PREO Powering Renewable Energy Opportunities

Capital required to maximise the productive use of energy in rural Sub-Saharan Africa

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Executive summary

At least $1.2 trillion is required to facilitate investment in the acquisition and powering of productive use of energy (PUE) appliances and equipment in rural sub-Saharan Africa (SSA) over the next 10 years, which translates to $120 billion per annum. Over the next decade a total investment of $662.3 billion is required for the acquisition of PUE equipment and appliances, while the remaining $528.9 billion will facilitate investment in solar Photovoltaic (PV) energy systems to power the equipment and appliances. While any economic modelling carries a level of uncertainty, we are most confident that the approach and methodology employed in this estimation yields a sensible and reasonable estimate.

"$1.2 trillion over the next 10 years is required to facilitate investment in the acquisition and powering of PUE appliances and equipment in rural SSA, which translates to $120 billion per annum."

An annual investment of $66.2 billion over the next 10 years is required to facilitate the acquisition of PUE appliances and equipment in rural SSA. The agriculture value chain accounts for the largest opportunity for the PUE capital investment. From the 47 PUE equipment and appliances identified – (water pump, solar dryer, freezer, milling machine and the oil press) account for 88% of the value of the market opportunity. These appliances are mainly used in the agriculture and agro-processing sectors, which accounts for nearly 75% of rural economic activity.

We estimate that a large investment of $52.9 billion per annum is required to power PUE activities in rural SSA. Current estimates on electrification are silent on the capital expenditure required to power PUE equipment and appliances. The Sustainable Energy for All (SEforAll) initiative estimates a requirement for an annual investment of $40 billion is required for global universal energy access. This will support investment in low tier energy access meant for lighting and cooking, and not necessