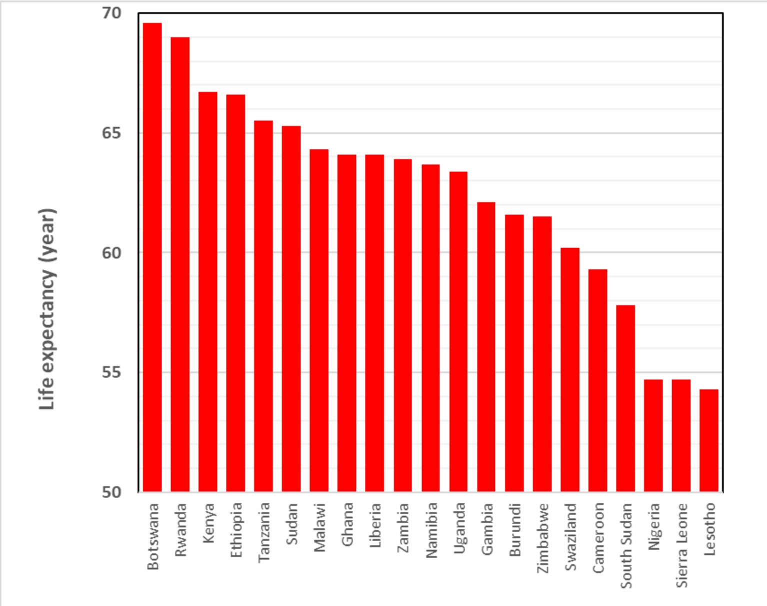

Figure 20 - Life Expectancy Rate in 2019

Human Development Index (HDI) in the countries considered in the study range from 0.43 (Burundi) – 0.74 (Botswana). Burundi, South Sudan, Sierra Leone, Liberia, Malawi, and Ethiopia had HDI values ranging from 0.4 – 0.5 while the HDI values from 0.5 – 0.6 for Gambia, Sudan, Lesotho, Tanzania, Nigeria, Rwanda, Uganda, Cameroon, Zimbabwe, and Zambia. Moreover, the HDI values for Kenya, Ghana, Swaziland, and Namibia ranged from 0.6-0.7 while Botswana had 0.74 HDI value (Figure 22 developed from UNDP's Human Development Insights).

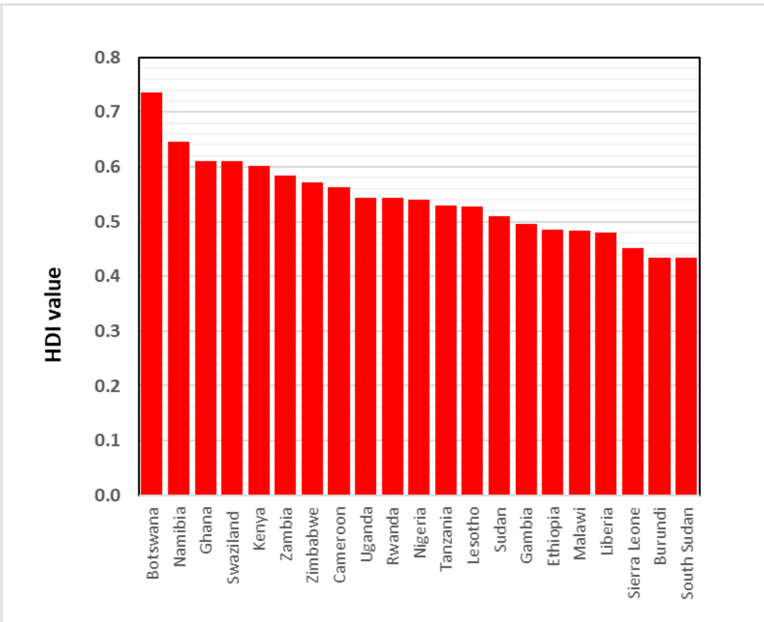

Figure 21 - Human Development Index in SSA countries

2.3 Conclusions

The collection of different indicators allows the reader to have a general overview about the singularity of each country and the possibility to observe some homogeneous behaviours. For this reason, each indicator is clustered in 4 different classes with the aim to have this global common vision. Each class has been identified with a *letter* (A, B, C and D) as reported in Figure 22. Letter "A" represents the best condition according to the potential of being developed while letter "D" represents the opposite, namely the most challenging situation for potential development.

Share of rural population (%)	**A**	**B**	**C**	**D**
	above 80	60 - 80	40 - 60	below 40
Agricultural land area per capita (hectares)	**A**	**B**	**C**	**D**
	above 1000	300 - 1000	100 - 300	below 100
Share of agricultural area with irrigation (%)	**A**	**B**	**C**	**D**
	2.0 - 5.0	1.0 - 2.0	0.1 - 1.0	0.0 - 0.1
Prevalence of severe food insecurity in the population (%)	**A**	**B**	**C**	**D**
	above 50	25 - 50	10 - 25	below 10
Rural electrification rate (%)	**A**	**B**	**C**	**D**
	above 50	25 - 50	10 - 25	below 10
Annual solar irradiation (kWh/m^2)	**A**	**B**	**C**	**D**
	above 2500	2000 - 2500	1500 - 2000	1000 - 1500
Mean annual temperature (°C)	**A**	**B**	**C**	**D**
	25 - 28	23 - 25	20 - 23	below 20
Annual mean rainfall (mm)	**A**	**B**	**C**	**D**
	above 1500	1000 - 1500	500 - 1000	below 500
Total annual freshwater withdrawals (Gm^3/year)	**A**	**B**	**C**	**D**
	above 10	2 - 10	1 - 2	below 1
Energy Intensity (kWh/US$)	**A**	**B**	**C**	**D**
	below 1	1.0 - 2.0	2.0 - 3.0	above 3.0
CO_2 emissions per capita (tons)	**A**	**B**	**C**	**D**
	1.0 - 5.0	0.5 - 1.0	0.2 - 0.5	below 0.2
GDP per capita (US$)	**A**	**B**	**C**	**D**
	above 5000	2000 - 5000	1000 - 2000	below 1000
Ease of doing business index	**A**	**B**	**C**	**D**
	below 50	50 - 100	100 - 150	above 150
Unemployment rate (%)	**A**	**B**	**C**	**D**
	0 - 5	5 - 10	10 - 15	20 - 25
Population below poverty line (%)	**A**	**B**	**C**	**D**
	below 20	20 - 30	30 - 50	above 50
Fertility rate per woman	**A**	**B**	**C**	**D**
	below 3	3 - 4	4 - 5	above 5
Mortality reate per 1000 live birth	**A**	**B**	**C**	**D**
	below 50	50 - 70	70 - 100	above 100
Life expectancy (years)	**A**	**B**	**C**	**D**
	65 - 70	60 - 65	55 - 60	50 - 55
Human Development Index	**A**	**B**	**C**	**D**
	0.7 - 0.8	0.6 - 0.7	0.5 - 0.6	0.4 - 0.5

Figure 22 - Indicator classification

The results for each dimension have been reported using a coloured representation, as well. Figure 23 and Figure 24 show the results of the agricultural, energy, and water dimension, and of the economic and human dimension, respectively.

Sub-Region	Countries	Rural Population share	Agricultural land area per capita	Share of agricultural area with irrigation	Prevalence of severe food insecurity in the population	Rural electrification rate	Annual solar irradiation	Mean annual temperature	Annual mean rainfall	Total annual freshwater withdrawals
North Africa	Sudan	B	C	A	C	B	B	A	D	A
Central Africa	Cameroon	C	D	C	B	C	C	B	A	C
East Africa	Burundi	A	D	B		D	C	C	B	D
	Ethiopia	B	D	A	C	B	B	B	C	A
	Kenya	B	D	C	B	A	B	A	B	B
	Malawi	A	D	B	A	D	C	C	B	C
	Rwanda	A	D	C		B	D	D	B	D
	South Sudan	A	B	D	A	D	C	A	B	D
	Tanzania	B	D	C	C	C	B	B	B	B
	Uganda	B	D	D	C	B	B	B	A	D
	Zambia	C	B	C	A	C	B	C	C	C
	Zimbabwe	B	B	B	B	C	B	C	C	B
West Africa	Gambia	D	D	C	C	B	C	A	C	D
	Ghana	C	D	C	D	A	D	A	B	C
	Liberia	C	D	C	B	D	D	A	A	D
	Nigeria	C	D	C	C	B	C	A	B	A
	Sierra Leone	C	D	C	B	D	D	A	A	D
Southern Africa	Botswana	D	A	D	C	B	A	B	D	D
	Lesotho	B	B	C	B	B	A	D	C	D
	Namibia	C	A	D	B	B	A	C	D	D
	Swaziland	B	B	A	B	A	C	C	C	C

Figure 23 - Countries' taxonomy classes: agriculture, energy and water dimensions

Sub-Region	Countries	Energy Intensity	CO2 emissions	GDP per capita	Ease of doing business ranking	Unemployment rate	Population below poverty line	Fertility rate per woman	Mortality reate per 1000 live birth	Life expectancy	HDI value
North Africa	Sudan	B	C	D	D	C	A	C	B	A	C
Central Africa	Cameroon	B	C	C	D	A	B	C	C	C	C
East Africa	Burundi	C	D	D	D	A	D	A	B	B	D
	Ethiopia	D	D	D	D	A	C	C	B	A	D
	Kenya	C	C	C	B	A	C	D	A	A	B
	Malawi	B	D	D	C	B	D	C	A	B	D
	Rwanda	B	D	D	A	A	D	C	A	A	C
	South Sudan	A	D	D	D	C	D	C	C	C	D
	Tanzania	C	D	C	C	A	C	C	B	A	C
	Uganda	C	D	D	C	A	C	C	A	B	C
	Zambia	C	C	C	B	C	D	C		B	C
	Zimbabwe	D	C	C	C	B	C	D	B	B	C
West Africa	Gambia	B	D	D	D	B	A	A	B	B	C
	Ghana	B	C	B	C	A	A	D	A	B	B
	Liberia	D	C	D	D	A	C	C	C	B	D
	Nigeria	B	C	B	C	B	C	A	D	D	C
	Sierra Leone	B	D	D	D	A	C	C	D	D	D
Southern Africa	Botswana	A	A	A	B	C	A	A	A	A	A
	Lesotho	C	B	C	C	D	B	D	C	D	C
	Namibia	A	B	A	C	C	A	D	A	B	B
	Swaziland	B	B	B	C	D	B	D	A	B	B

Figure 24 - Countries' taxonomy classes: economic and human

An additional classification according to the previous analysis permits to identify countries whose general context presents better or more challenging opportunities for this project. In order to do so, only the most relevant indicators have been evaluated: rural population share, share of agricultural land with irrigation, rural electrification rate, annual solar irradiation, annual freshwater withdrawals, GDP per capita, ease of doing business, unemployment rate, population under poverty line, and HDI value. Each country has been scored by adding the complete set of relevant individual indicators (the value of "1" has been assigned to each letter "A" in ascending order until letter "D" with its corresponding value of "4"). The following criteria was used to categorize the country's context (Figure 25):

Country context	Score range
High opportunity	[21 - 25]
Medium opportunity	[26 - 30]
Challenging	[31 - 35]

Figure 25- Country-specific context evaluation criteria

The final country classification can be observed in Figure 26. On one side, countries like Kenya, Sudan, Ghana, Botswana, and Swaziland rank as the ones with the best contexts for potential development. On the other side, South Sudan, Liberia, and Sierra Leone appear in the lowest rankings exhibiting thus the most challenging contexts.

Sub-Region	Countries	Final score	
North Africa	Sudan	23	High opportunity context
Central Africa	Cameroon	28	Medium opportunity context
East Africa	Burundi	31	Challenging context
	Ethiopia	24	High opportunity context
	Kenya	21	High opportunity context
	Malawi	30	Medium opportunity context
	Rwanda	27	Medium opportunity context
	South Sudan	35	Challenging context
	Tanzania	25	High opportunity context
	Uganda	28	Medium opportunity context
	Zambia	29	Medium opportunity context
	Zimbabwe	25	High opportunity context
West Africa	Gambia	30	Medium opportunity context
	Ghana	23	High opportunity context
	Liberia	34	Challenging context
	Nigeria	25	High opportunity context
	Sierra Leone	34	Challenging context
Southern Africa	Botswana	23	High opportunity context
	Lesotho	27	Medium opportunity context
	Namibia	24	High opportunity context
	Swaziland	23	High opportunity context

Figure 26** - **Classification according to country-specific context

2.3.1 Country Selection for Stakeholder Engagement

Several countries were considered for the stakeholder engagements, nonetheless, the consortium finds that the possibility for effective engagement with stakeholders is dependent on the strength of existing partnerships and relationships. Therefore, the choice of existence of partnerships in Sub Saharan Africa countries became a crucial factor in selecting Nigeria, Zimbabwe, Rwanda and Zambia.

Nevertheless, data indicates that the selected countries provide some crucial insights for the study in SSA. According to Figure 26, Rwanda and Zambia contexts have been classified as with "Medium opportunity" and Zimbabwe and Nigeria contexts as with "High opportunity" for potential development. With a rural population of about 100 million people, Nigeria (in West Africa) has the highest rural population among countries examined and presents a remarkably good electrification rate, freshwater withdrawals, GDP per capita and unemployment rate. Rwanda, one of the countries with the highest rural population in the East

Africa sub-region (83%) was selected based on existing partnerships with relevant stakeholders in the study. In addition, Rwanda exhibits one of the best scenarios in terms of ease of doing business and unemployment rates. While the consortium sought to have a country from each African sub-region, the lack of existing partnerships with relevant stakeholders and the consortium members made it impossible. Although geographically located in the same sub-region, Zambia and Zimbabwe present both strong partnerships and interesting distinctions which make them suitable for in-depth analysis. For example, while Zambia ranks better under ease of doing business, Zimbabwe performs better under share of agricultural land with irrigation and unemployment rates.

Figure 27 summarizes the indicators for the 4 selected countries together with their respective final scores and context classification.

	Rwanda	Zambia	Zimbabwe	Nigeria
Rural Population share	A	C	B	C
Share of agricultural area with irrigation	C	C	B	C
Rural electrification rate	B	C	C	B
Annual solar irradiation	D	B	B	C
Total annual freshwater withdrawals	D	C	B	A
GDP per capita	D	C	C	B
Ease of doing business	A	B	C	C
Unemployment rate	A	C	B	B
Share of potulation below poverty line	D	D	C	C
HDI value	C	C	C	C
Final score	27	29	25	25
Country context potential	Medium	Medium	High	High

Figure 27 - Comparison between countries selected

In order to deepen this analysis through interviews and discussion with local stakeholders and institutions, an additional in-depth literature review research has been carried out for these countries collecting other data in order to have the local perspectives about the development of agriculture business.

3 Literature review on the target countries

The literature review research has been carried out incorporating data points as similar to the Focus Group Discussions as possible. The findings from this research are categorised into three areas and presented by country. The areas covered are (i) Agricultural value chains overview, (ii) Irrigation, and (iii) Crop processing.

3.1 Nigeria

3.1.1 Agricultural value chains overview

Nigeria's agricultural sector contribution to national GDP has averaged at 25% in recent years, employing nearly half (48%) of the total workforce in the country (Statista, 2021; PwC, 2020). According to USAID Power Africa, the most strategic crops for smallholder farmers in Nigeria are cassava, rice, maize, cowpea, and sorghum (Santana et al., 2020). The average area of cultivated land by smallholder farmers is 0.5 hectares (ha) (Takeshima et al., 2017).

There exists a high participation of smallholder farmers and small-scale processors within Nigerian agricultural value chains. Small and medium scale traders are also active stakeholders who typically buy crop produce from farmers and sell it to processors. The small scale crop processing sector has a well-developed presence of processing-as-a-service practices, where small processing plants charge a fee to process a farmers or traders crop (Santana et al., 2020).

However, value chain barriers encountered in the country relate to increasing diesel prices, high transportation costs, lack of access to improved seeds, fertilizers, and irrigation equipment, and lack of knowledge about sustainable development of value chain activities such as impact of renewable energy in agriculture (Sahel Capital, 2017; Santana et al., 2020).

Public agencies and international donors are increasingly focusing on the agricultural productive use sector. An example of it is the recent 3-year "Energizing Agriculture Program'' which was launched in early 2022 by the Nigerian Renewable Energy Agency (REA) and Rocky Mountain Institute (RMI) and aims at stimulating the use of mini–grid electricity in agricultural productive uses (Rockefeller Foundation, 2022).

3.1.2 Irrigation

According to a USAID Power Africa report on the solar irrigation sector (Power Africa - NPSP, 2022), the share of farmers that irrigate their lands equates to about 10%. The most commonly irrigated crops are vegetables, maize, wheat, sugarcane, potatoes, and rice, which are predominantly grown in the semi-arid northern region of the country. From the irrigated lands, the most prevalent irrigation systems used depend on the cultivated crop. For example, surface or flood irrigation is typically utiilized for rice, while drip irrigation is more common for vegetables.

90% of the farmers report having their farms more than 1 mile away from the village according to USAID Power Africa (Power Africa - NPSP, 2022). Technical aspects of irrigation systems state that smallholder farmers count on average with 1 HP solar pumps powered by 1 kW solar PV, pumping 30 m3/day in 7 hours/day on a 1 ha land. The size of the system ultimately depends on the crop requirements: for rice for example, the maximum water requirement can reach 130 m3/day powered by a 4 kW solar system. Costs of individual solar pumps (4 HP) can be around 796 USD, diesel pumps 512 USD, and an entire solar pump system 4268 USD accounting for pump, motor, solar panels, water tank, piping, and installation costs.

The main barriers for the small-scale solar irrigation sector are the lack of knowledge and financial support to leverage these systems, lack of consistent and reliable electricity access, high cost of diesel pumping and high costs of pumps.

3.1.3 Crop processing

Nigeria's access to mechanized activities remains low, having 90% of the farmers still conducting farm operations using hand tool technologies (Sahel Capital, 2017). However, some crop processing activities in the cassava value chain and the milling in the wheat, rice, cowpea, and sorghum value chain are typically performed using old diesel-powered machinery (Santana et al., 2020).

The main barriers encountered for mechanizing or electrifying crop processing activities are the lack of energy technology knowledge, upfront costs of the machines, fragmented land holdings, poor access to maintenance and service parts, and poor development of agricultural equipment fabrication sector (Santana et al., 2020).

3.2 Rwanda

3.2.1 Agricultural value chains overview

Agriculture is a major economic sector in Rwanda, employing about 70% of the total population and contributing about 31% to GDP. 75% of Rwanda's agricultural production comes from smallholder farmers. The principal national crops include coffee, pyrethrum, tea, flowers, beans, cassava, banana, irish potatoes, rice, wheat, and sugarcane. The Rwanda Development Board (RDB) also indicates fields such as food processing (mainly beans, rice, maize, potatoes), irrigation and sale of agricultural equipment, and cold chain infrastructure, among others, as high-potential investment opportunities (RDB, 2022).

According to the 2020 Agricultural Household Survey, 77.2% of agricultural households operate on farms with less than 0.5 hectares of size, 13.6% on farms ranging from 0.5 to 1 hectare of size, 8.7% on farms ranging from 1 to 5 hectares of size. The average smallholder farmers farm size for crop cultivation is 0.4 hectares (ha) (NISR, 2020).

The agricultural sector is mainly dominated by small-scale, subsistence, rain-fed, and mixed-cropping farming, with a progressive adoption of modern technologies and practices. Farmers are typically grouped in cooperatives, which aggregate crop produce to be sold to commercial processing plants. For example, crops like cassava and beans are moved down the chain by cooperatives to sell to large-scale processing plants and urban markets. The government of Rwanda has a strong intervention in the maize commodity value chain and major maize buyers are Africa Improved Foods (AIF), a public-private partnership enterprise, and World Food Programme (WFP) (FAO, 2020; WFP, 2018).

The underdevelopment and sometimes absence of a small-scale processing sector, together with the subsistence type of farmers are some of the main barriers in the field.

3.2.2 Irrigation

Between 9% and 15% of farmers practice irrigation in Rwanda. From these, only 9% are smallholder farmers, which accounts to a very low total proportion of the latter with access to irrigation (NISR, 2021).

Of the farmers that have access to irrigation, 76% irrigate with traditional methods (human or animal power), while flood and surface irrigation are the most common modern irrigation methods. In addition, 52% of farmers use lake/stream water as a source, and 36% use underground water (NISR, 2020).

3.2.3 Crop processing

Following the results from the 2020 Agricultural Household Survey, mechanical equipment was used by 0.1% of agricultural households (includes farm operations and processing activities) (NISR, 2020).

The most relevant crops that could benefit from processing are maize, beans, and cassava (Rwanda Inspirer, 2018). Furthermore, an analysis carried out by GIZ states that improved access to storage (cold storage facilities, affordable storage and warehousing) can be a good opportunity for the agricultural sector, especially at the premises of the planned Kigali Wholesale Market for Fruits and Vegetables, as well as investing into drying and dehydration facilities (GIZ, 2019).

However, the lack of access to electricity and its unreliability are a major constraint to private investment in the agriculture sector, particularly in the processing segment. There is therefore an opportunity for green operations based on a combination of solar and grid energy. Since agriculture in Rwanda is dominated by small-scale subsistence farming, the low level of skills of farmers and other value chain actors slows down the development of farming management, crop usage, and farm specialization (GIZ, 2019).

3.3 Zambia

3.3.1 Agricultural value chains overview

Agriculture contributes about 19% to national GDP and employs three quarters of the population. Domestic production mainly consists of crops such as maize, sorghum, millet, and cassava. Groundnuts is another strategic crop according to the 2019 Rural Agricultural Livelihoods survey (RALS) (IAPRI, 2019). The majority of Zambian farmers are small-scale, subsistence farmers. Medium-scale farmers produce maize and a few other cash crops for the market. Large-scale farmers produce various crops for the local and export markets (US International Trade Administration, 2021).

On average 62.8% of smallholder households in Zambia cultivate less than 2 hectares (ha). 30% cultivate between 2 and 5 ha of land and only 7.2% of the households cultivate lands greater than 5 ha. The majority of the smallholder farmers are not able to produce enough surplus for sale. As stated by the public entity Indaba Agricultural Policy Research Institute (IAPRI), “even if they were able to produce something for sale, it would not be enough to propel them out of poverty given that they produce mostly low value food crops such as maize and their productivity is very low” (IAPRI, 2019).

Agricultural cultivation in Zambia is mostly non-mechanized, and the sector is overwhelmingly rain-fed. As reported by the US International Trade Administration, the opportunities for investment include large-scale farming, farm inputs and equipment supply, irrigation systems, agro-processing, and commodity trading (US International Trade Administration, 2021).

The maize value chain is highly intervened by the government of Zambia, mainly through the Food Reserve Agency (FRA), a public entity who is one of the main maize buyers and highly regulates its selling prices. There is high participation from both small- and large-scale processors in the country. Small-scale traders also play an important role buying crop from smallholder farmers in the villages and selling it in larger markets, to millers or to FRA (IAPRI, 2019).

The main barriers in the sector are described in a private stakeholder consultation workshop by the Renewable Energy and Energy Efficiency Partnership (REEEP) as lack of formal economic activity and predictable (or regular) liquidity, and lack of knowledge and awareness (REEEP 2019).

3.3.2 Irrigation

The majority of farms in Zambia remain dependent on rain-fed growing cycles according to the US International Trade Administration (US International Trade Administration, 2021). The same scenario is confirmed by the Rural Agricultural Livelihood survey stating that ownership of irrigation equipment is very low, implying heavy reliance on rain fed agriculture. 6.1% of the fields were reported to be irrigated at the national level (IAPRI, 2019). An older survey report from 2015 mentions that almost 90% of the irrigation is categorized as "Well/river/stream and bucket", while only 4% used motorized pumps (Ngoma et al. 2017).

3.3.3 Crop processing

Access to agricultural machinery such as tractors and processing machines is very low in Zambia. According to a nationally representative survey conducted by IAPRI in 2015, only 1.8% of all households used mechanical power in their farm operations (Adu-Baffour et all., 2018). The RALS reports farming households having 1.8% access to hammer mills, 0.8% access to oil expellers, and 0.1% access to mechanized maize shellers (IAPRI, 2019).

The REEEP stakeholder consultation report (REEEP 2019) identifies key applications for productive use as milk chilling, fish drying and oil pressing, or more broadly applications that would reduce logistics costs or allow for more efficient local processing. Market segments with high potential benefits from improved energy services include irrigating, spraying, harvesting, drying, grinding, milling, pressing.

The same report describes that a key goal of rural productive use of energy would be to retain more of the value of agricultural outputs locally – i.e. retaining more stages of a given "value chain" in a given locality rather than lose value to actors located elsewhere. If farm produce is to be sent to a town, increasing local preparation and reducing logistics costs are perceived as important areas of productive use. Other areas for productive use include replacing inefficient and/or "dirty" energy – i.e. manual labour and drudgery in water transport and crop treatment, or diesel-powered energy in pumping. However, substantial capacity building efforts would be needed to improve local technical capacity for system assembly and maintenance.

3.4 Zimbabwe

3.4.1 Agricultural value chains overview

The agricultural sector contributes to about 14% of GDP and provides employment for some 70% of the population. The Ministry of Foreign Affairs and International Trade of Zimbabwe states soya beans, honey, poultry, wheat, barley, dairy, tea and coffee production and processing sectors as key investment opportunities (Ministry of Foreign Affairs & International Trade 2021). A FAO report also mentions maize, tobacco, vegetables, groundnuts, sorghum, and millet as the main crops produced by most farmers (FAO, 2021). The average plot size for the smallholder sectors is around 0.5 hectares (ha) according to a national agricultural survey (ZIMSTAT, 2017).

A remarkable presence of both small and large scale processors exist in the country. The small-scale processing sector operates mainly under fee-for-service arrangements and remains very labour-intensive, as reported by Chimedza (2015). The maize market is a national strategic commodity so it is highly intervened by government entities that buy and sell according to national reserves.

FAOs country brief describes the general challenges facing smallholder farmers, which include low and erratic rainfall, low and declining soil fertility, low investment, shortages of farm power - labour and draft animals, poor physical and institutional infrastructure, poverty and recurring food insecurity. Agricultural production is also vulnerable to periodic droughts. The peasant sector, which produces 70% of staple foods (maize, millets, and groundnuts), is particularly vulnerable as it has access to less than 5% of national irrigation facilities (FAO, 2019).

The main barriers in the agricultural sector are stated by the Zimbabwe Livelihoods and Food Security Programme (LFSP), and account for inefficient equipment resulting in production of high priced unattractive products, high local costs (e.g. utilities) making industries uncompetitive, and remote production and poor road networks which increase transaction costs (LFSP, 2021). Unavailability of electricity and irrigation are also raised as barriers, where the major limiting factor in value addition is lack of capital (Jaravaza and Isaac 2015).

3.4.2 Irrigation

Following the results of the 2017 Zimbabwe Smallholder Agricultural Productivity Survey (ZIMSTAT, 2017) and from the second edition Agricultural Sector Survey 2019-2020 (Zimbabwe Agricultural Society, 2020), the percent of irrigated plots in Zimbabwe range from 3.7% to 8.0%. Informal/traditional irrigation is practised in an estimated 20000 hectares (ha) of wetlands/inland valley bottoms (dambos) and small gardens by many rural families. Vegetables are produced during the wet and dry seasons. Usually, irrigation is done with buckets/cans from hand dug shallow wells. Up to 90% of the 10000 ha formal irrigation area is under surface irrigation, water being drawn from rivers, storage reservoirs or deep boreholes. The remaining 10% is under sprinkler irrigation and centre pivots.

The 2019-2020 agricultural sector survey (Zimbabwe Agricultural Society, 2020) indicates that the type of crops that would benefit the most from irrigation are wheat and sugarcane. Coffee, tea and cotton also have growth potential with irrigation. Recently, it has also been used for high value crops, such as tobacco and horticulture and food security crop production such as maize.

It also depicts that electricity availability and prices is a major concern and is affecting farming operations especially for irrigated crops. Farmers highlighted that they are being driven out of producing certain crops due to electricity shortages and high prices.

3.4.3 Crop processing

From the 2021 Rural Livelihoods Assessment report (ZimVAC, 2021), only 18% of households are using quality control technologies (sorting and grading) nationally, whilst only 31% are involved in drying and packaging their agricultural produce. Only 17% process their agricultural produce, and around 35% of farmers are adopting solar energy.

The major value addition activities that are done by farmers are bagging, bottling, chilling, drying, shelling and pressing, curing and grinding. The most prevalent activity is basic bagging of maize, ground nuts and soya beans according to Jaravaza et al (2015). Peanut butter making and maize milling are also present in the small-scale processing sector in Zimbabwe (Chimedza, 2015).

The 2019-2020 Agricultural Sector Survey (Zimbabwe Agricultural Society, 2020) states as main barriers in the processing sector the limited access to agricultural machinery (there is a national deficit in shellers), and the poor agronomic and processing practices (lack of knowledge) in the country.

4 Stakeholder analysis

4.1 Stakeholder Engagement

To further gain qualitative and additional quantitative insight on the practicality of the energy-agriculture-water nexus in SSA, the two sets of questionnaires were developed. A set was to collect individual stakeholder perspectives of relevant experts with experience in Agriculture, Water and Energy Access in the rural context of SSA while the other set of questionnaires was designed for Focus Group Discussions with the experts.

While all the 21 sub-Saharan African countries were covered in the taxonomy, the stakeholder engagement and focus group discussion were limited to Nigeria, Zambia, Rwanda, and Zimbabwe.

The individual stakeholder questionnaire covers issues on land, irrigation and energy access. The irrigation needs covered in the questionnaire include the crop types, irrigation season, timing and frequency, irrigation type and capacity as well as water limitations, water storage and use. Issues of rural energy access included in the questionnaire are the purpose of farming (income or subsistence), the demand, use, tariff and relevant applications of electricity, farm location, investment in technology by smallholder farmers and incentives – including support mechanisms.

The questionnaire was shared with individual experts and their responses submitted ahead of the Focus Group Discussion. While the questionnaire developed to guide the Focus Group Discussion focused on issues in the questionnaire for individual stakeholder, it further deepens the perspectives covered in the questionnaire for individual stakeholder.

Areas covered in the questionnaire for Focus Group Discussion include crop production (covering types, irrigation, yield and revenue); processing (Needs, scale, capacity and limitations); irrigation (type, capacity, pump types, willingness to pay, joint procurement, management and limitations) and the benefits of modelling to the stakeholders towards improving energy access to increase irrigation and farming operations of smallholder farmers.

Figure 28 and Figure 29 show the main outputs planned with Stakeholders interview and Focus Group discussion.

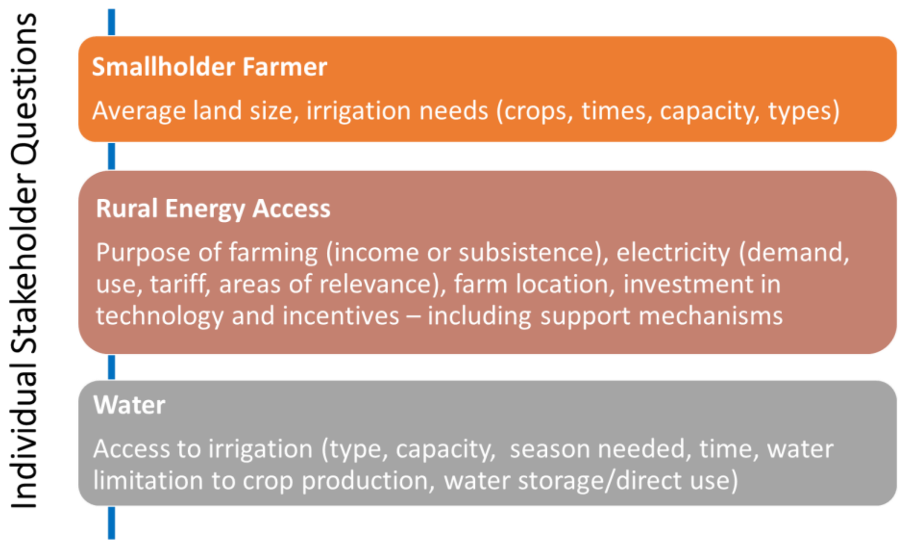

Figure 28 – Stakeholders questions

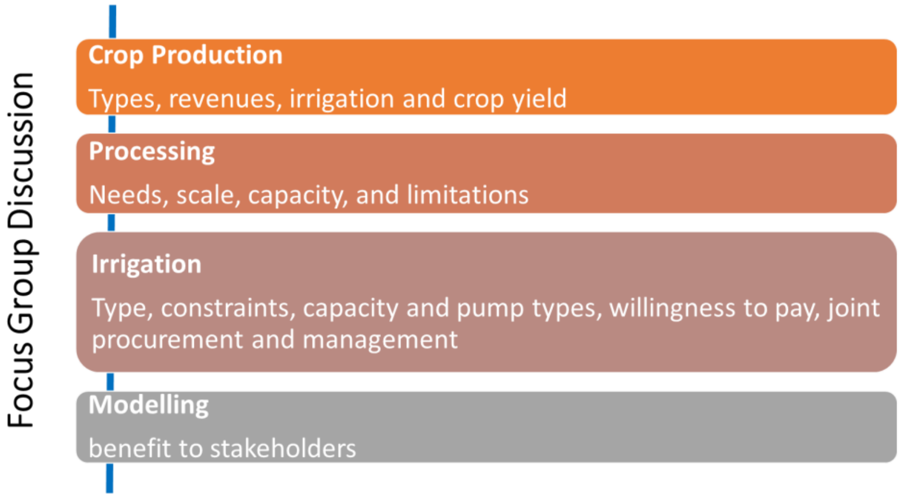

Figure 29 – Focus Group topics

4.2 Nigeria

Farming operations in Nigeria can be categorized based on scale into: smallholder, medium and large scale. This project focuses only on the smallholder farmers (Figure 30 and Figure 31).

The various responses from the stakeholders through the individual engagement reveals that the average land size cultivated by smallholder farmers in Nigeria range from 0.5 - 1.5 hectares. Maize (white and yellow), rice, wheat, and vegetables were found to be the most prominent commercial crops due to their short gestation period and low water requirement, thus, are cultivated round the year. While the most strategic crops for income generation and food security vary with location (climatic conditions), vegetables are mostly cultivated for income generation, while rice and maize are for food security. Farmers experience water stress during the dry season (around November - March) and the timing and duration of the water stress has been influenced in recent years by climate change. Nigeria has a low access rate to irrigation as only 5 - 35% of smallholder farmers have access to irrigation systems with most of the available irrigation systems being in northern Nigeria largely because most of the political leaders at the national level emerged from the region. However, on a national scale, Tube-wells, dams and surface irrigation are the most prevalent irrigation type mostly having 2.6-3.7 kW capacity having 2" - 3-1/2" diameter using pipeline plastic made. Specific examples are one Diesel-powered 415V, 100kVA generator (Newage Standford, England) and six 18.7kW pumping machines (Lincoln Multiguard ac motors, USA). Water extraction for irrigation is mostly carried out at the time of use (for irrigation) compared to the less prevalent use of storage facilities for decoupling between extraction and usage. The timing for irrigation generally varies with weather conditions, however, most carried out in the morning and evening. Smallholder farmers in Nigeria spend an average cost of USD 192 – 220 per acre on irrigation per year.

On energy demand and use, up to 30% of rural electricity demand is from the agricultural sector with tariffs ranging from 0.19 - 0.29 USD/kWh mostly for household use, farming and processing.

S/N	Subject question	Outcome
Q1	Average land size under cultivation	0.5 - 1.5 hectares
Q2	Share of farmers with irrigation system	in the range 5 - 35%
Q3	Prevalent Irrigation systems	Tube-wells, dams and surface irrigation (1% have pressurised system (sprinkler))
Q4	Irrigation Cost	NGN 80,000 - NGN 100,000 (USD 192 - 220) per acre
Q5	Season for water stress	dry season (around November- March)
Q6	Crop type cultivation limitation	Year-round cultivation of maize, rice and vegetables except for vegetables due to short gestation period and low water requirement
Q7	Capacity of Irrigation system /Technologies	2.6 - 3.7 kW / 2" - 3-1/2" pipeline diameter
Q8	Water extraction time	Mostly at the time of use (rarely stored)
Q9	Share electricity demand from Agric sector	Up to 22% (85% of 26%)
Q10	Agricultural demand for electricity	30%
Q11	Electricity tariff for farmers	0.19 - 0.29 USD/kWh
Q12	Financing for Farming machinery	Farmer are willing to invest in services or machinery
Q13	Purpose of electricity	Household, farming and processing
Q14	Productive Agricultural electricity use	Milling, grinding, drying, dehusking, grating, frying, and refrigeration
Q15	Scale of farming	Mostly commercial
Q16	Location of Farm	2 - 30 km from household
Q17	Relevance of electricity on the farm	Not very essential, except for rechargeable appliances (e.g. fumigator)
Q18	Farmers Investment in Technology	Willing if it is affordable and increase profit
Q19	Farmers' acquisition of adv. Technology	Government, Multilateral, and NGOs

Figure 30 – Stakeholder outcomes - Nigeria

The most productive electricity use for agriculture is mainly in processing of agricultural produce such as milling, grinding, drying, de-husking, grating, frying and refrigeration. There exist major limitations to the direct impact of electricity on agriculture partly due to the location of farmlands generally distant (averagely more than 4 km) from the habited areas of rural communities hence not favoured by the economics of grid extension, both for mini-grids or national grid.

S/N	Topic discussion	Outcome
T1	Farmers' typology	smallholder, medium-scale and large scale
		Less than 5% use irrigation due to cost
T2	largest barriers to PV adoption	Long distance location of farm to habited area (> 4km)
T3	Irrigation time	Variable with weather conditions (daily and/or seasonal)
T4	Irrigation system size	Diesel electricity generator + electrical pumps
T5	Importance of electricity load for crop processing and its seasonality	Incentivise to scheme productive use to the day
		Suggest cropping coherent with crop processing load optimization
T6	Most Popular Crop	Vegetables, Rice, Gini Corn, Millet, Maize (yellow, white), wheat are the most commercially sold crops
T7	Proximity of Crop processing	mostly within or close to the village
T8	Ownership of Processing Facility	With government support, Pay per Use, pre-paid electricity
T9	Co-Ownership	Rarely individual ownership of processing facilities
T10	Specification of Processing Facility	Milling machine (15-20 hp), Grinding machine (4-5 kW)
T11	Most strategic Crop for income generation/Food security	Varies with location
		Vegetables are mostly for income
		Rice and Maize for food
T12	Buyers of Crops and Tranportation	Weekly markets with buyers from outside the villages
		Farmers transport to market
T13	Most useful information in your planning activities	profiling activities in target community and the energy demand
		Energy plant sizing based on current energy demand
		Difficult to plan irrigation scheme at the central planning level

Figure 31 - Focus Group outcomes - Nigeria

Moreover, a common challenge of rural energy investors is the security of electricity demand and use throughout the year to prevent technical and economic losses. In Nigeria, this is being addressed by energy companies by incentivizing productive use during the day when household electricity use is minimal thus reducing productive use in the evening when household electricity use is at maximum. This is also complemented by engaging farmers to adopt cropping practices and schedules that are coherent with crop processing load optimization to ensure electricity load for crop processing and its seasonality. Due to scale and cost of acquisition of crop processing facilities, individual ownership of processing facilities is rare, rather, there are processing facilities in close proximity to the farmers including within their respective villages which are procured often with the support of the government and made available to farmers' use using pay per use, or pre-paid business models. Examples of common processing facilities are 18hp (13kW) three phase milling machines, and 6hp (4.5kW) Grinding machines among others.

Smallholder farming are mostly for commercial purposes, nonetheless, a smaller proportion of the produce is consumed by the farmers and their family. Moreover, stakeholders opined that electricity access is not much essential on the farm except for electric rechargeable appliances like fumigator. Also, smallholder farmers are willing to invest in technology especially if the technology is affordable and will optimize profit. Government, Multilateral organizations and non-governmental organizations also provide support farmers in acquiring advanced technological equipment.

4.3 Rwanda

The engagement in Rwanda has been managed both with a stakeholder interview as well as specific focus group discussion. The outcomes are summarized in Figure 32 and Figure 33, respectively.

The average land size cultivated in Rwanda ranges from 0.5-10 ha with maize, beans, vegetables, banana and fruits as the most strategic crops from nutritional and economic point of view for smallholder farmers. Irrigation plays a major role in influencing the types of crops to be cultivated and their yield. Water stress comes to its peak between June, July and August, hence, stakeholders opined that the deployment of irrigation facilities is the most urgent action that is required to increase and stabilise crop yield.

While land and climatic conditions in the country are suitable for the cultivation of Chai seeds, the irrigation deficiencies limit its cultivation yet smallholder farmers are willing to pay for water access especially for high value crops and examples of such paid access to irrigation services exist. Both Food (such as maize, beans and sweet potato) and cash (banana, coffee, tea, pepper, and vegetables) crops will benefit from irrigation. Generally, the prevalent irrigation systems in Rwanda depend on the nature of the available energy source. Areas without electricity access adopt marshland irrigation while electrified farm areas adopt centre pivot or sprinkler irrigation systems. Farm areas powered by solar systems mostly adopt drip irrigation while those using diesel and petrol adopt pipe flow irrigation systems. While the accumulation of rainwater is relevant, it also requires energy access for irrigation management.

The capacity range for groundwater pump varies with the land size to be irrigated and water extracted is mostly stored and discharged to the farmlands by gravity but also requires energy to distribute the water to the field. Surface water extraction is often prioritised over groundwater extraction due to its lower cost. Portable surface pumps are the most prevalent pumping facility in use by smallholder farmers in Rwanda mostly with a 30 m^3 per hour pumping rate. Most pumps are diesel powered and carried out anytime of the day, while solar-powered pumps are operational during sunny days and can store water for future irrigation. As an incentive, the government provides 50% of advance funding on solar pumps.

While maize, beans, vegetables, banana and fruits are the most nutritional and economic crops grown by smallholder farmers, maize and rice should be prioritised in consideration of modelling for crop processing machinery.

S/N	Subject question	Outcome
Q1	Average land size under cultivation	0.5 – 10 hectares
Q2	Most strategic crops from nutritional and economic view	Maize, beans, vegetables, maize, banana, fruits
Q3	Months with increased water stress	June, July and August
Q4	Actions to increase and stabilize crop yields	development of irrigation facilities
Q5	Prevalent irrigation systems	No electricity areas – Marshland irrigation
		Electricity areas - Center pivot/sprinkler Irrigation
		No electricity but solar – Drip irrigation
		Solar/Diesel/Petrol – Pipe flow
Q6	Crop-specific irrigation schemes	Complementary irrigation
Q8	Crops not planted due to lack of water access	Chai seeds
Q9	Farmers willingness to pay for water access	Especially irrigating high value crops
Q10	Famers willingness to implement irrigation system	Similar system exists
Q11	Relevance of rainwater accumulation	It is relevant and requires energy
Q12	Range of groundwater pump	It varies with land size to be irrigated
Q13	Extraction of water	Extracted when sun is up and discharged by gravity
Q14	Prioritizing groundwater or surface water extraction	Surface water extraction due to minimum cost
Q15	Crop processing machinery to be modeled	Maize and rice
Q16	Obstacles to start processing	Lack of knowledge and skills and capital/finance
Q17	Investment in technology	Government provide subsidies as incentives for irrigation and post harvest handling infrastructures.
Q18	Promoting the purchase of advanced technology	Government Subsidies and exemption of VAT on specific items
Q19	Relevance of electricity to smallholder farmer	Household > other uses
Q20	Proximity of houses to farmland	Not properly answered
Q21	Importance of electricity access on farms with distant houses	Very important. Farmers live far from households
Q22	Crops not being engaged in due to lack of electricity	Vegetation (because of irrigation)
Q23	Willingness of smallholder farmers to pay for electricity	They are ready to pay, as some pay for irrigation
Q24	Energy solutions in place of electricity	Pump operation for irrigation

Figure 32 - Stakeholder outcomes – Rwanda

The Rwandan government provides subsidies as incentives for investment in technology for irrigation and post harvest handling infrastructure while there are tax exemptions of VAT on specific items. The ownership of processing machines is generally by consortium (such as cooperative societies) and the most value addition potential that could accrue from energy input is preservation of produce through refrigeration and drying. The most important process machines to improve agricultural productivity and practice are shellers and drying machines. Most of the standalone mills used by smallholder farmers are connected to the main electricity grid.

While electricity is crucial to farmers' livelihood, however, smallholder farmers prioritise electricity access for household use rather than other uses. Nonetheless, the farmers identify the remote distance of farmlands from residential areas as the major factor that accounts for the lack of electricity access on farmlands. The lack of electricity access on the farmlands also contributes to the lack or inadequate access to irrigation which negatively impacts yield and makes the cultivation of vegetables impossible despite soil and climatic suitability yet smallholder farmers are willing to pay as some already do pay for irrigation services. However, pump stations are employed for irrigation for farmlands without electricity access.

S/N	Topic discussion	Outcome
T1	Type of Farmers and crops to benefit from irrigation	Food crops (maize, beans, sweet potato) and cash crops (bananas, coffee, tea, peppers, vegetables)
		Marshlands areas can also be equipped for irrigation with dam systems.
T2	Pumps for pumping process	Portable surface pumps
T3	Time for water pumping or extraction	Most pumps are diesel powered and done anytime
		Solar pumps are done when sun is available, and water is stored.
		50% upfront financing on solar pumps by government
T4	Process of water storage	Stored water is released via gravity. Energy needed for field distribution.
T5	Ownership of irrigation equipment	Most farmers adopt irrigation
T6	Pumping rate and size/power of system	30 m^3 per hour
T7	Proximity of farmland from homes	Farmers live in settlements far from farmlands
T8	Most important crop for processing	Rice and Maize
T9	Most important processing machine	Shelters and drying facilities
T10	Ownership of appliances	Consortium/Cooperative
T11	Connection of standalone mills to wider system	Most mills are connected to main electricity grid
T12	Most value addition potential from energy input	Preservation of produces through refrigeration and drying
T13	Production links with demand side	Multilateral and international development organisations are the major buyers.
		Middle-men buyers between farmers and city
		Ministry of Agriculture & Ministry of Commerce set minimum crop prices
T14	Location of farm products sale	Buyers buy on farm at cheaper rate; however, cooperatives assist to move to city markets to sell at better prices
T15	Financing type for smallholder farmers	Cooperative financing works more
		Bank financing (easier with irrigation facility)
T16	Most important processing machine	Shelters and drying facilities
T17	Ownership of appliances	Consortium (Cooperative)
T18	Useful information during planning activities	Farmer-level information for 5-10year horizon on water/energy demand, cost of actions in development programs, and impact of climate change

Figure 33 - Focus Group outcomes – Rwanda

4.4 Zambia

The survey on Zambia has been managed through focus group discussion. The outcomes are summarized in Figure 34.

Agricultural mechanisation in general and irrigation in particular are the most potential value addition of energy access to agriculture for smallholder farmers in Zambia.

Irrigation is crucial to agriculture given the insufficiency of rainwater and its accumulation in the country. Irrigation is essential for the cultivation of food crops (maize, cassava, rice and groundnut) which are mostly grown by women and cash crops (soybean, cotton, tobacco) that are mostly grown by men especially in the dry season. Most of the smallholder farmers use groundwater irrigation systems comprising 0.5 – 3 hp and 18-25 cubic metre capacity with pumps powered by solar energy that have an average of 4.5-h sunshine hours/day. Most irrigation pumps are powered as standalone while few are powered by mini-grids.

Generally, mini-grids are developed and operated to provide electricity for community use comprising households and businesses while modern energy services in the farm, where they are available, are standalone. Groundwater irrigation system is a more favoured irrigation solution by new business models, VAT exemption, erratic nature of rainfall and climate change. Generally, most smallholder farmers extract and store water in tanks during the day when the Sun is up (particularly for those using solar) and release it for irrigation via gravity in the morning and evening especially for large scale farmers while smallholder farmers generally pump on demand.

S/N	Topic discussion	Outcome
T1	Type of Farmers and crops to benefit from irrigation	Food crops (mostly grown by women): maize, cassava, rice, groundnut
		Cash Crops (mostly grown by men): Soybean, Cotton, Tobacco
		Such crops also include vegetables and legumes
		Especially in dry season
T2	Trade-off between groundwater aquifer versus groundwater bodies	Groundwater is favoured by new business models VAT exemption, erratic rainfall and climate change
		Some experts opined that surface water is more in use due to affordability and technical feasibility
T3	Time for water pumping or extraction	Smallholder farmers: pumping on demand
		Larger famers: storage and used afterwards
		For solar powered irrigation, pumping is carried out when the sun is up, stored in tank, use for irrigation morning and evening
T4	Pumping rate and size/power of system	0.5 - 3 HP pumping (4.5 sunshine hours/day) and 18-25 m^3 water on daily output
T5	Water Storage	Daytime pumping and exploiting gravity to release water on field
T6	Relevance of rainwater accumulation	Rainwater collection is insufficient to replace irrigation.
T7	Most value addition potential from energy input	Irrigation and mechanisation to boost productivity
		cultivation of crops with higher economic values such as onions
		processing of soyabean, sunflower, groundnuts, sugar beet, cassava for income
		Processing of cereals for food
T8	Distance of farmland. Diesel vs pump vs mini-grid distance	Solar pump is cheaper than diesel pumps
		Mini-grid mostly suitable for cooperatives
T9	Relevant crop processing energy demand	Milling, shelling, drying and storage of grains.
T10	Standalone power mills and pump or Mini-grid	Mostly standalone with few powered by mini-grid
T11	Co-existence of mini-grid and standalone pump	Mini-grid for community use and standalone for field use.
T12	Seasonality of energy demand	Energy demand all-year round due to cropping patterns and rotation
T13	Management of power access in mini-grids	There is scheduling and pre-allocation of time for electricity aided by smart metering for high energy intensive appliances.
T14	Ownership of appliances	Ownership currently on cooperative level due to affordability
T15	Farmers carrying out processing themselves	No, due to affordability. Entrepreneurs are into processing business.
T16	Barrier to crop processing	Access to finance and market
T17	Entities farmers that buy crop	Government (largest buyers)
		Cooperative and energy developers
		Seed companies , business organisations and other off-takers buy on contract
T18	Production links with the demand side	Local markets (low prices)
		City market (high prices)
T19	Prices of selling crops generally	Determined by national market price, scale of production, transportation cost with profit margin
T20	Barrier to crop processing	Access to finance and market; poor transportation facilities (road and vehicles) and lack of electricity for processing
T21	Financing for smallholder farmers	PAYGO, Supply credit, and rent-to-own
		Equipment acquisition with installment payment
T22	Crop residue utilization after harvest	Crop residues are put to only a little use
T23	Mini-grid tariffs charged to farmers	Tariffs differ with business models, energy efficiency measures and diversity of sectors
T24	Government policies supporting technology uptake	Removal of taxes on agricultural equipment
		Farmer Input Support Programme
T25	Design of mini-grids	Designs are made on current energy demand with projections for future energy use 8-10% annual increase in energy demand.
T26	Useful information during planning activities	Use of updated and validated data on energy and water demand, crop potential and yield, among others
		Focus on climate-smart practices
		Demand evolution at granular level
		Understanding challenges of smallholder farmers across the value chain
		knowledge of productivity per resource input, energy demand, affordability and willingness to pay coupled with the local income levels

Figure 34 - Focus Group outcomes - Zambia

Solar pumps are cheaper than diesel-powered pumps, however, the irrigation system is powered by mini-grid where cooperative advantages are available for smallholder farmers. The tariff charged for electricity consumption from mini-grid differ with business models adopted, energy efficiency measures and diversity of sectors being served by the mini-grid. Generally, appliances are owned as a cooperative due to challenges of individual affordability occasioned by the limited access to finance, poor transportation facilities (road and vehicles) and lack of electricity access especially for processing. In Zambia, milling and shelling are the most relevant crop processing activities and it is mostly operated and powered as a standalone. In addition to milling, drying and storage of grains are also relevant crop processing that would benefit from energy access.

There are various financial models on the ownership and use of processing machinery including PAYGO (pay as you go), supply credit, and rent-to-own. Government provides support for the acquisition of agricultural equipment through removal of taxes on agricultural equipment, institution of a Farmer Input Support Programme and off-taking (buying) support as the government is the largest buyer of crop produce. Other buyers include cooperative and energy developers including other off-takers who buy on contract. Moreover, smallholder farmers sell their produce at local markets for lower prices and at city markets at relatively higher prices.

Smallholder farmers rarely own or carry out the processing of the produce also due to the challenge of affordability, rather, there are crop processing business organisations that undertake such as billable services. The adoption of cropping patterns and rotation, as well as scheduling and pre-allocation of time for electricity use aided smart metering for high energy intensive appliances are essential strategies towards ensuring all-year round energy demand. For daily operation, various levels of electricity usage are scheduled to maximise energy generated, stabilise electricity demand, and minimise electricity usage. Generally, high electricity-intensive equipment such as crop processing equipment are scheduled for operation and usage during the day (9am-5pm). Generally, mini-grids are designed based on current energy demand with a projected 8-10% annual increase in energy demand.

For planning, experts recommended updated and validated data, focus on climate-smart practices, knowledge of the evolution of demand at granular level, and willingness and ability to pay relative to the local income levels; as being crucial for planning activities for smallholder farmers. An understanding of the challenges of smallholder farmers across the value chain, knowledge of productivity per input resource are useful information.

4.5 Zimbabwe

The survey on Zimbabwe has been managed through focus group discussion. The outcomes are summarized in Figure 35.

The average land size cultivated by smallholder farmers in Zimbabwe ranged from 0.5 – 5.0 hectares, however, the farmers are not able to maximise the potential of their cultivation due to gross deficit in access to irrigation. More than 90% of farmers in Zimbabwe lack access to irrigation systems despite proximity to water sources, a situation that is largely attributed to the lack of modern energy access. A variety of crops have the potential to benefit from the provision of access to irrigation: food crops (maize, wheat and beans), cash crops (vegetables, tomatoes, onions, and peppers) and export crops (dry chili, garlic, ginger, and peas).

Generally, smallholder farmers sell their produce at the local market and in nearest cities, however, maize (and other grains) must be sold to the government as they are considered to be strategic crops and are controlled by the Ministry of Grain Reserves. Common irrigation systems employed by smallholder farmers in the country comprises 0.5-5 kW submersible pump, 40-60 m borehole, 14,000 litres/day with 2.3 hp per hectare pumping rate (drip irrigation) while there is a growing interest in solar irrigation of 3,600 litres/hectare.

Although energy cost by smallholder farmers vary with usage, smallholder farmers spend on average USD 0.12/kWh on electricity while those who generate electricity from private fossil-powered use more than USD

1.6/litre of diesel or petrol. Generally, costs associated with irrigation, equipment, fuel (petrol/diesel cost) and transport cost represent the biggest cost of crop production for smallholder farmers and the instability and weakness of the Zimbabwean Dollar also contribute to a high exchange rate which negatively impacts the farming business. Moreover, the provision of access to electricity will also facilitate the energy demand for processing of crops such as milling, peanut processing, and cold storage for vegetables.

S/N	Topic discussion	Outcome
T1	Status and prospects of irrigation	More than 90% farmers lack access to irrigation systems despite proximity to water source.
		Energy access is a major challenge to irrigation
T2	Average plot sizes	0.5 – 5 hectares
T3	Type of Farmers and crops to benefit from irrigation	Food crops: maize, wheat, beans
		Cash crops: vegetables, tomatoes, onions, peppers
		Export crops: dry chili, garlic, ginger, peas
T4	Pumping rate and size/power of system	0.5 - 5 kW submersible pump
		40 - 60 m borehole
		14,000 liters/day with 2.3 HP pump per hectares (Drip irrigation)
		Solar irrigation of 3,600 liters/hr gaining interest
T5	Prioritizing cash crops when switching to irrigation	Depends on market reliability for cash crops
T6	Relevance of crop processing energy demand	milling, processing (peanut), cold storage for vegetables
T7	Connection of standalone mills to wider system	Grid supply for mechanized farmers
		Diesel for smallholders
T8	Processing among smallholder farmers	Farmers prefer to sell their produce as raw materials than pay for processing (high cost)
T9	Most value addition potential from energy input	Groundnut processing
		Onsite processing and packaging for corn
T10	Production links with demand	Farmers sell at local markets, nearest cities
T11	Entities to whom farmers sell to	Maize (other grains) must be sold to the government. Free market is sometimes allowed
T12	Biggest cost for farmers	Irrigation cost, equipment prices, petrol/diesel costs, and transport.
T13	Issues with currency	Critical the exchange rate of the Zimbabwe Dollar
T14	Compulsion to sell maize to government	Some grains are strategic and controlled by the Ministry for grain reserves.
T15	Energy cost for smallholder farmers	0.12 USD/kWh for electricity, but varies with usage
		Diesel / petrol -> 1.60 USD/litre
T16	Useful information during planning activities	Energy demand estimation
		Irrigation information and projection
		Market information
		Soil quality information

Figure 35 - Focus Group outcomes - Zimbabwe

While standalone mills employed by mechanized farmers are connected to the wider electricity grid supply, standalone mills serving smallholder farmers are mostly powered by diesel. However, smallholder farmers prefer to sell their produce as raw materials rather than pay for processing due to increased cost of production. Given the Zimbabwean agricultural context, groundnut processing and on-site processing and packaging of corn would be the most value addition of energy access.

Smallholders identify soil quality information, energy demand estimation, irrigation information and projection, and market information as crucial to their planning activities.

4.6 Emerging Trends (Nigeria, Rwanda, Zambia and Zimbabwe)

The minimum size of farmland cultivated by smallholder farmers across Nigeria, Rwanda and Zimbabwe are the same (0.5 ha), however, the upper limit differ: 1.5 ha in Nigeria, 10 ha in Rwanda and 5 ha in Zimbabwe.

The most prevalent crops being grown from an economic point of view are mostly grains and vegetables, mostly for income generation and food security. The choice of the crops cultivated, and their yield are limited by water requirement and availability. Farmers are unable to maximise the potential of their cultivation due to gross deficit of access to irrigation which is largely attributed to lack of electricity access. Yet, farmers are willing to pay for water access especially for high value crops as many of the farmers are not able to plant some crops largely due to water stress, such as the Chai crops in Rwanda. While there is accumulation of rainwater, energy is required for distribution to the farmlands. The lack of electricity access on farm lands is largely due to their distance from the habited areas of rural communities, generally more than 4km away from the habited areas of rural communities as it is in Nigeria.

Stakeholders from the four countries agree that irrigation is the most urgent action that is required to increase and stabilise crop yield. Irrigation is essential for the production of food and cash crops for farmers to maximise the potential of their cultivation especially during the dry season when the water stress is at its peak. Generally, irrigation systems powered by fossil-fuel are operated to pump and distribute water when needed: usually in the morning and evening. On the other hand, solar-powered irrigation systems are used to pump and store water when the sun is up and the stored water is released to the farmlands when needed, usually in the morning and evening. In Rwanda, the government provides 50% advance funding for acquisition of solar pumps. Generally, surface irrigation seems to be the most prevalent irrigation type across the countries, except in Zimbabwe where drip irrigation is more prevalent.

On a daily base, rural energy operators incentivise the high energy-intensive equipment especially for productive use during the day to ensure availability of electricity for households at night. The scheduling is particularly aided with scheduling and pre-allocation of time for electricity use aided by smart metering for high energy-intensive activities in Zambia. Furthermore, farmers are encouraged to adopt crop rotation in order to foster energy demand for crop processing throughout the year.

Equipment for drying and storage for preservation of farm produce is more commonly needed by smallholder farmers. Individual ownership of crop processing equipment is rare due to the cost vis-à-vis the affordability, therefore, ownership of agricultural processing equipment is by consortium, cooperative or businesses and are offered as billable services. Indeed, farmers are willing to invest in technologies if it will maximise profit and the government provides various forms of support for the acquisition of the equipment such as tax exemption on the equipment procured. Governments in Rwanda and Zimbabwe also provide off-taker support as the governments buy the grains from the smallholder farmers.

5 General Conclusions

This report synthesises evidence collected through four main sources of information:

- national statistics and indicators and a related country taxonomy;
- scientific and grey literature on agriculture-energy-water-development nexus in SSA and in focus countries;
- written questionnaires filled by stakeholders;
- face-to-face focus groups with stakeholders.

These activities fall under the umbrella of Task 12.1 of the LEAP-RE WP12 "RE4AFAGRI" project.

The report lays down the base for achieving the proper balance between an Africa-wide representative top-down approach and a country-specific bottom up approach. The use of a funnel type method that presents the general context of the region through macro level indicators and narrows the analysis down to country-specific cases through national stakeholders' engagements provides the right framework to achieve the reports objectives.

It is therefore now crucial to provide some general conclusions that can benefit the reader and represent at the same time an input for the follow-up research activities in Tasks 12.2-3 (modelling integration; data collection, calibration and validation) and Task 12.4 (business model research). Moreover, such insights are also fundamental for the capacity building activities planned as part of Tasks 12.5 (modelling training) and 12.6 (policymakers and stakeholders capacity building).

The first important conclusion is that there are both cross-country similarities and notable country (or sub-national) specificities with regards to the agriculture-energy-water-development nexus issues and challenges analysed in RE4AFAGRI. These characteristics pertain to the environmental (climate, land, ground and surface water availability), agricultural (dominant crops, irrigation practices and infrastructure, crop processing machinery availability), market (sale and purchase of crops, market structure), infrastructure (power grid, roads), energy (rural electricity access, diffusion of diesel vs. solar pumping systems), socio-economic development (GDP per-capita, farmer disposable income), and market conditions (regulatory framework for decentralised energy access, risk and interest rates).

The most prominent similarity between different countries in SSA pertains to the relevance and typology of agriculture: about 80% of agricultural land in SSA is cultivated by smallholder farmers, i.e. farmers owning and/or managing only few hectares of land (in general, 0.5 – 2 hectares per household), part of which is used for subsistence and part for yield sale to market. This picture is confirmed both by literature and data-driven insights, and by stakeholder engagement activities, where the salient characteristics of smallholder farming in SSA were discussed. In parallel, another crucial similarity refers to the availability of irrigation: more than 90% of cultivated cropland in SSA is rainfed, with irrigation covering mainly specific large-scale farms or limited pilot schemes. Erratic rainfall – exacerbated by climate change impacts – and the difficulty of cultivating water-intensive profitable crops (most prominently vegetables) outside of the rainy season was systematically listed by stakeholders from different countries and sectors as a key reason behind the persistent poverty of SSA smallholder farmers, together with the year-to-year variation in yields and revenues, in turn jeopardising food security and the possibility of the farmers to perform multi-year infrastructure investments to be paid in instalments.

Thus, a core result of the analysis is that the structural challenges of the agricultural production system are rather consistent across SSA. Irrespective of this apparent similarity, crucial differences - as highlighted in the preceding chapters of this report - are and will increasingly have an important impact on the design of infrastructure and policy (and on the investment implications) to foster agricultural development in different SSA countries. For instance, focus group discussions highlighted the heterogeneous situation in terms of the location of the smallholder farmer-owned agricultural land compared to the rural village core, ranging from a few hundred metres to up to 3-5 km. This range of variability depends on the geographical and morphological configuration of each country, as well as on the speed of communities clustering and urbanisation in rural areas: for instance, a small and relatively dense country like Rwanda shows a much closer proximity of cropland to villages than a vast and scarcely populated country like Zambia. These types of geographical differences play a key role in the economic trade-off between different electricity supply, water pumping, and irrigation systems. They thus must necessarily be factored into the modelling assumptions and business model design if realistic results are to be provided to stakeholder active in this domain.

Additional aspects that were found to be very variable depending on the socio-economic, policy, and business context in question include the degree of livelihood of the policies and market for solutions seeking to tackle the above mentioned challenges. Historically more homogeneous, SSA is becoming increasingly polarised in terms of countries and systems capable of attracting private or development infrastructure financing (thanks to regulation, political and economic stability, and local entrepreneurial culture), and those who struggle to witness a surge in capital inflows into rural development projects.

Different levels of market development and value chain dynamics result in differentiating potential business models within a country's specific context, tailoring these to each individual need. For example, the more developed small-scale crop processing sector in Nigeria could probably adapt more easily to new and innovative business models than Rwanda which presents a nascent small-scale processing sector. At the same time, distinct levels of government intervention in some crop commodity prices, such as in the Zambia and Zimbabwe maize value chain, require the business model analysis to consider different approaches tailored to each case.

Nonetheless, similarities regarding business models and enabling environments between countries can also be found from this study. Focus Group Discussion insights provide a high-level overview of relevant government support mechanisms, and some of them are replicated in many cases, such as the Rwandan and Zimbabwe government subsidies to access solar pumps and post-harvest processing machinery. These data points will be further analysed in upcoming deliverables of the RE4AFAGRI project due to their impact in the feasibility of deploying different types of business models. In addition, the presence of cooperative-owned processing equipment rather than individual farmer ownership in Nigeria, Rwanda, and Zambia, for example, makes the case for business models to be properly adapted to this market segment.

Focus Group Discussion insights provide the necessary high-level background information to focus the upcoming business model analysis on the most relevant aspects of the several country-specific value chains, starting with the identification of high-potential value chains and their dynamics. Furthermore, data points gathered from stakeholder engagement sessions such as irrigation and crop processing costs, and energy costs serve as inputs for determining the techno-economic potential of specific value chain activities to be electrified.

The next RE4AFAGRI deliverables on the modelling and business model research will provide additional information on the use of the collected information for deriving decision making-relevant insights.

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Our World in Data: https://Ourworldindata.org

GET.invest: https://www.get-invest.eu

LEAP-RE, WP12 RE4AFAGRI

Deliverable 12.2 – Annex I

Minutes of the Focus group discussions

Table of contents

1st LEAP-RE RE4AFAGRI FOCUS-GROUP on Nigeria

Draft Meeting minutes

10/12/2021 - 10am – 12pm CET/WAT

Google Meet

Participants:

1. Adedoyin Adebodun Adeleke (POLIMI)
2. George Kabutha (Value Seeds Ltd.)
3. Olayinka Jelili Yusuf (Kwara State University)
4. Babatunde Olarewaju (consultant)
5. Abigail Botsha (Green Village Energy)
6. Samuel Babalola (consultant)
7. Akinyele Balogun (MAX.NG)
8. Prof. Thomas Stephen Ijimdiya (Ahmadu Bello University)
9. Katundu Imasiku (University of Rwanda)
10. Giacomo Falchetta (IIASA)
11. Alison Hughes (UCT)
12. André Troost (TFE)
13. Muhammad Awais (IIASA)
14. Diana Shendrikova (POLIMI)
15. Francesco Semeria (POLITO)
16. Manfred Hafner (HEAS)

Meeting agenda:

- Welcome, introductory round (moderated by Adedoyin Adebodun Adeleke)
- Introduction to the LEAP-RE RE4AFAGRI project (Prof. Manfred Hafner)
- Focus group 1 – irrigation and water pumping (moderated by Giacomo Falchetta)
- Focus group 2 – crop processing (moderated by Giacomo Falchetta)
- Focus group 3 – economics and business models (moderated by Giacomo Falchetta)
- Final questions – research output and scale
- Wrap-up

Meeting minutes:

- Introductory round where all Nigerian stakeholders introduced themselves highlighting their position, organizational affiliations, and expertise.

- Manfred Hafner (RE4AFAGRI coordinator) presented the concept and approach of the RE4AGRI project within the overall LEAP RE, including its concept and approach. He highlighted the fundamental role of stakeholder for the project and the strong

commitment to ensure a continuous and long-term relationship between stakeholders and the RE4AFAGRI consortium.

- Giacomo Falchetta (coordinator of modelling integration and development) and André Troost (coordinator of business model development) then engaged with the stakeholders on the technical focus of the discussion

The first focus group session focused on irrigation and water pumping: Giacomo provided an introduction on the significance of irrigation for stabilising and increasing yields and opened the discussion.

Q1: According to your experience, what is the typology of farmers and the type of crops that would benefit the most from irrigation? And what is the preferrable source for extracting water: ground/surface water?

- **Power is the strongest barrier to irrigation**. Irrigation is sparsely used by farmers (below 5%), although some areas with government interventions e.g. community under water basins authorities. **Fossil fuel prices** are increasing and are expected to increase by a lot by the government. In this sense, diesel water pumping is not sustainable! Solar will thus have increasing competitiveness, not only for irrigation, but also processing such as threshing.
- Depending on type of farmer (smallholder, medium-scale, large-scale, three types), the technology and costs for irrigation is very different. Of course local climate / rainfall matters a lot. But even where water is abundant, the way water is used matters a lot. In one word: **capacity**. Cost technical skills for maintenance also play a huge role for smallholder farmers, besides upfront cost for purchasing irrigation appliances. E.g. appliance breaks down after 5 years, and then it is left unused because broken. Solar-powered pumps shows low adoption because it is largely unaffordable -> lack of technical skills. **Affordability** is not only the cost of the product, also **availability of product and technical support (e.g. spare parts)**. Payment schemes -> problem with instalment payments because cost is significantly higher and it becomes unaffordable and farmers often default. Nobody guarantees for the farmer. Growing diesel prices increase also the cost of production.
- Irrigation farming is practiced around the river basins in Nigeria and 70 -75% of the large irrigation schemes are concentrated in the North western part of Nigeria. Perhaps, this may be due to the fact that the Federal government of Nigeria has mostly been led by persons that hail from the North western part of the country. As a result, there is **irrigation practice knowledge gap among other ethnic nationalities**
- **Provision of improved infrastructure** for irrigation farming in Nigeria has been the major source of crisis for **conflict between the farmers and herders.** The conflict points are majorly concentrated around the **water infrastructure. This is also linked to the poor or non-existence of water governance structure.**

Q2: What are therefore the **largest barriers to the adoption of photovoltaics**, given it is increasingly becoming more competitive than diesel?

Major issue: distance of farmlands to the closest mini-grid connection. **More than 1 km is challenging** because it implies growing costs and voltage decrease (and low consumption on the farm). But usually **cropland is >4 km** from the core of the village where e.g. a mini-grid operates. In these contexts, it makes more sense to have a standalone power supply system on farm even though in the village there is a mini-grid. Emerging role of small-scale solar kits.

Q2.1: Is **4 km a usual distance** for Nigeria?

- It could actually be **more** in many villages, as **cropland is expanding** to look for more fertile land once land becomes overexploited. So it is very difficult to expand grid/mini-grid to reach the pumps in the farmland.

Q3: To my knowledge **irrigation time** is generally in the morning when evaporation is lower. Do you agree according to the experience? This affects energy demand of course.

- It depends on different locations in the country. And on the season (dry/wet). And on the crops. **Most farmers do it in the morning, but some also in the evening from 5pm (twice).** Smallholder farmers only using pumps are different from farmers **close to the dam**, where they carry the pump to the dam reservoir tributaries and extract the water from there (surface water extraction).

Q4: Power systems size used for smallholder irrigation?

- Different size are in use. Many of **the smallholder farmers use 6.5 Hp pumps**. But there are case in which ione (1) diesel fuelled 415 V, 100 kVA generator (Newage Stanford, England) + six (6) 18.7 kW pumping machines (Lincoln Multiguard ac motors, USA). Most of the generators are quite obsolete, as such efficiency is low and spare parts may not be readily available.

The second focus group session focused on **crop processing**: Giacomo provided an introduction on the significance of crop processing for increasing value added of yields and opened the discussion.

Q4: Crop processing is more concentrated in space than irrigation, when it comes to energy demand. This session seeks to understand the relevance of the crop processing energy demand, and the economics, e.g. processing appliances cost, ownership **How important is the load from crop processing** for a rural mini-grid? And how big of an issue is it the **seasonality** of such load for mini-grid financial sustainability?

- Example of community with strong rice processing activities. The mini-grid company tries to incentivise processing to take place during daytime, and **by 6-7pm most agro processing activities switch off, which is when the residential loads peak**. During the seasons, they try to **suggest to farmers**

cropping rotation such that the crop processing load is quite constant all around the year. So community cooperation effort beyond technical planning of mini-grid. GVE presents farmers with options about cropping coherent with crop processing loads optimisation.

Q5: What are the most popular crops?

- Main ones: Vegetables, Rice, Gini **Corn, Millet, Maize (yellow, white), wheat are the most commercially sold crops**.

Q6: Is crop **processing mostly in close proximity** of the village?

- Some villages **already had** crop processing sites before mini-grid installation which were powered via fossil fuels. When installing the mini-grid they advised processors **to move processing machines slightly away** from residential locations to mitigate noise issue. Some existing processing facilities remained where they were, But **distance between the mini-grid and processing location is not an issue**. These machines only operate in the daytime, not 24 hours.

Q7: When it comes to **ownership** of crop processing facilities, how does a farmer community organise to purchase and use these processing units? How is the ownership and payment structure? For both upfront cost and energy.

- **Machinery** -> GVE started some **appliance financing schemes** funded by State and Federal level governments and donor agencies. GVE as an **intermediary and guarantor** for those farmers. Following completion of instalment payment over a specified period of time, the machine/appliance becomes the possession of the customer.
- Thanks to **low interest rates** within these programs, some farmers are able to **pool and buy appliances** in instalments.
- **Pre-paid energy purchases through toke**ns -> farmers purchase tokens and input it in the meter to get the energy.
- GVE also offers grant financing to customers to purchase components in order to manufacture appliances locally themselves.

Q7.1: Co-ownership diffused?

- Commodity-based machinery at the village-level or individual level who then makes other farmers **pay to use them, e.g per given unit of processing (kg). Smallholder farmers typically do not own their own processing machines.**

Q8: Names and specifications of **crop processing machinery**?

- **Milling machine: 18 hp, three phase. (13 kW), and smaller. Grinding machine 6 hp (4.5 kW) and smaller too.**

The third focus group session focused on the **economics**: Giacomo provided an introduction on the potential to increase yield and value added of yields and opened the discussion.

Q9: What are the **most strategic crops** (largest potential) for **income generation / food security**?

- Location-dependent. Vegetables for income. Rice and maize for food. The relative greater importance of **fertilizers** (in some instances even more than irrigation, which is mostly relevant to **stabilize** yields) for these latter food crops, also against pests**. Crop processing is mostly relevant for staple crops, whilst the largest factors for vegetables (value crops) is storage/cooled preservation**.

Q10: Who are the **buyers of crops** sold by smallholder farmers usually, and how the **transport to markets** occurs?

- Weekly markets are the main outlets. Buyers tend to come to the village, both wholesale purchasers and individuals from the cities. **Farmers are responsible for transportation. They need to pay for the cost of transportation, which removes part of the income generation potential**.
- Need to remember also **quality of energy and machinery infrastructure**

Q11: Crop prices at which smallholder farmers are able to sell crops?

[unaddressed question]

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The fourth and final focus group session focused on the **outputs from the modelling tools**: Giacomo provided an introduction on the purpose of the modelling platform being development and the type of insights it can offer-

Q12: What are the **most useful pieces of information** in your planning activities?

- Challenge of **estimating the energy demand and activities going on in the area** without going to carry out extensive field work. What activities are potentially productive uses of energy?
- Issue of **sizing technology**. In their experience, system design was based on what observed in the village as already in use, but a model can provide more detailed insight, also on the potential future evolution!
- Difficult to **plan irrigation scheme** because actual use by farmers is challenging to estimate at a central planning level

Q13: What are the spatial and temporal scale of interest for the platform outputs?

- Useful to have information at the **farmer/village level**.

1st LEAP-RE RE4AFAGRI FOCUS-GROUP on Rwanda

Draft Meeting minutes

25/02/2022 - 10.30am – 12pm CET

Google Meet

Participants:

1. Giacomo Falchetta (IIASA)
2. Manfred Hafner (HEAS)
3. André Troost (TFE)
4. Ackim Zulu (UNIZA)
5. Simon Rukera Tabaro (UNIRWA)
6. Gregory Ireland (UCT)
7. Alison Hughes (UCT)
8. Diana Shendrikova (POLIMI)
9. Katundu Imasiku (UCT)
10. Francesco Semeria (POLITO)
11. **Papias Mucyo, Irrigation specialist working for Rwanda Agriculture Board RAB;**
12. **Jean Claude Gakwaya, managing director ECM a service provider in this sector;**

Notes

Prof. Charles Bucagu, the deputy director general in RAB couldn't attend the meeting but expressed his interest in meeting soon on another occasion.

Meeting agenda:

- Welcome, introductory round
- Introduction to the LEAP-RE RE4AFAGRI project (Prof. Manfred Hafner)
- Focus group 1 – irrigation and water pumping (moderated by Giacomo Falchetta)
- Focus group 2 – crop processing (moderated by Giacomo Falchetta)
- Focus group 3 – economics and business models (moderated by Giacomo Falchetta)
- Final questions – research output and scale + wrap-up

Meeting minutes:

- Introductory round where Rwandan stakeholders introduced themselves highlighting their position, organizational affiliations, and expertise.

- Manfred Hafner (RE4AFAGRI coordinator) presented the concept and approach of the RE4AGRI project within the overall LEAP RE, including its concept and approach.

He highlighted the fundamental role of stakeholder for the project and the strong **commitment to ensure a continuous and long-term relationship between stakeholders and the RE4AFAGRI consortium**.

- Giacomo Falchetta (coordinator of modelling integration and development) and André Troost (coordinator of business model development) then engaged with the stakeholders on the technical focus of the discussion

The first focus group session focused on irrigation and water pumping: Giacomo provided an introduction on the significance of irrigation for stabilising and increasing yields and opened the discussion.

Q1: What are the types of farmers and crops that would benefit the most from the input of irrigation?

- A balance of both **food crops** (maize, beans, sweet potato) and **cash crops** (bananas, coffee, tea, peppers, vegetables).
  Eastern Province -> affected by drought. It is the district where it is most crucial to develop irrigation in Rwanda. Water is limiting factor in farming, so irrigation gap should be meaningful. -> Farmers are very keen to get irrigation to increase yields.
- Marshlands areas can also be equipped for irrigation with dam systems.

Q2: With what pumps is pumping carried out?

- **Groundwater is very limited, mostly used for livestock.**
- Usually (vast vast majority) **portable surface pumps**. This is because surface water is widely available. Farmers bring them to the field, use them and bring them with them as they leave the field.

Q3: When does the water pumping generally carried out? On demand when needed vs. extraction + storage?

- Generally when needed, unless with solar pumps, which is when there is sun available and pumping water in reservoirs, and then gravity is used to release water when needed.
- Vast majority of existing pumps are diesel powered today; government is putting up important schemes to support PV and electrical pumps, e.g. financing 50% of the upfront cost.

Q4: How does the water storage work?

- With gravity, but some energy might be necessary to distribute the water onto the fields.

Q4.1: Do farmers own their irrigation equipment?

- Among the farmers who irrigate, most of them own their irrigation equipment.

Q5: Pumping rate and size/power of system for the average smallholder farmer in Rwanda?

Generally, about 30 m^3/h to pump from surface sources

Q6: How far is farmland from homes? Diesel vs. pump vs. mini-grid and the role of the distance.

- In Rwanda, Farmers live in community settlement and farm are far from houses.

The second focus group session focused on **crop processing**: Giacomo provided an introduction on the significance of crop processing for increasing value added of yields and opened the discussion.

Remark made without question: storage facilities are crucial to enable storage in the first place!

Q7: Most important crops for processing?

- Rice and maize.
- "Crop intensification program" in Rwanda promoted by the government to reduce losses. https://www.degruyter.com/document/doi/10.1515/jafio-2021-0010/html#:~:text=Rwanda's%20%E2%80%9CCrop%20Intensification%20Program%20(CIP,potato%2C%20beans%2C%20and%20cassava.

Q8: What type of processing machines are most important?

- Shelters, drying facilities

Q9: Ownership of appliances: small scale or consortium?

- Government is providing subsidies to farmers and investments under the Ministry of Agriculture, but insufficient. E.g. mobile dryer
- Most farmers own don't own processing (mills, small factories) appliances. As farmers group into cooperatives, they can have the possibility to own their processing equipment.

Q10: What is the average cost of fuel/electricity for farmers?

- 50’000 RWF per hectare (50 USD), but if you use electricity instead of diesel, less. [unsure about unit of time. Per growing season?]

Q11: Are those mills standalone powered or connected to a wider system e.g. mini-grid?

- Mostly powered by the grid, not many solar powered appliances seen by the stakeholders so far.

The third focus group session focused on the **economics**: Giacomo Falchetta provided an introduction on the potential to increase yield and value added of yields and opened the discussion.

Q12: From the point of view of farmers, where is the most value addition potential thanks to energy input?

- High expectations on the role of storage for farmers: for preservation of products through refrigeration and for drying.

Q13: How does the production links with the demand side? Who are the buyers?

- There is one agency of Ministry of Agriculture (Africa Improved Foods – AIF), that act as buyer for maize and soybean. **From AIF website:** *AIF is a joint venture between the Dutch Multinational DSM (the largest producer of vitamins globally), the International Finance Corporation (IFC is part of the World Bank), FMO, (the Dutch development bank), CDC, (the Development Finance Institution of the UK Government’s Department for International Development) and the Government of Rwanda.* **Also:** *WFP purchases the majority of the production output. Meanwhile, the Government of Rwanda also purchases a substantial volume. A smaller part of the plant’s capacity is used to produce commercial products that are be sold via retail outlets in Rwanda, Kenya and Uganda. The remaining production capacity is allocated to the production of fortified blended foods for private companies such as Tropikal Brands which entrusted the production of its commercial product ‘NutriPro’ to us.*
- Some contract farming is present, but not very much organized and often breached.
- Many middle-men that intermediate between farmers and city markets.
- Ministry of Agriculture & Ministry of Commerce collaborate to set minimum prices for crops

Q14: Where do farmers sell their products? e.g. buyers coming to the village themselves, etc.

- Most of the times buyers come to the farm, buying at very low price.
- Some cooperatives buy/rent a truck to transport to close markets to obtain better prices.

Q15: What kind of financing have you seen to be working with smallholder farmers? Ownership through cooperative?

- Financing still hard ("banks still look at farmers as losers")
- **If farmers already have irrigation schemes up, it's easier for them to access financing.**
- It's possible to access finance as cooperatives, too.

Q16: Government policies to support the uptake of technologies?

- Gov't subsidies: 50% of capital cost on pumps.
- Portable processing machinery (e.g., "mobile driers") given to private enterprises.

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The fourth and final focus group session focused on the **outputs from the modelling tools**: Giacomo provided an introduction on the purpose of the modelling platform being development and the type of insights it can offer-

Q17: What are the **most useful pieces of information** in your planning activities?

- Reliable estimates of water/energy demand.
- Reliable estimates of costs of actions in development programs.
- Farm-level information would be very important because in the county / district there might be significant differences!
- 5-10 years -> a good horizon!
- Impacts of climate change are very important and felt by farmer communities

1st LEAP-RE RE4AFAGRI FOCUS-GROUP on Zambia

Draft Meeting minutes

14/01/2022 – 10.00 am – 12.00 pm CET

Google Meet

Participants:

1. Giacomo Falchetta (IIASA)
2. Manfred Hafner (HEAS)
3. André Troost (TFE)
4. Ackim Zulu (UNIZA)
5. Simon Tabaro (UNIRWA)
6. Adriano Vinca (IIASA)
7. Alison Hughes (UCT)
8. Katundu Imasiku (UCT)
9. Francesco Semeria (POLITO)
10. Marta Tuninetti (POLITO)
11. **Joshua Nyoni (Zambia Renewable Energy Association)**
12. **Suzyo Silavwe (Rural Electrification Authority)**

Notes

Patricia Chibowa (Good Nature Agro) was absent from the meeting. As a result, the meeting has been more focused on the energy aspects, and less on the purely agricultural issues.

Meeting agenda:

- Welcome, introductory round
- Introduction to the LEAP-RE RE4AFAGRI project (Prof. Manfred Hafner)
- Focus group 1 – irrigation and water pumping (moderated by Giacomo Falchetta)
- Focus group 2 – crop processing (moderated by Giacomo Falchetta)
- Focus group 3 – economics and business models (moderated by Giacomo Falchetta)
- Final questions – research output and scale + wrap-up

Meeting minutes:

- Introductory round where Zambian stakeholders introduced themselves highlighting their position, organizational affiliations, and expertise.

- Manfred Hafner (RE4AFAGRI coordinator) presented the concept and approach of the RE4AGRI project within the overall LEAP RE, including its concept and approach. He highlighted the fundamental role of stakeholder for the project and the strong

commitment to ensure a continuous and long-term relationship between stakeholders and the RE4AFAGRI consortium.

- Giacomo Falchetta (coordinator of modelling integration and development) and André Troost (coordinator of business model development) then engaged with the stakeholders on the technical focus of the discussion

The first focus group session focused on irrigation and water pumping: Giacomo provided an introduction on the significance of irrigation for stabilising and increasing yields and opened the discussion.

Q1: What are the type of farmers and crops that would benefit the most from the input of irrigation?

- A balance of both **food crops** (maize, cassava, rice, groundnut) [these are the crops where women are mostly involved] and **cash crops** (soybean, cotton, tobacco) [prioritise income generation, especially among men]

Q2: How is the trade-off between pumping from groundwater aquifer vs. groundwater bodies? Prioritisation criteria and specific issues…

- Cost minimisation depending on proximity to farmland
- New business models + VAT exemption are making groundwater pumping increasingly attractive (which so far has been to expensive for farmers)
- Erratic rainfall and climate change in Zambia are further leverages to the adoption of groundwater
- Access to water not an issue from a regulatory point of view

Q3: When does the water pumping generally carried out? On demand when needed vs. extraction + storage?

- Encouraged practice -> pump when sun available and store in tank to exploit gravity
- Irrigation schedule -> early morning and evening
- Battery storage is often too expensive (a large share of total CAPEX in a solar pump system). Also, without battery the system is more sustainable.

Q4: How does the water storage work?

- Pump the water during the daytime and exploit the gravity to release the water to the field
- But of course, trade-off with cloud cover if you do not include a battery in the system

Q4.1: Is rainwater accumulation relevant?

- Challenging due to erratic rainfall and climate impacts.
- It cannot replace irrigation.

Q5: Pumping rate and size/power of system for the average smallholder farmer in Zambia?

- 0.5 – 2 hp, but of course varies if it's single farmer of cooperative. (500 W – 1 kW)
- Average daily output: 18 – 25 m^3

Q6: How far is farmland from homes? Diesel vs. pump vs. mini-grid and the role of the distance.

- Size of pumps is the first parameter, together with proximity
- Safety of equipment concerns if power generation equipment is too far from homes
- Solar is mostly cheaper than diesel pumps today, also because prices of diesel are increasing + deliberate government incentives or tax waivers on solar equipment
- Mini-grid mostly suitable for cooperatives → role of business models in determining this technology choice

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The second focus group session focused on **crop processing**: Giacomo provided an introduction on the significance of crop processing for increasing value added of yields and opened the discussion.

Q7: What is the relevance of crop processing energy demand, what are the most relevant transformations, how much energy they consume?

- Crop processing is very important to reduce the levelized cost of electricity, besides income generation
- 50-70 kg / hour solar hammer mill for maize; 100 – 150 kg / hour cassava; 150 – 200 kg / hour for millet. Equipment rate: 1.3 – 1.7 (hp)
- In Zambia there are 1,500+ solar hammer mills in the country lacking sustainable business models, and excess of 124% due to lack of battery storage
- In these systems solar PV array 12.5 kWp but demand to run them about 3.8 kW, but waste of energy due to lack of storage!

Q7.1: Are those mills standalone powered or connected to a wider system e.g. mini-grid?

- Projects to utilize the excess energy to the community to serve household + productive demand, but currently they are standalone only.
- But to make these projects more sustainable, you need more productive use, increase the profitability of the system
- Need for income generation to ensure that the replacement of components e.g. battery after 8-10 years can be achieved

Q8: Is seasonality of demand an issue?

- Depends on type of agriculture carried out, cropping patterns, rotation etc. Capacity building for farmers can place a huge role in this sense to ensure sustained utilisation of crop appliances. Energy is just an enabler; you need to educate farmers to its smart use.

Q9: Ownership of appliances: small scale or consortium?

- Ownership currently on cooperative level by pooling of assets by farmers; it is more affordable

Q10: It is very rare for smallholder farmers to carry out processing themselves. Is there a space for rural entrepreneurs offering this type of services?

- Main challenge why farmers do not carry out crop processing is affordability
- With right business model / incentive, they are very much willing to do so
- Entrepreneurship: e.g. offering cold storage with innovative business model
- In the long-run, however farmers should be able to afford their own appliances

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The third focus group session focused on the **economics**: Giacomo provided an introduction on the potential to increase yield and value added of yields and opened the discussion.

Q11: From the point of view of farmers, where is the most value addition potential thanks to energy input?

- Urgent action is adapting seeds and fertilisation. However fertilisation requires irrigation not to damage soil. Improve mechanisation to boost productivity. Knowledge and capacity building -> climate-smart agriculture, e.g. conservation farming, water harvesting, drip irrigation. Need for right business models to enable all these solutions.

Q11: How does the production links with the demand side? Who are the buyers, how are products transported.

- Market access major challenge, especially for high volume crops!
- Innovative business models: solar system suppliers can also offer production purchase contracts. Farmers to sign regular supply contracts, because they are a guarantee of regular cashflow

Q12: Who are the entities to whom farmers (and their cooperatives) sell crops? Entities that buy the crops to process them e.g. coming to the village themselves?

- Depends very much on the variety of crop.
- Example of maize, which shows very little profit margin. Usually government is the largest buyer.
- Cooperatives -> economies of scale to have more market power with sellers

Q13: What kind of financing have you seen to be working with smallholder farmers? Ownership through cooperative? PAYGO to finance on the ground?

- Case-by-case. Financing model depends on willingness and ability to pay.
- Most mini-grid operator use PAYGO to promote productive uses -> this is also because farmers want to own infrastructure!
- Awareness building is also very important among smallholder farmers to consider the innovative financing schemes.
- Supply credits (supply allows to pay in instalments after 20-30% upfront payments, short-term instalments e.g. 1-2 years; tricky with smallholder farmers with unstable income) schemes; or rent-to-own (this is more flexible to e.g. skipped payment of one monthly instalment) schemes have large potential for equipment for productive use.
- Importance of financing scheme FLEXIBILITY for the farmer

Q14: After harvest is there a common practice on crop residues utilisation (burnt/sold/produce electricity)?

- Today little value of crop residues attributed by smallholder farmers -> good potential for their valorisation in the future!
- E.g. green charcoal from crop residues as an alternative to deforestation
- Power for cooking falls short in most electricity access solutions developed today. So significant potential for power generation for cooking purposes from crop residues.
- SNV (SNV Netherlands Development Organisation) has worked on use of biodigesters from animal residues
- Importance of energy efficiency in this process!

Q15: Mini-grid tariffs charged to farmers (from 5-20 Kwacha / kWh according to the written replies). How does it vary?

- Depends a lot on business models and on the case to case
- New business models encourage energy sold as a service, rather than *per se*, coupled with aggressive energy efficiency measures
- Depends very much on the sectors of demand present. The more sectors you have to supply in the community, the harder it is to come up with lump-sum tariffs
- Smart business models and knowledge / capacity building tend to increase willingness to pay!

Q16: Government policies to support the uptake of technologies?

- Government proposed removal of taxes on agricultural equipment in 2022
- FAISP -> Zambia's Farmer Input Support Program

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The fourth and final focus group session focused on the **outputs from the modelling tools**: Giacomo provided an introduction on the purpose of the modelling platform being development and the type of insights it can offer-

Q16: What are the **most useful pieces of information** in your planning activities?

- Importance of having validated, recent and updated data!
- Must integrate all WEFE aspects in the modelling to come up with coherent policies, as today policies have many inconsistencies across sectors
- Need to foster climate-smart practices
- Demand evolution at granular level; willingness and ability to pay coupled with the local income levels are both very interesting and useful insights for planners.
- Energy access explorer could perhaps incorporate our modelling outputs!

2nd LEAP-RE RE4AFAGRI FOCUS-GROUP on Zambia

Draft Meeting minutes

21/01/2022 - 10,00 am – 12.00 pm CET

Google Meet

Participants:

1. Giacomo Falchetta (IIASA)
2. Manfred Hafner (HEAS)
3. André Troost (TFE)
4. Ackim Zulu (UNIZA)
5. Katundu Imasiku (UCT)
6. **Chrispin Moyo (Ministry of Agriculture, Zambia)**
7. **Geoffrey Kaila (Muhanya Solar)**
8. **Cholwe Kagoli (Musika)**

Meeting agenda:

- Welcome, introductory round
- Introduction to the LEAP-RE RE4AFAGRI project (Prof. Manfred Hafner)
- Focus group 1 – irrigation and water pumping (moderated by Giacomo Falchetta)
- Focus group 2 – crop processing (moderated by Giacomo Falchetta)
- Focus group 3 – economics and business models (moderated by Giacomo Falchetta)
- Final questions – research output and scale + wrap-up

Meeting minutes:

- Introductory round where Zambian stakeholders introduced themselves highlighting their position, organizational affiliations, and expertise.

- Manfred Hafner (RE4AFAGRI coordinator) presented the concept and approach of the RE4AGRI project within the overall LEAP RE, including its concept and approach. He highlighted the fundamental role of stakeholder for the project and the strong **commitment to ensure a continuous and long-term relationship between stakeholders and the RE4AFAGRI consortium**.

- Giacomo Falchetta (coordinator of modelling integration and development) and André Troost (coordinator of business model development) then engaged with the stakeholders on the technical focus of the discussion

The first focus group session focused on irrigation and water pumping: Giacomo provided an introduction on the significance of irrigation for stabilising and increasing yields and opened the discussion.

Q1: What are the types of farmers and crops that would benefit the most from the input of irrigation?

- Smallscale farmers, who mostly perform rainfed agriculture, contrarily to commercial farmers. E.g. floods are an issue, but they then constitute a great groundwater table resource during the dry season, provided infrastructure to extract it is there.
- In particular, maize, vegetables [tomato, cabbages, eggplants] (especially in dry season) are very rentable.

Q2: How is the trade-off between pumping from groundwater aquifer vs. groundwater bodies? Prioritisation criteria and specific issues…

- Most farmers cannot afford boreholes so currently shallow wells are the main source where smallholder irrigation is there. Streams, where available in proximity.
- Mostly a technical-feasibility AND an economic consideration. But smallholder farmers show a preference for surface water where possible because it is cheaper than installing a borehole.

Q3: When is water pumping generally carried out? On demand when needed vs. extraction + storage?

- Smallest farmers: DIRECT -> switch on the pump in the morning (9-10am) and use water directly
- Larger farmers 1,000 – 5,000 – 10,000 litres : water pumped when most convenient, and then released in morning and afternoon

Q4: Pumping rate and size/power of system for the average smallholder farmer in Zambia?

- 0.5 for smallest farmers (mostly women farmers); others, 1-2 hp solar pumps.
- Also depends on what type of irrigation system is put in place (drip etc.)

Q5: What is the main source of power for pumps? Diesel vs. pump vs. mini-grid?

- Mostly standalone systems!
- Very few irrigation systems linked to mini-grids. There is a pilot project, but not very frequently observed so far.

Q6: Is it the case that mini-grid and standalone solar pump can coexist in the same community?

- Yes, it makes sense. Mini-grid for community use (residential, crop processing). While standalone for pumping in the fields (also not to take up too much of the peak load)

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The second focus group session focused on **crop processing**: Giacomo provided an introduction on the significance of crop processing for increasing value added of yields and opened the discussion.

Q7: What is the relevance of crop processing energy demand, what are the most relevant transformations, how much energy they consume?

- For most applications, people process crops for sunflower for oil and soyabeans oil because they are very profitable.
- Sweet potatoes; cassava; groundnut for peanut butter; maize/rice (scale of machinery -> 200-250 metric tons / day)
- Milling machine, shelling machine are the most frequent / useful

Q8: Ownership of appliances: small scale or consortium?

- A) Pooled resource used by a smallholder cooperative (pay per use). E.g. Storage container to increase lifespan of products (e.g. example of tomatoes) by a few weeks before sold.
- B) Alternative model: cooperative buys in instalments the facility, but not always feasible.

Q9: Is access to finance the main barrier to start processing?

- Yes.
- Also, access to market where to sell the crops is crucial
- Also, the skills / capacity

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The third focus group session focused on the **economics**: Giacomo provided an introduction on the potential to increase yield and value added of yields and opened the discussion.

Q10: From the point of view of farmers, where is the most value addition potential thanks to energy input? I.e. what are the most strategic crops?

- For income: Soyabean; **sunflower**; groundnut; **sugarbeet; cassava** (also for ethanol and starch)

- For food: Cereals: Maize (for food security) is crucial; rice, where suitable.

Q11: Who are the entities to whom farmers (and their cooperatives) sell crops? Entities that buy the crops to process them e.g. coming to the village themselves?

- Firms who carry out crop processing set up aggregation points in the communities, who buy the crops directly upon processing.
- Or, providers of inputs e.g. seed companies

Q12: What are the prices at which crops are sold in general? Is there a profit margin?

- National market price, adjusted for transport cost
- In turn, farmers respond to prices adjusting their amount of land cultivated
- E.g. for soya beans: last year 600 kwacha for a 50 kg bag
- 100x100 field -> produces about twenty 50-kg bags (about 1 ton of production), sold for 12,000 kwacha per hectare
- Average: 12 kwacha / kg; but it varies a lot from year to year
- 70% of that goes to the farmer, the rest is for transport etc.
- Among cereals in rainfed farming, the main profitable crop is rice (maize has a much lower profit margin because of low productivity and high cost of production)
- Vegetables are generally very profitable, especially if cultivated in the dry season thanks to irrigation

Q13: What kind of financing have you seen to be working with smallholder farmers? Ownership through cooperative? PAYGO to finance on the ground?

- Engaging smallholder farmers to access equipment -> a company buys (small-scale) machinery from vendors and then enters an agreement with the farmers (mostly women) to pay over a period of time with a minimum interest
- Quite successful scheme, so far. Little default rate.
- More challenging to make it work out for larger equipment, even when using a credit guarantee, also for currency instability issues

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The fourth and final focus group session focused on the **outputs from the modelling tools**: Giacomo provided an introduction on the purpose of the modelling platform being development and the type of insights it can offer-

Q14: What are the **most useful pieces of information** in your planning activities?

- If you are going to deploy a mini-grid for productive uses, it would be great to have information accessible for specific areas through a web interface!
- Energy and water demand; crop yield; any information that helps to understand the challenges around a specific area , and the barrier / reasons for an area to be lagging behind; why is the crop potential low?

Q15: What spatial resolution are the insights most interesting (farm, community, country)?

- All levels are equally interesting, actually, and complementary!
- Also in terms of temporal resolution, a few years (e.g. 5-10) ahead information is highly interesting.
- Ward level used by the Ministries as the planning unit.

3rd LEAP-RE RE4AFAGRI FOCUS-GROUP on Zambia

Draft Meeting minutes

28/01/2022 - 10.00 am – 12.00 pm CET

Google Meet

Participants:

1. Giacomo Falchetta (IIASA)
2. Manfred Hafner (HEAS)
3. André Troost (TFE)
4. Ackim Zulu (UNIZA)
5. Adriano Vinca (IIASA)
6. Gregory Ireland (UCT)
7. Alison Hughes (UCT)
8. Katundu Imasiku (UCT)
9. Francesco Semeria (POLITO)
10. **Brenda Mwamba (Zambia Agriculture Research Institute)**
11. **Nyumbu Situmbeko (ENGIE Power)**
12. **Patricia Chibowa (Good Nature Agro)**

Notes

Noel Simukonde (National Association for Small Holder Farmers in Zambia) was absent from the meeting.

Meeting agenda:

- Welcome, introductory round
- Introduction to the LEAP-RE RE4AFAGRI project (Prof. Manfred Hafner)

- Session 1 – irrigation and water pumping (moderated by Giacomo Falchetta)
- Session 2 – crop processing (moderated by Giacomo Falchetta)
- Session 3 – economics and business models (moderated by Giacomo Falchetta)
- Final questions – research output and scale + wrap-up

Meeting minutes:

- Introductory round where Zambian stakeholders introduced themselves highlighting their position, organizational affiliations, and expertise.

- Manfred Hafner (RE4AFAGRI coordinator) presented the concept and approach of the RE4AGRI project within the overall LEAP RE, including its concept and approach. He highlighted the fundamental role of stakeholder for the project and the strong **commitment to ensure a continuous and long-term relationship between stakeholders and the RE4AFAGRI consortium**.

- Giacomo Falchetta (coordinator of modelling integration and development) and André Troost (coordinator of business model development) then engaged with the stakeholders on the technical focus of the discussion

The first focus group session focused on irrigation and water pumping: Giacomo provided an introduction on the significance of irrigation for stabilising and increasing yields and opened the discussion.

Q1: What are the types of farmers and crops that would benefit the most from the input of irrigation?

- Right now: maize and legumes first crops and most vulnerable without irrigation.
- Climate change-related issues: rainfall amount is reduced, high variability (less predictability of the beginning of the rain season compared to the past), also floods frequency is increased. This is bad for farming as it makes it very difficult to plan. Irrigation can be very useful.
- Advice farmers to transition to a diversification of crops. E.g.: basic crops (millet, sorghum, groundnut, etc.) + high value crops: onions, mushrooms, sunflower
- Favour smaller grain crops for better drought-resistance.

Q2: How is the trade-off between pumping from groundwater aquifer vs. groundwater bodies? Prioritisation criteria and specific issues…

- Groundwater prioritised by agro-equipment suppliers because it is more widely available (larger number of farmers can be targeted)

Q3: Pumping rate and size/power of system for the average smallholder farmer in Zambia?

- From 1HP to 3HP, depending on the field. Pumping 4.5-5 sunshine hours / day.

Q4: How far is farmland from homes? Diesel vs. pump vs. mini-grid and the role of the distance.

- Some pilot sites where pumping is powered by solar mini-grids are ongoing -> pumping during the day, because the battery in the dark hours is used to power homes
- Less than 20% of farmers have access to power; solar ideal because of remoteness
- It’s possible that minigrids and stand-alone system co-exist!

Q5: What are the logistical costs of building and operating mini-grids in remote areas?

- [unaddressed question]

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The second focus group session focused on **crop processing**: Giacomo provided an introduction on the significance of crop processing for increasing value added of yields and opened the discussion.

Q6: What is the relevance of crop processing energy demand, what are the most relevant transformations, how much energy they consume?

- Grain drying sheds facilities and storage facilities (equipment for drying)

Q7: For mini-grids: how is access to power managed to avoid outages?

- “Soft-start” components and pre-allocated time windows for using energy-demanding appliances to avoid outages. Spark-meter to allow energy access only in that time-frame.

Q8: Ownership of appliances: small scale or consortium?

- Group ownership of processing appliances. If cheaper sources are found, individual ownership schemes could be attempted.

Q9: What prevents farmers from processing?

- Access to financing; road network and vehicles; lack of power

Q10: Energy consumption and processing scale of crop processing machinery among smallholders?

- E.g: Hammermill (very energy demanding appliance), 3phase 7.5kw (rated power). Soft start included to avoid outages. Utilization from 9am in the morning to 5pm.

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The third focus group session focused on the **economics**: Giacomo provided an introduction on the potential to increase yield and value added of yields and opened the discussion.

Q11: From the point of view of farmers, where is the most value addition potential thanks to energy input?

- Baseline economic output per season for the majority of the farmers: 150 USD/ha
- Switch to legumes -> 600 USD/ha per season
- Potential to switch to even higher value crops e.g. onion -> 4,000 USD/ha thanks to irrigation, and also continue traditional cropping during the rainy season. However these high value crops are sensitive, they require proper storage, transportation. Here the role of energy can be crucial!

Q12: How does the production links with the demand side? Who are the buyers, how are products transported.

- Usually two options: local markets [collection centres near the producers community] (most of the times very low prices), city markets (hard for smallholder farmers, transportation costs on them).

Q13: Who are the entities to whom farmers (and their cooperatives) sell crops? Entities that buy the crops to process them e.g. coming to the village themselves?

- Concerning Good Nature Agro, for the crops that they support, they are the buyers. with an Online system for purchases and farmer with mobile money. Farmers are contracted for providing fixed amounts of products. If farmers have surplus, they can sell to others in markets. The company is in charge of transportation (this cost is embedded in the selling price). They as a company have the possibility to reach different markets to obtain the best price.

Q14: What is the biggest issue that farmers face, preventing their development?

- Access to financing. But also transportation due to remoteness of the area. Power access, especially for processing.

Q15: How are mini-grids designed? Is it easy to scale up if electricity demand from a community increases beyond system capacity?

- Two different designs: short term (2/3years) and long term (10 years).
- Customer categorization: A-B-C-… depending on their electricity demand.
- From surveys current demand is estimated, then projections are done, based on their experience, for the next 2/3 years. Systems can be redesigned later as it’s very easy to scale up (both batteries and PV). From their experience 8-10% increase in demand per annum for mini-grids, as more people join from a given community and more appliances are connected.

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The fourth and final focus group session focused on the **outputs from the modelling tools**: Giacomo provided an introduction on the purpose of the modelling platform being development and the type of insights it can offer-

Q16: What are the **most useful pieces of information** in your planning activities?

- Concerning Good Farm Agro: to know challenges that community of smallholder farmers face, at different times. E.g.: diseases/pests.
- Concerning Zambia Agriculture Research Institute: crop productivity per unit area (Yield/unit area), for different resource input. For understanding economic feasibility of interventions (expansion vs intensification of agriculture) and monitoring.
- Concerning ENGIE Power: to know what is the energy demand of a community, to know the present/planned activities. Also it’s key to know the distance from the planned/present mini-grid and the willingness to pay for the service (“can they afford it?”).

1st LEAP-RE RE4AFAGRI FOCUS-GROUP on Zimbabwe

Draft Meeting minutes

20/04/2022 – 11.00 am – 13.00 pm CET

Google Meet

Participants:

1. Giacomo Falchetta (IIASA)
2. André Troost (TFE)
3. Alison Hughes (UCT)
4. Francesco Semeria (POLITO)
5. Gregory Ireland (UCT)
6. Alison Hughes (UCT)
7. Fabio Inzoli (POLIMI)
8. **Nyasha Bamhare - Samansco**
9. **Isaiah Nyakusendwa - Renewable Energy Association of Zimbabwe**
10. **Shanta Bloemen – Mobility for Africa**
11. **Hilton Chingosho – University of Zimbabwe**
12. **Maggie Makanza & Brian Nhlema – FAO**
13. **Rob Jarvis – Agricultural Research Trust**
14. **Dr. Thomas Mupetesi – Farmers Association of Community Self-Help Investment Group**

Meeting structure:

- Welcome, introductory round
- Introduction to the LEAP-RE RE4AFAGRI project (Prof. Manfred Hafner)
- Focus group 1 – irrigation and water pumping (moderated by Giacomo Falchetta)
- Focus group 2 – crop processing (moderated by Giacomo Falchetta)
- Focus group 3 – economics and business models (moderated by Giacomo Falchetta)
- Final questions – research output and scale + wrap-up

Meeting minutes:

- Introductory round where Zimbabwean stakeholders introduced themselves highlighting their position, organizational affiliations, and expertise.

- Giacomo Falchetta (RE4AFAGRI lead modeller) presented the concept and approach of the RE4AGRI project within the overall LEAP RE, including its concept and approach. He highlighted the fundamental role of stakeholder for the project and the strong **commitment to ensure a continuous and long-term relationship between stakeholders and the RE4AFAGRI consortium**.

- Giacomo Falchetta (coordinator of modelling integration and development) and André Troost (coordinator of business model development) then engaged with the stakeholders on the technical focus of the discussion

The first focus group session focused on irrigation and water pumping: Giacomo provided an introduction on the significance of irrigation for stabilising and increasing yields and opened the discussion.

Q1: Current status and prospects of irrigation in Zimbabwe?

- Farming -> great business in Zimbabwe, but farmers lack the knowledge of irrigation...
- Rainy summer and dry winter are the two seasons in Zimbabwe.
    - Summer -> food crops (grains) for household food security and little income, irrigation only used as supplement;
    - Winter -> cash crops mainly grown, vegetables, here irrigation is key.
- 90+% of farmers in Zimbabwe do not have irrigation, despite they have access to nearby water. Very little support from government or other development partners for those individual farmers.
- Communal irrigation schemes: main focus of the country so far -> 5-50 ha for smallholder irrigation schemes under different technologies, predominantly surface irrigation with channels and lined/cemented canals, with water conveyed by gravity or pumped from dams, reservoirs, rivers... -> generally, very successful schemes
- Energy -> a big challenge for these schemes. Some used grid electricity, other used diesel so far, but looking at decentralized using solar energy
- Discussion in the country on the direction to take for future farmer-led irrigation development given the mixed success of schemes so far.
- FAO department of irrigation is assisting discussions for future planning of smallholder farmer irrigation
- Sprinkler irrigation is growing quickly
- Drip irrigation less widespread, it used to be more promoted in the past by development partners e.g. for 100 m2 plots, but water would be lifted manually and thus challenging...

Q2: Average size of plots for farmers?

- Smallholder farmers: mostly 0.5 - 5 ha per farmer
- 3 schemes:
    1. Resettlement scheme: allocation of village and farmland of 3-4 ha per farmer
    2. 2 – 6 ha plots
    3. Big scale: 30+ ha

Q3: What is the type of farmers and crops that would benefit the most from the input of irrigation?

- Food crops: maize, wheat, beans
- Cash crops: vegetables, tomatoes, onions, peppers
- Export crops: dry chili, garlic, ginger, peas
- Maize used to be the key crop, but these days focus of smallholder farmers is switching towards vegetables, which are more profitable
- Climate change impact on water availability is increasingly felt in Zimbabwe
- Drip irrigation is deemed a good one because it is highly resource-efficient

Q4: Pumping rate and size/power of system for the average smallholder farmer in Zambia?

- Size of pumps very wide ranged...prevalently diesel or petrol-powered so far
- River ponds are the most common withdrawal source
- 40-50-60 m boreholes are also observed and becoming more and more popular
- 1 ha, drip irrigation -> 14,000 l/day, generally 2.3hp pump, also determined by the number of panels that supply that pump
- 0.75-1-1.5 kW submersible pump is the most popular -> average 1 liter / second / hectare
- But even less. Range: 0.5 - 5 kW
- Extensive hydroelectric grid in Zimbabwe does not however reach most of farmers -> decentralised systems are key
- Renewable energy is gaining attention in agriculture: solar and hydro decentralised systems (e.g. 11 kW system funded by EU mentioned)
- Submersible solar pumps -> massive uptake
- Solar irrigation units -> 3600 l/h, portable
- Grid/power outages, security, maintenance of the PV system are the main challenges

Q5: When switching to irrigation, do farmers prioritize cash crops for income maximization or balance also food crops?

It depends on how much they can rely on markets, e.g., how close they are.

The second focus group session focused on crop processing: Giacomo provided an introduction on the significance of crop processing for increasing value added of yields and opened the discussion.

Q6: What is the relevance of crop processing energy demand, what are the most relevant transformations, how much energy they consume?

- Little value addition from smallholder farmers so far in Zimbabwe. Also, knowledge gap
    - 2hp motor for peanut butter processing
    - Smallholder: 1hp-5 hp for onsite milling
    - Highly mechanized farms: 10-20 hp appliances
- Solar energy can play an important role to abate processing costs
- Storage -> cold storage for vegetables requires electricity. Solar also here could play a major role!
- Most smallholder farmers are remote from markets. And have no storage. So much production loses value because they all travel to markets in the same season. If there was storage, they could sell in off-peak season at higher prices.
- Milling is the main processing issue -> currently machineries use diesel and petrol. Few solar mills uptake so far

Q7: Are those mills standalone powered or connected to a wider system e.g. mini-grid?

- Energy supply ranking: grid supply for the highly mechanised farms, diesel power too for the mechanised and smallholder farmers comes second, then solar for lighting and some for drying. Wind power uptake is quite low. We have a very high use of woody biomass for tobacco curing activities, though there is some small uptake of solar thermal
- Mini-grids are up to 99 kW because of legislative limit
- Village + 3/4 ha per family remote about 1 km from houses

Q8: It is very rare for smallholder farmers to carry out processing themselves. Is there a space for rural entrepreneurs offering this type of services?

- Not much common between Zimbabwean farmers
- Milling using diesel/petrol/electricity. Usually not done by farmers. Not done with solar yet
- Refrigeration -> issue of duties for import (60% on imports + 30/40% VAT)! Very high pricing negatively affects uptake. Duties are there to protect local fridges producers historically, but has this negative side-effect for local potential buyers. But no DC refrigerators from local industries
- Cooling as a service as an opportunity alternative to individual farmers buying refrigerators
- Farmers prefer to bring their raw products to the market rather than pay for processing, but if they are given a fair price for processing, there might be potential

The third focus group session focused on the **economics**: Giacomo provided an introduction on the potential to increase yield and value added of yields and opened the discussion.

Q9: From the point of view of farmers, where is the most value addition potential thanks to energy input?

- Groundnut processing, 50% more profitable
- Onsite processing and packaging for corn. Sold to local markets and good profitability

Q10: How does the production links with the demand side? Who are the buyers, how are products transported.

- Farmers bring their products to markets, to the nearest city/town, as you get a better market price. But sometimes 100+ km distant
- Some farmers get into some sort of contracting, especially if they can combine their production with their neighbours
- Only when processing plant throughputting is close-by and affordable, the profits of the farmers is significantly larger.
- Generally small processing tends to sell to local community
- Demand drives the movements of the farmers. For vegetables, trucks travelling in the night from Mutoko area to the markets (e.g. large market near Harare)

Q11: Who are the entities to whom farmers (and their cooperatives) sell crops? Entities that buy the crops to process them e.g. coming to the village themselves?

- Maize (maybe other small grains) must be sold to govt body (strategic controlled products). Strategic grain reserves must be built up.
- Often seasonal grain control, depending on reserve status and production. Sometimes free market allowed, sometimes not.

Q12: What are the biggest cost for farmers?

- At the moment there is a sharp increase on fertilizers prices. Usually, large costs are: buying equipment, petrol/diesel costs. Labour if farmers source labour from outside. Also transportation costs to markets
- Transportation of inputs to the farm, and costs within the farm
- Irrigation system costs constitute most of the costs.
- Cost of expertise: e.g., agronomists.
- Crop protection cost are high (pesticides, chemicals). Fuel/electricity costs are very significant.

Q13: Is there a currency issue?

- Input costs are in us dollars. If farmers sell in Zimbabwean dollars, it can be not profitable as exchange rate varies a lot
- Distortion due to USD/Zimbabwan Dollar (ZD). Right now, Electricity company works under sub-economic conditions, and asked for a tariff revision

Q14: Why must maize be sold to a governmental body?

- Specific products are strategic, thus controlled by the ministry for the grain reserves
- Price stipulated at the beginning of the season
- Parastatal body that buys and then sells to private companies that want to process etc.
- This applies to the most important grains

Q15: Cost of energy for smallholder farmers?

- Generally, 0.12 USD / kWh for electricity, but there are now distortions, depending on use. Can be even less.
- Diesel / petrol -> 1.60 USD / litre
- 0.2 USD / kWh for decentralised systems to sustain them financially

______

The fourth and final focus group session focused on the **outputs from the modelling tools**: Giacomo provided an introduction on the purpose of the modelling platform being development and the type of insights it can offer-

Q16: What are the most useful pieces of information in your planning activities?

- Energy demand estimation, also demand scenario according to productivity.
- Irrigation: mapping of water bodies, population, water table, water uptake for irrigation. Today and in 5yr time
- Market issue: demand for different crop products. E.g.: What's the market size, affordability for solar millers?
- Soil info, water quality. Expertise for farmers is also key. Farmers run into losses for lack of knowledge.
- For farmers that grow products for export: standards requirements for products. They are achievable, but farmers need assistance.
- Also standards for equipment.
- River catchments modelling. Also info at farmer-level. Today and in 5-10 yrs

Q17: Spatio-temporal resolution desired?

- Village level and environmental units

LEAP-RE, WP12 RE4AFAGRI

Deliverable 12.2 – Annex II

Stakeholders answers to the Questionnaires

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Nigeria

Value Seeds Limited

Prof. Thomas Stephen Ijimdiya (Ahmadu Bello University)

Green Village Electricity

Samuel O. Babalola

Olayinka Jelili Yusuf

Questions to be asked in advance

- **Value Seeds Limited**

1. What is the average areal extent of land cultivated by a smallholder farmer you generally deal with?
   Ans: 0.5ha - 1.5ha
2. What share of the farmers have access to irrigation system for their farming operations (i.e. do not solely depend on rainfall)?
   Ans: 25% - 35%
3. When present, what are the prevalent irrigation systems (in areas with/without electricity)?
   Ans: Tube-wells and Dams (All requires pumping machines)
4. How much do the typical irrigation systems used by smallholder farmers cost?
   Ans: Depending on the crop and soil water retention capacity in question, Rice farmers spend more on irrigation due to the fact that Rice requires more water than any other crop, however, a sketchy costing will be around 80,000 for other crops such as Maize, Wheat and Cowpea while Rice could be around 100,000
5. In what season of the year are smallholder farmers' crops most likely to undergo water stress?
   Ans: Early cessation of rains during the wet season
6. Are there crops that are suitable for land conditions available that the farmers would like to plant, but are not able due to lack or inadequate access to water for irrigation?
   Ans: Yes, Crops such as Maize, Rice, Cowpea and Wheat are suitable for land conditions however, farmers will rather prioritize cultivation of these crops base on market demands as such Maize and Rice have gain more attention with little of wheat and merger attention to cowpea. Meanwhile with adequate water for irrigation, farmers will increase scopes of crops to be grown during the dry season.
7. What range of size of irrigation water pump (e.g. liters/hour or kW) is generally used by smallholder farmers?
   Ans: (1.) 3.5 horse power. 2 inches hose. 2.5Litres (Fuel tank), and 600Litres/Minute. (2.) 4.9 horse power. 3 inches hose. 3.6Litres (Fuel tank), and 1,100Litres/Minute
8. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available to use PV, and water is stored in tanks for later use?
   Ans: Water is generally extracted when needed, in some cases of dam, water is usually released from central dam when water body drops

Questions to be discussed at the focus groups

1. What are the most strategic crops from a (i) nutritional and (ii) economic point of view for smallholder farmers?
   Ans: (i). Smallholder farmers are more inclined to quantity than quality, and sociocultural preference has bottlenecked most progress of availing nutrient-dense crops varieties to farmers. i.e. Biofortified Maize with Pro-Vitamin-A (yellow kernels) are less preferred to white maize variety.
   (ii). From economic point of view smallholder farmers tend to make more returns from cultivating yellow maize varieties however, are still head-bent on white due to fast market sales and popular demand.
2. What are, in your opinion, the most urgent actions to increase and stabilize crop yields of smallholder farmers? And what is the potential contribution of irrigation in this sense?
   Ans: Quality Seeds has given the farmer 50% of total yield thus if followed with GAP and technical backstopping at during strategic operations smallholder farmers have no limitation to achieving optimum yield, this can only be achieved with access to top quality seeds from reputable seed company with proven track record of quality.

If these GAP and quality seeds can be replicated during the dry season under irrigation it will immensely increase profit and income to smallholder farmer, research has also shown that better quality of most crops cultivated by smallholder are far better than when produced during the wet season.

3. Should groundwater or surface water extraction be prioritised, i.e. what is the key selection criterion between the two solutions (minimum costs, legal constraints, depth/distance)?
   Ans: Surface water extraction through creation of artificial dams could really cub this challenge, like stated legal constraint, cost, depth/distance of ground water would really be a challenge achieving groundwater extraction.
4. Costs and revenues for smallholder farmers: what are the largest costs and the main chance to generate income? How much profit do smallholder farmers make when selling crops (Naira/kg)?
   Ans: Largest cost for smallholder farmers had always been fertilizer……..
5. What type of electric crop processing machinery should we model, i.e. what crops and what transformations are most relevant?
   Ans: proactive advancement in processing entails state-of-the-art machines that is capable of processing tons of seeds in little time with capability of separating color mixed seeds/grain.
6. What are the names, specifications and costs of the typical pumps and processing machines used by farmers?
   Ans: (1.) 3.5 horse power. 2 inches hose. 2.5Litres (Fuel tank), and 600Litres/Minute. (2.) 4.9 horse power. 3 inches hose. 3.6Litres (Fuel tank), and 1,100Litres/Minute
   Products: (1.) UNIVERSAL Water Pump Generator Machine (100,000), (2) Honda GP-H (180,000)
7. What processing scale (kg/day) are reasonable to consider (needs of smallholder farmers)?
   Ans: 500kg/hr
8. Ownership of the crop processing machinery: private/village-level/county-level by consortium? What scales do the machinery in use have (kg/day OR kW)?
   Ans: village level
9. Do smallholder farmers have crop losses because of insufficient processing capacity? If yes, could you quantify the share of this waste?
   Ans: 30%
10. Are there agricultural crops and practices the farmers would like to engage in but are not able or limited in doing so due to lack of electricity access?
    Ans: Yes, there are a lot of e-extension packages created to reach smallholder farmers such as Radio jingles, TV adverts/shows, Social media, virtual farmers training etc.
11. What are the main obstacles for farmers to start crop processing (lack of machinery, lack of finance, lack of skills, bureaucracy, other)?
    Ans: Lack of finance and machine.
12. Should there be access to water that requires payment, would the farmers be able and willing to pay?
    Ans: Farmers have over time indicated interest and willingness to welcome such arrangement just as far it generates more income for them.
13. Would the farmers be willing to pool resources together to implement an irrigation system and jointly manage (govern) the irrigation system?
    Ans: Most of smallholders farmers are resource-challenged, however, they can pool resources for maintenance purposes.
14. At what spatial resolution(s) would you benefit the most from the modelling insights? Farmer? Village? Administrative unit? Environmental unit (e.g. river basin?)
    Ans: Farmer

15. At what temporal horizon(s) would you benefit the most from the modelling insights? Today? Five years time? 10 years time? 2050?
    Ans: Five years time

- **Thomas Stephen Ijimdiya (Ahmadu Bello University)**

In addition to all that has already been said by other participants at the discussion, I will to add a few things:
The major crops cultivated by smallholder irrigation farmers in Nigeria are majorly the following crops:

1. Vegetables,
2. Rice
3. wheat

However, there could be variations as you move from one region of Nigeria to another.

From my experience, I will like to share with you some of the key issues affecting smallholder irrigation farming in Nigeria. I have had the privilege of conducting infrastructural assessments of irrigation schemes in both the North western and North eastern parts of Nigeria; as a result, I will begin by giving a brief background of irrigation farming practiced in Nigeria.

Brief Background

Basically, Irrigation farming is practiced around the river basins in Nigeria and 90% of the irrigation schemes are concentrated in the North western part of Nigeria. Perhaps, this may be due to the fact that the Federal government of Nigeria has mostly been led by persons that hail from the North western part of the country. As a result, there is **irrigation practice knowledge gap** among other ethnic nationalities. Therefore, only one ethnic nationality has been empowered by the Federal government by providing both small, medium and large irrigation infrastructure and the necessary training. As one moves from the North west to other parts, you will observe that mostly, the empowered ethnic nationality are the ones involved in irrigation farming in the various river basins.

Secondly, provision of improved infrastructure for irrigation farming in Nigeria has been the **major source of crisis or conflict between the farmers and herders**. The conflict points are majorly concentrated around the water infrastructure. Recently, I was involved in carrying out a feasibility study for United States Agency for International Development (USAID) in North eastern part of Nigeria, and the project involves the provision of water infrastructure for both smallholder irrigation farming and water points for herders as part of resolving the water conflict between the farmers and herders.

Key issues affecting irrigation farming in Nigeria

The major issues affecting irrigation farming in Nigeria are summarized as follows:

a. Unavailability of water due to climate change, this factor is most severe in the North eastern part of Nigeria;
b. **lack of power/energy**;
c. lack of water distribution infrastructure;
d. lack of water storage facilities (especially in the north eastern parts of Nigeria);
e. dilapidated state of dams/water retention or detention ponds;
f. poor management and maintenance of water supply systems
g. Poor or non-existence of water governance structure;
h. lack of access roads;
i. depleting ground water potentials as the average depth of boreholes are within the range of 50 – 200m, especially in the North east

Since the major concern of LEAP-RE has to do with providing an innovation in renewable energy, I will like to throw light on issues of power or energy supply as it affects irrigation farming in Nigeria.

Some of the irrigation schemes I have been privileged to work in, use diesel generators that supplies pumping machines which supply water to the farming fields.
Details of the power systems of some of the projects are:

1. One (1) diesel fuelled 415 V, 100 kVA generator (Newage Stanford, England).
2. Six (6) 18.7 kW pumping machines (Lincoln Multiguard ac motors, USA).

Findings: if all the pumping machines are to be operated, especially, in the dry season, the generators output will not match their demand (about 112 kW). Most of the generators are quite obsolete, as such efficiency is low and spare parts may not be readily available.

- **Green Village Electricity's Reply**

1. The level of the energy requirement for agricultural sector determines the choice of electricity supply technology. Where the agricultural energy demand is high, especially with inductive users; an adoption of National Grid extension is advisable, and the option of PV can suffice for low energy demanding agricultural processes or activities.
2. Most grid sites are off grid and a major factor as to site selection is its potential to stimulate the economy of the resident and neighboring communities. As compared to other energy sector demands, agricultural demand happens to a key determinant as to deploying mini grid sites more so if the backbone of the communities' activities are agriculture-related.
3. Our tariff system is blended, a band that runs between N80-N120 per kwh, with incentives for commercial users.
4. GVE in its journey to where it has gotten to today has offered appliance financing from its coffers and carried out same in collaboration with donor agencies. Most small holder famers have willingly paid for electricity, once value has been established.
5. Relevance of electricity for small holder farmers as experienced on our mini grid sites is in the order of c-b-a
6. Most activities are centered around processing, they include Milling Grinding, Drying and Refrigeration/Preservation.
7. Most agriculture activities are commercial and for income purposes, as majority of these smallholder farmers sell for income.
8. It can be estimated at 5 - 10km
9. Currently energy access on farmlands in such communities are not priority as most farmland activities and processes are not energy dependent.
10. Most farmers are willing and open to technology especially if it gives room for profit optimization.
11. To a large extent, there are a lot of multilateral organizations that are interested in promoting activities of smallholder farmers. Government through its agencies like NIRSAL, BOA etc. is also doing its best but there is room for improvement.

- **SAMUEL O. BABALOLA**

1. How much is the share of demand from agricultural sector relevant in the determination of the optimal electricity supply technology (from PV on the field to national grid extension)?
   Ans: In general, the productive electricity demand in a minigrid is about 26%, and in this, the agricultural sector can make up about 85% of this or more depending on communities. Therefore, to size a hybrid minigrid system, the existing and anticipated agricultural activities (which includes processing equipment used or needed) must be carefully studied to size a minigrid plant. Failure to do this, the minigrid operator will not adequately reach the productive electricity consumers which could have generated more revenue, and at the same time not be able to support income generating activities in the village which is essentially a key purpose for providing electricity to the community.

2. How important is agricultural demand (compared to other types of demand) when selecting a mini-grid site?
   Ans: Data from existing sites have revealed that the revenue from agricultural activities alone amounts to about 30% of the overall revenue (depending on the number of customers in this category), and the energy demand from this category of customers could be from morning until night time. Hence, during surveys, one of the important things to look out for are the agricultural practices in the communities, and an understanding of the value chain. By onboarding the existing farmers (that is those with high rated power appliances) on the minigrid network and providing support for newer ones, the energy demand from the agricultural group will be high which will directly lead to more revenue for the minigrid operators.

3. What electricity tariffs do you charge for farmers?
   Ans: Form my experience in two minigrid companies, we have employed different strategies…firstly, we gave a discounted tariff of about 75% to the operators of milling and grinding machines to reduce their operating costs as they consume a significant amount of energy produced from the minigrid. Also, we have employed a flexible tariff scheme in which contrary to the price per kWh levied on other household customers, they (farmers) pay a reduced price per kWh and a fixed amount monthly. This was found to be a cheaper option for them

4. Do you offer financing of equipment, e.g processing machinery? Are smallholder farmers able and willing to pay for electricity? If possible, could you quantify it?
   Ans: Yes, we did. This idea was received with much enthusiasm and majority of them signed up for the appliance loan. At one of our sites in the South West, about 4 small electrical grinding machines were given out to operators to retrofit their previous mechanical machines. However, some of them were unwilling because they had diesel-fueled machines which they had obtained on loan as well and had been struggling to pay up.

5. What are the areas of relevance of electricity access to smallholder farmers?
a. On the farm/field? Ans: Pumping/Irrigation, lighting
b. Preservation and processing? Ans: Drying, Grinding, Milling, Dehusking, Cold room (refrigeration), Smoking
c. In the household? Ans: Lighting, Entertainment (TV, Radio), Cooling

6. Which agricultural activities do smallholder farmers use electricity for?
   Ans: drying of cocoa and cassava; Dehusking of maize; milling of grains (rice, maize, millet etc); Grinding; Grating of cassava, frying of garri; Drying and smoking of fish

7. Do smallholder farmers sell their crops for income, or do they consume it for subsistence only?
   Ans: A bulk of what they harvest are sold for income, while some are left for their families

8. What is the typical distance between houses of smallholder farmers and the farmland?
   Ans: In most cases, the farmlands are about 4 km from the village. But when these old farms are not yielding as they used to, the farmers go in search of farmlands at further distances away from their communities.

9. If the houses are far, is electricity access important on the farm?
   Ans: When the farms are at about 1km distance from the minigrid distribution channel, it becomes difficult to transmit electricity to the farm areas. In this case, they use standalone petrol generators or standalone solar kits for their activities

10. How often do farmers invest in technology and what are their main incentives?
    Ans: Farmers are motivated to invest in technology for business expansion, and to ease their operations as much as possible. The major incentive to them is the cost of the technology and next to this is access to fuel (or energy) and its affordability. With this, every farmer is motivated by flexibility of purchase of farm machineries and access to electricity with a pocket-friendly tariff.

11. Does the government or organizations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?

    Ans: Yes, there are NGO supports for agricultural machineries which some farmers already benefit from. There are also farmers cooperatives where they easily obtain loans to buy their machines without heavy collateral demands

- **Olayinka Jelili Yusuf**

Stakeholder: Smallholders' Perspective

1. What is the average area extent of land cultivated by a smallholder farmer you generally deal with?
   1.5 – 2 acres, usually in staggered plots.

2. What share of the farmers have access to irrigation system for their farming operations (i.e. do not solely depend on rainfall)?
   Generally, one out of every twenty farmers or less (<5%). However, in jurisdiction where Lower Niger River Basin Development Authority (LNRBDA) coverage reaches, more farmers, usually between 10-20% of farmers engage in irrigation farming.
   This also depends on enterprise of farmers; vegetable farmers depend more on irrigated farming and tend to cultivate all year round along river banks.

3. When present, what are the prevalent irrigation systems (in areas with/without electricity)?
   Surface irrigation (gravity driven option) are prevalent types. Pressurized system (sprinklers) although extremely rare occurs one in a hundred (1%).

4. How much do the typical irrigation systems used by smallholder farmers cost?
   An average of 100, 000 depending on farm size. Depending on farm size cultivated, the amount may be more than quoted. Response in #7 below give estimate per acre of land.

5. In what season of the year are smallholder farmers' crops most likely to undergo water stress?
   During dry season. But with deepening change in climate, wet/dry season moving away from conventional Mar-Sept/Oct-Feb, farmers' crop undergo water stress more around November to Late march.

6. Are there crops that are suitable for land conditions available that the farmers would like to plant, but are not able due to lack or inadequate access to water for irrigation?
   Yes; Maize, Rice, Vegetables including Tomatoes and Pepper for example, could be grown, almost all year round, but lack of access to adequate water or heavy dependence on rain-fed agriculture inhibits this potential. Farmers, however, prefer use of irrigated farming for vegetable cultivation which has less water needs and lower gestation period (often 4 – 6 weeks). Hence, vegetables are often available even at dry season, although at higher costs.

7. What range of size of irrigation water pump (e.g. liters/hour or kW) is generally used by smallholder farmers?
   On one acre of land (containing 8 plots of 100mx50m per plot), 16 litres of fuel is used thrice a week for irrigation → 100 kWh/ha/week (400 kWh/month)

8. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available to use PV, and water is stored in tanks for later use?
   Water is often generated when needed. Rarely, is water stored in tank and used at irrigation time. The later occurs in the use of sprinkler irrigation system. In areas of LNRBDA jurisdiction, farmers dig canal round their farm land, and store water in it drawn from nearby river, which are then used for crop irrigation as needed.

Rwanda

- **Rwanda Agricultural Board**

1. Smallholder farming and irrigation

a. What is the average areal extent of land cultivated by a smallholder farmer? Or, how many farmers you represent and for how much cropland area they account?
0.5 – 10 Ha

b. What is the proportion of smallholder/medium/large farmers you represent / in the country?
According to the Household survey report, 2020 published by National statistics of Rwanda the average land size in Rwanda is 0.4 Ha.
- Less than 0.5 ha: 77.6 % of the agricultural households
- 0.5-1 Ha: 13.5%
- 5 ha and above: 0.4%

c. What are the most strategic crops from a (i) nutritional and (ii) economic point of view for smallholder farmers?
(i) Maize, beans,
(ii) Vegetables, Maize, Banana, Fruits

d. In what season of the year are smallholder farmers' crops most likely to undergo water stress? Which months are involved?
Season C: June, July and August

e. What are, in your opinion, the most urgent actions to increase and stabilize crop yields of smallholder farmers? What is the potential contribution of irrigation in this sense?
- Irrigation development
- Provision of required water to reach the optimal crop yield either in dry season or as a complement to the available rain

f. What share of the farmers have access to irrigation system for their farming operations?

g. What are the prevalent irrigation systems (in areas with/without electricity)?
- Marshland irrigation: Dams here there is no electricity
- Center pivot/sprinklers where there is electricty
- Drip irrigation where there is electricity or not but solar system are used
- Pipe flow where solar system are used or diesel/petrol

h. What are the crop-specific irrigation schemes? Is the crop irrigated always to avoid any water stress issue, or some deficit irrigation practices are included in the scheme?
   - Crops are mostly maize, soybeans, vegetables (Tomatoes, Onions, chili, red peppers)
   - Both are used. In dry season we irrigate to avoid any water stress but also in other seasons we irrigate to cover the deficit water which is required. Which is complementary irrigation.

i. Do farmers practice crop rotation? What are the main obstacles for practicing it? Can irrigation system help and to what extent?
   - Yes farmers practice crop rotation. They do maize, soybeans, beans, and vegetables
   - Irrigation system help especially when crop are gown in dry period especially in dry season when farmers are growing vegetables

j. Are there crops that are suitable for land conditions available that the farmers would like to plant but are not able due to lack or inadequate access to water for irrigation?
   Yes. Chia seeds is being popular currently in Rwanda

k. Should there be access to water that requires payment, would the farmers be able and willing to pay?
   Yes. Paying irrigation services, there would be able depending on crop grown, when they irrigate high value crops they can pay

l. Would the farmers be willing to pool resources together to implement an irrigation system and jointly manage (govern) the irrigation system?
   Yes. Based on the subsidy program implemented by the Government of Rwanda farmer contribute to 50% of irrigation development either as individual farmer or as association or cooperatives.

2. Energy use and machinery

a. Is rainwater accumulation relevant and does it generally imply energy use?
   - Yes, it very relevant. We use harvested water from houses for irrigation
   - It does not generally imply energy use for harvesting but when you need to use it you need energy

b. What range of size of groundwater pump (liters/hour) is generally used by smallholder farmers?
   It really depends on the area to be irrigated and the total head as Rwanda is mountainous. Most of farmers are using petrol pumps of 30m3/hour with 27m head.

c. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available, and water is stored in tanks for later use?
   Depending on pump used:
   - They extract water when needed if they are using petrol/diesel pumps

- They pump water to reservoir when there is sun if they are using solar then water flows by gravity

d. Should groundwater or surface water extraction be prioritised in the modelling work, i.e. what is the key selection criterion between the two solutions (minimum costs, legal constraints, depth/distance)?
In my opinion, the priority should be surface water extraction due to minimum costs

e. Costs and revenues for smallholder farmers: what are the largest costs and the main chance to generate income?
To be discussed. Cost of land acquisition, labor, inputs, irrigation, pest control????

f. What type of crop processing machinery should we model, i.e. what crops and what transformations are most relevant?
To be discussed. Ussually on consolidated land farmers grow maize, rice, and does the transformation means processing???

g. What are the main obstacles for farmers to start crop processing (lack of machinery, lack of finance, lack of skills, bureaucracy, other)?
Lack of knowledge and skils, capital/finance

h. What processing scale (kg/day) are reasonable to consider (smallholder farmers)?
I am not a specialist in this domain

i. Ownership of the crop processing machinery: private/village-level/county-level by consortium?
I am not a specialist in this domain

j. What are the different tools, equipment and machines used by commercial (large, medium, small) and village farmers in each of the farming/processing stages? What are their prices? What are the main barriers for farmers to obtain technology?
I am not a specialist in this domain

k. How often do farmers invest in technology and what are their main incentives?
The Government provide subsidies as incentives for irrigation and post harvest handling insfrastructures.

l. Does the government or organisations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?
The Government provides subsidies but also for some specific item VAT is exempted

3. Electricity supply

a. How important is the size of demand from agricultural sector in the electricity supply technology trade-off (from PV on the field to national grid extension)?
I am not an expert.

b. What are the areas of relevance of electricity access to smallholder farmers?
   i. On the farm?
   ii. Preservation and processing?
   iii. In the household?

I THINK IN THE HOUSEHOLD then other priority comes after

c. What is the proximity of the houses of smallholder farmers to the farmland?
Just small plot and kitchen garden for vegetables.

   i. If the houses are far, how is electricity access important on the farm?

In Rwanda, Farmers live in community settlement and farm are far from houses.

d. Are there agricultural crops and practices the farmers would like to engage in but are not able or limited in doing so due to lack of electricity access?
Farmers can not grow vegetables for example if they don't have access to irrigation. Having electricity can enable them to do irrigation

e. Are smallholder farmers able and willing to pay for electricity access? If possible, could you quantify it?
Farmers are willing to pay electricity. In Rwanda we have cases where farmers pay electricity to operate pumps in irrigation schemes but they are grouped into cooperatives

f. What are the energy solutions for or in place of electricity that are currently being used by farmers?
They are used to run pumps stations for irrigation

Zambia

AGRICULTURAL STAKEHOLDER – GNA

AGRICULTURAL STAKEHOLDER – MoA

ENERGY STAKEHOLDER - Engie

ENERGY STAKEHOLDER - Muhanya

ENERGY STAKEHOLDER - REA

ENERGY STAKEHOLDER - ZARENA (JOSHUA KUMBUSO NYONI)

WATER STAKEHOLDER - ZARI

- **GNA**

1. What is the average areal extent of land cultivated by a smallholder farmer you generally deal with?

Response: 2.5ha is the average field size of the farmers GNA deals with.

2. What share of the farmers have access to irrigation system for their farming operations (i.e. do not solely depend on rainfall)?

Response: The majority of the farmers depend on rainfall. Roughly 0.27% of the 17000+ farmers registered under GNA

3. When present, what are the prevalent irrigation systems (in areas with/without electricity)?

Response: GNA is promoting borehole drilled, solar powered irrigation systems as most of our farmers are off the grid, rural farmers.

4. How much do the typical irrigation systems used by smallholder farmers cost?

Response: The systems GNA promotes are roughly US $11,000 covering drilling costs, solar powered pump, tanks and stands and drip irrigation kits.

5. In what season of the year are smallholder farmers' crops most likely to undergo water stress?

Response: Pre and post rain season

6. Are there crops that are suitable for land conditions available that the farmers would like to plant, but are not able due to lack or inadequate access to water for irrigation?

Response: High value horticultural crops which require steady and consistent water supply in order to produce the standards that that better markets require. These are largely available in agro supply shops.

7. What range of size of irrigation water pump (e.g. liters/hour or kW) is generally used by smallholder farmers?

Response: 0.5hp (2500 litres/hr) to 2hp (3500litre/hr)

8. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available to use PV, and water is stored in tanks for later use?

Response: Water is extracted when the sun is available and stored in tanks.

- **MoA - Zambia**

1. What share of the farmers have access to irrigation system for their farming operations?

Response: Majority of farmers have no access to irrigation. The share of farmers that have access to irrigations is unknown. But the number is small.

2. When present, what are the prevalent irrigation systems (in areas with/without electricity)?

Response: In areas with electricity pump water from boreholes, dams & streams/rivers use overhead sprinklers, and drip kits (combined with reservoir tanks). In areas without electricity, farmers use buckets to draw water from wells & streams. They also use diesel, solar & petrol water pumps to draw water from wells, boreholes and streams/rivers.

3. Is rainwater accumulation relevant and does it generally imply energy use?

Response: It is relevant because it provides water for domestic use, livestock and irrigation. It also provides a source of protein i.e. fish (aquaculture)

4. In what season of the year are smallholder farmers' crops most likely to undergo water stress? Which months are involved?

Response: Crops usually undergo water stress in hot months and dry (September to mid-December) for irrigated crops.

5. Are there crops that are suitable for land conditions available that the farmers would like to plant, but are not able due to lack or inadequate access to water for irrigation?

Response: Yes, farmers usually target to grow crops like maize, bananas, cabbages, water melons and citrus fruits like oranges but face challenges of inadequate water for irrigation.

6. What range of size of groundwater pump (e.g. liters/hour or kW) is generally used by smallholder farmers?

Response: Usually 1hp

7. How many hours per day are the pumps used? Differentiated between seasons.

Response: 6-8 hours in dry season and less in rainy season depending on soil moisture

8. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available, and water is stored in tanks for later use?

Response: For farmers who have storage tanks (minority) extraction is when needed especially those with electricity. Those without storage tanks (majority) and without electricity, it’s carried out at specific times when sun is available and also some scheduled times to save on fuel

- **Engie - Zambia**

1. How important is agricultural demand (compared to other types of demand) when selecting a mini-grid site?

Response: The main activities carried out by the rural community to earn an income and sustain their living is agriculture. Therefore, one third of the population in the community is involved in agricultural activities of which the mini-grid focuses on by tapping into the agro-energy nexus opportunities available. As part of our selection criteria, agriculture activities as an economic activity provide for an expected demand for electricity especially along the value chain, therefore area with such activities are preferred and have a higher scoring. Additionally, agro-processing activities serve as anchor loads for a sustainable mini-grid business model.

2. What electricity tariffs do you charge for farmers?

Response: The farmers are productive use customers, who are under bundle type E and are charged at ZMW5.1/kwh.

3. Do you offer financing of equipment, e.g., processing machinery? Are smallholder farmers able and willing to pay for electricity? If possible, could you quantify it?

Response: Community engagements and site visits conducted before a mini grid is set up seek to assess the willingness and ability of the community/famers to pay for electricity. The community knowing the benefits of power, confirm their willingness to pay once connected to the mini grid whilst Engie also assess their ability to pay through the various economic activities that they are involved in. On average a client who owns a hammer mill pays ZMW1,500.00 per month as electricity bills

4. What are the areas of relevance of electricity access to smallholder farmers?

    a. On the farm/field?

    b. Preservation and processing?

    c. In the household?

Response:

A) Access to mini-grid electricity for a farm provides that added value and efficiencies thereby increasing his/her yield. However, we are yet to implement an irrigation project which will be connected to the mini grid

B) As indicated in Q3, smallholder farmers are accorded the opportunity to have access to processing equipment being powered by the mini grid. It's worth to note that before installation of the mini-grid, farmers used diesel powered hammer mills which are expensive to run due to high operations and maintenance costs. Fridges are also provided for cooling purposes.

C) Farmers can come home to a good, cooked meal through our clean cooking solutions we provide using pressure cookers. Further, basic lighting of the household provides good visibility, children can also study at night, preservation of for longer hours as well as initiating other household businesses like Freezit selling. This improves the overall wellbeing of the household.

5. Which agricultural activities do smallholder farmers use electricity for?

Response:

- Producing of mealie meal from the harvested maize using the hammermill which draws power from the solar mini grid
- Producing cooking oil from sunflower using the oil expeller machine which draws power from the solar mini grid.
- Producing groundnut powder from the harvested groundnuts using the groundnut powder making machine which draws power from the solar mini grid.
- Irrigation project for 40 smallholder farmers to grow vegetables, tomatoes etc on 1 hectare plot. The submersible and booster pumps will draw power from the solar mini grid.

6. Do smallholder farmers sell their crops for income, or do they consume it for subsistence only?

Response: Part of the crops from the smallholder farmers is sold for income and the other is consumed for subsistence.

7. What is the typical distance between houses of smallholder farmers and the farmland?

Response: The distance is the range of 300m – 500m.

8. If the houses are far, is electricity access important on the farm?

Response: For houses that are very far from the solar min grid distribution network, the alternative source of electricity is through Solar Home System and independent Off – grid solar system packages based on the client's requirements.

9. How often do farmers invest in technology and what are their main incentives?

Response: Generally, farmers would want to invest in technology to improve their farming abilities, reduce time spent in the field and increase their yearly yield. However, as mentioned earlier their seasonal incomes makes it difficult for them to invest in modern technologies. It's for this reason that Engie provides a well-rounded solution to its clients on a lease to own basis coupled with capacity building programmes to train them on different aspects such as equipment usage, entrepreneurship, health, and safety etc

10. Does the government or organizations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?

Response: The government through ZRA has allowed farmers to input agriculture equipment at zero rate customs duty and exempted VAT for most of these equipment's.

- **Muhanya**

1. How important is agricultural demand (compared to other types of demand) when selecting a mini-grid site?

Response: Most rural economies are based on agriculture. Therefore agriculture is an important consideration when selecting a site.

2. What electricity tariffs do you charge for farmers?

Response: USD (0.70 to 1.5) per kilowatt-hour

3. Do you offer financing of equipment, e.g., processing machinery? Are smallholder farmers able and willing to pay for electricity? If possible, could you quantify it?

Response: Most farmers are willing to pay for electricity

4. What are the areas of relevance of electricity access to smallholder farmers?

a. On the farm/field?

b. Preservation and processing?

c. In the household?

Response: b and c

5. Which agricultural activities do smallholder farmers use electricity for?

Response: Poultry, irrigation and milling machine

6. Do smallholder farmers sell their crops for income, or do they consume it for subsistence only?

Response: both

7. What is the typical distance between houses of smallholder farmers and the farmland?

Response: Varies 100m to 5km

8. If the houses are far, is electricity access important on the farm?

Response: Yes, they use portable solar irrigation system

9. How often do farmers invest in technology and what are their main incentives?

Response: Solar irrigation systems incentive is PAYGO schemes

10. Does the government or organizations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?

Response: MFI loans and PAYGO Schemes. Govt has exempted solar equipment and most agro-equipment from VAT and Import duty

- **REA Zambia**

1. How important is agricultural demand (compared to other types of demand) when selecting a mini-grid site?

Response: It is important as a source of income, stimulant to economic activities and productive use of energy.

2. What electricity tariffs do you charge for farmers?

Response: Overall charge based on ability and willingness to pay is ranging between $4 to $7 per month.

3. Do you offer financing of equipment, e.g., processing machinery? Are smallholder farmers able and willing to pay for electricity? If possible, could you quantify it?

Response: REA does not provide financing equipment because it's not our mandate. We strive to collaborate with the mandate such as CEEC, National Saving bank as sources for financing. Yes, there are willing as start-up capital.

4. What are the areas of relevance of electricity access to smallholder farmers?

a. On the farm/field?

b. Preservation and processing?

c. In the household?

Response:

a. drip irrigation;

b. Cold storage and ice block making;

c. basic lighting, entertainment, phone charging

5. Which agricultural activities do smallholder farmers use electricity for?

Response: Vegetable gardening, Poultry farming

6. Do smallholder farmers sell their crops for income, or do they consume it for subsistence only?

Response: it's a source of income and for household consumption

7. What is the typical distance between houses of smallholder farmers and the farmland?

Response: Ranging between 1 to 5km depending on land availability

8. If the houses are far, is electricity access important on the farm?

Response: Very important

9. How often do farmers invest in technology and what are their main incentives?

Response: Depending on level of income, distance to access the equipment

10. Does the government or organizations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?

Response: Yes, agriculture input are duty free

- **ZARENA - Zambia**

1. How important is agricultural demand (compared to other types of demand) when selecting a mini-grid site?

Response: Agriculture demand is quite significant as it forms what is called productive demand. Therefore, this contributes to lowering of the levelized cost of energy/electricity of the mini grid system compared to a scenario which only has residential demand. From experience, a nexus of energy, food (agriculture demand) and water goes a long way in enhancing livelihoods and ensuring a sustainable ecosystem.

2. What electricity tariffs do you charge for farmers?

Response: Tariffs depends on the ability and willingness to pay of farmers benchmarked against the cost of the electricity supply including the associated operation and maintenance cost. Moreover, using a service-based approach, there is a possibility of setting an agricultural tariff for farmers, with different tiers based on demand or consumption or services demanded.

3. Do you offer financing of equipment, e.g., processing machinery? Are smallholder farmers able and willing to pay for electricity? If possible, could you quantify it?

Response: This depends on the business model to be adopted. One can do detailed surveys and load assessment to have a benchmark of the ability and willingness to pay for electricity. Besides, equipment financiers can do due diligence or a market assessment of a business case for equipment financing. It's possible to build capacity and empower farmers with equipment under a lease to own business model or pay as you go. Providing electricity and the machinery is not enough to ensure sustainability. What matters is capacity building and ownership model centred on the farmers or communities. Energy acts only as an enabler, therefore, bringing forward endless possibilities on how farmers can utilize the electricity to increase the income and pay for any equipment is crucial. Additionally, rural cooperatives are the potential investors and operators of solar mills, oil presses, cold rooms, milk chillers, etc. However, they are often characterised by weak governance structures and a very limited scope of commercial activities. In many cases, they do not take the opportunity to do bulk procurement and joint marketing of products. Thus, the management of an irrigation scheme or processing machine is quite a challenge, which causes high risks in terms of the investment profitability and for potential financiers. The more experience a cooperative has in running commercial activities, the higher the chance that it can successfully manage a PUE system. To answer the last part of the question "**YES**" quantification is possible to both the financing aspect and electricity affordability. For instance, investment costs for various applications are given below.

EUR 1500-30,000 for solar irrigation pumps for individual smallholder farmers (1-2 acres), and up to (EUR) 30,000 for systems such as solar cold rooms, which are run by cooperatives or micro, small, and medium-sized enterprises (MSMEs). The investment costs heavily depend on the project scale, specifically the required capacity (e.g. for irrigating a certain surface area) and configuration (with/without batteries). All RE systems are challenged by the relatively high upfront costs, which are not affordable for many customers such as smallholder farmers and rural cooperatives. That is the reason why system suppliers often offer attractive payment schemes such as supplier credit, leasing/rent to own, pay as you go.

4. What are the areas of relevance of electricity access to smallholder farmers?

   a. On the farm/field?

   b. Preservation and processing?

   c. In the household?

Response: From experience, a smallholder prioritizes electricity for irrigation (or on the farm/field) and then in the household. It's rare that a small holder farmer in the Zambian context would engage or get involved in preservation or processing. This is because most of them cannot afford such equipment.

5. Which agricultural activities do smallholder farmers use electricity for?

Response: The common use watering/irrigating fresh fruits and vegetables. [tomatoes, onions, vegetables, green paper, beans, etc]. Sometimes irrigation of the maize field if the rains delay coming. Some smallholder farmers engage in chicken rearing or poultry farming as part of the broad spectrum of small-scale farming in addition to agricultural activities highlighted above.

6. Do smallholder farmers sell their crops for income, or do they consume it for subsistence only?

Response: From experience most small holder farmers sell their crops for income. They are usually weekend or part jobs with regular jobs and careers during the week for some. However, in some cases a small percentage of the produce goes to self-consumption to prevent the produce from going bad owing to reduced demand or increased yield not matching up to the demand. Besides, Agriculture is the backbone of most economies in sub-Saharan Africa (SSA). In Zambia, it provides a livelihood to over three quarters of the population, mostly small-scale farmers. It contributes 20% of the country's Gross Domestic Product. In many countries, subsidies are provided e.g. to smallholder farmers to help them in the transition from subsistence farming to commercial agriculture and (small scale) processing (local value addition).

7. What is the typical distance between houses of smallholder farmers and the farmland?

Response: Less than 100m. Most fields are very close the homestead.

8. If the houses are far, is electricity access important on the farm?

Response: Usually houses are very near the field. However, if the farm is far electricity access still remains an important aspect of the farm depending on the size of the farm, water needs, proximity to a river or stream. Electricity access in this regard would involve decentralized solution (i.e. solar PV usage).

9. How often do farmers invest in technology and what are their main incentives?

Response: Frequently, they usually invest in communication technologies because of the need for remote management of the farming enterprise. Transport is also important. Renewable energy solutions are also getting adopted at a rapid rate. Incentives are attributed to value addition prospects and government support mechanisms to promote certain technologies such tax deductions on zero duty on certain products translating in cost reductions (making such product affordable to the farmers). However, if the RE rural market is to be sustainable the provision of modern energy services via RE should be linked to economic activities. Given that the rural market in Zambia is mostly agrarian, catalysing increased agricultural productivity and building supporting agro industries is the easiest economic activity to raise economic activities in rural areas and support productive use of electricity. These social development aspects cannot be left to the private sector to nurture – this is the role of the state and civil society.

10. Does the government or organizations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?

Response: Renewable energy systems are zero rated and thus this is an indirect incentive to promote technology adoption and deployment. However, technology purchase is the least of Zambia's problems especially in the renewable energy rural space. Governments must strive to incentivise active extension service providers. These give advice to farmers and rural cooperatives e.g. on good farming practices, are not only potential multipliers for PUE systems, but could also ensure that farmers and cooperatives operate the systems efficiently and profitably. For example, they can give recommendations on the kinds of crops to grow in the dry season that could be irrigated with a solar system. They can also help producers maximise the harvest of perishable products, which can be stored in cold rooms before getting sold. Finally, they can create linkages between farmers and buyers. The rural market for RE is challenging for developers as the uptake of RE is still very limited. Demand for electricity is very low and most mini-grids are operating at low capacity. A key problem with the rural market is the lack of consistent income throughout the year, most rural people therefore cannot consistently afford to pay for energy services even if they are connected. Thus, providing RE without considering the potential to generate income and pay for energy services does not achieve long term impact. Due to lack of economies of scale, cost of electricity from mini-grids is generally high. Mini-grid investments in rural areas are thus not viable unless they are accompanied by subsidies due the poor clientele and inherent high energy costs. Also, the rural market is dispersed, the roads are typically bad, making cost of servicing such markets unsustainable. Current analysis shows the least cost electrification of remote rural areas is via standalone RE systems.

Additional comments: One huge area that is getting more and more attention from governments is the irrigation of cultivated land; climate change is leading to unpredictable rainfall patterns and shorter periods of rain, which threatens the sustainability of the agricultural sector. In Zambia, the territory is 75 million hectares (752,000 km^2), out of which 58% (42 million hectares) is classified as medium-to high-potential for agriculture production. However, only 15 percent of this land is currently under cultivation. Zambia enjoys 40 percent of sub-Saharan water resources. Despite this, there is very little mechanical irrigation. The majority of farms are dependent on rain-fed growing cycles[i] ; manual bucket irrigation is the most prevalent irrigation technology used by more than 80% of smallholder farmers.

Further, there is a need for enhanced coordination in planning between energy and economic sector ministries such as agriculture, livestock, fisheries, industry, commerce, mines, etc. Energy-centric rural development strategies should therefore follow integrated energy economy models, especially prioritising the water-energy-food nexus and climate resilience as key elements of the modern rural development framework. Such rural growth strategies should also be modelled based on an “ecosystem approach” that supports entire value chains from energy provision, economic production, and access to markets. This can include supporting energy driven agricultural value chains, including RE based water pumping, irrigation, mechanisation, post harvesting value addition, agro processing, cooling, transport and cold storage chains. This can be expanded to other non-agriculture productive use of energy (PUE) activities that support the local industries, such as use of power tools. An overarching element of this rural energy market development should be a mainstreaming engagement between beneficiary communities, private sector, and public entities.

Moreover, there is a need for providing affordable finance to support both supply-side and demand-side investments. For RE developers, innovative financing combined with de-risking instruments are required to improve viability. On the other hand, mature RE markets can only be achieved with large scale public and private investments. Thus, there is a need for developing innovative financing mechanisms tailored for the local market and relevant business models. This should be supported by funding mobilisation including green funding vehicles available via climate change mitigation. Improved access to affordable finance will lead to increased RE diffusion and ultimately improved energy supply and security.

[1] https://www.export.gov/apex/article2?id=Zambia-Agricultural-Sector

- **ZARI - Zambia**

1. What share of the farmers have access to irrigation system for their farming operations?

Response: less than 10% of small holder farmers have access to irrigation facilities

2. When present, what are the prevalent irrigation systems (in areas with/without electricity)?

Response: bucket irrigation (in the dambo areas), treadle pump irrigation, engine pumps, drip irrigation

3. Is rainwater accumulation relevant and does it generally imply energy use?

Response: Rain water accumulation is relevant, and it does generally imply energy use in some cases

4. In what season of the year are smallholder farmers' crops most likely to undergo water stress? Which months are involved?

Response: During the rainy season when prolonged dry spells occur; most if not all of our smallholder farmers practice rainfed agriculture. This can occur in the following months- anywhere between December and March

5. Are there crops that are suitable for land conditions available that the farmers would like to plant, but are not able due to lack or inadequate access to water for irrigation?

Response: Yes, high value crops like vegetables and even fruit trees; also offseason cash and food crops like wheat and green maize

6. What range of size of groundwater pump (e.g. liters/hour or kW) is generally used by smallholder farmers?

Response:Am not sure about the pump size

7. How many hours per day are the pumps used? Differentiated between seasons.

Response: The pump is used for many hours during the dry season and less hours during the rain season

8. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available, and water is stored in tanks for later use?

Response: Water is generally extracted exactly when needed in most cases

Zimbabwe

Agricultural Research Trust Zimbabwe

Zimbabwe Renewable Energy Association & Celfre Energy (Isaiah Nyakusendwa)

- **Agricultural Research Trust Zimbabwe**

1. What is the average areal extent of land cultivated by a smallholder farmer you generally deal with?
   Varies from 2ha to 50ha.

2. What share of the farmers have access to irrigation system for their farming operations (i.e. do not solely depend on rainfall)?
   Not great probably less than 10% overall.

3. When present, what are the prevalent irrigation systems (in areas with and without electricity)?
   In mountainous areas it is largely gravity fed systems going down into the river valleys below. In other areas it can be organized irrigation systems fed by furrow usually or sometimes by pumping systems with sprinkler deliveries. A few centre pivot driven either by electricity or solar power. We have such a demonstration unit on A.R.T. Farm with the aim to demonstrate its use.

4. How much do the typical irrigation systems used by smallholder farmers cost?
   Varies tremendously from a few hundred US Dollars for the gravity systems for piping, to thousands of dollars for organized flood, overhead or pivot systems.

5. In what season of the year are smallholder farmers' crops most likely to undergo water stress?
   Dry season between April to October. Sometimes supplementary in the summer rainfall period to get crops away (November/December) at optimum times and to ameliorate drought mid-season (January/February).

6. Are there crops that are suitable for land conditions available that the farmers would like to plant, but are not able due to lack or inadequate access to water for irrigation?
   Yes many, potatoes, vegetables, wheat, plantation crops like bananas, avocados, macadamia nuts, fodder crops.

7. What range of size of irrigation water pump (e.g. liters/hour or kW) is generally used by smallholder farmers?
   Vast range, gravity nil, small wells and boreholes 5 kva upwards

8. Is water generally extracted exactly when needed (at irrigation time) or is the extraction carried out at specific times, e.g. when sun is available to use PV, and water is stored in tanks for later use?
   Usually extracted when needed. Some may have access to small dams/reservoirs. In many cases if relying upon ZESA, pump when they can, i.e. when no power cuts.

- **Zimbabwe Renewable Energy Association & Celfre Energy**

1. How important is demand from the agricultural sector when planning the optimal electricity supply technology in off-grid areas (from PV on the field to national grid extension)?
   Demand is key in the planning process – The nature of the country's terrain, population and current national grid backbone enables decision making for grid extension and or off-grid solutions. Affordability of the electricity supply is also key as we have seen electrification with no uptake in some remote agricultural areas.

2. How important is agricultural demand (compared to other types of demand) when selecting a mini-grid site or selecting an area to sell off-grid systems?
   For Zimbabwe agriculture is in mainstay of the economy and it follows that agricultural demand becomes key and it defines economic activity in any area.

3. What electricity tariffs are farmers charged in Zimbabwe? If you sell electricity to farmers, please also specify the tariffs/prices that you charge to farmers.
   When it was USD the tariff used to be on average $0.12 per kWh and given the depreciating ZWL is now below $0.05 per kWh and not cost reflective. The Utility has asked for a review.
   Not that many mini-grid are in operation in Zimbabwe and those that are in existence charge as much as $0.20 per kWh for them to be sustainable.

4. Do you offer financing of equipment, e.g processing machinery? Are smallholder farmers able and willing to pay for electricity? If possible, could you quantify it?
   Most companies funded through grants like Celfre Energy have been offering terms on equipment for say solar irrigation. Much has been talked about to offer energy as a service. We do not have much solutions for processing in the country. Equipment by nature have a large ticket size which make affordability an issue for smallholder farmers. If financing for equipment is made available farmers are willing to pay for electricity provided it is affordable. At the moment it is very difficult to quantify.

5. Where do farmers typically use electricity?
   a. On the farm/field?
   b. Preservation and processing?
   c. In the household?

   Large commercial farmers use electricity in all three areas and whilst for smallholder farmers it is in a) and b).

6. Which agricultural activities do smallholder farmers use electricity for?
   Irrigation

7. Do smallholder farmers sell their crops for income, or do they consume it for subsistence only?
   Its for both.

8. What is the typical distance between houses of smallholder farmers and the farmland?
   Smallholder farmers typically have three fields.
   a) Area around the homestead
   b) Gardens near the water source
   c) Open fields away from the homestead – in some cases as far as a 500m/1km depending on the community set up

   Open fields are now largely not utilised

9. If the houses are far, is electricity access important on the farm?
   Electricity access is important

10. How often do farmers invest in technology and what are their main incentives?

    Technology uptake has been slow because of lack of awareness and affordability issues. Farmers have relied on fossil fuels and in some cases grid electricity. Incentives now become reduction in costs and reliability. However the key incentive is affordability

11. Does the government or organizations promote farmers to purchase advanced technologies e.g. by providing loans or VAT exemption?
    Loans have been provided through banks for centre pivots mainly benefiting large farmers. Advanced technologies are in the main unsupported without VAT exemptions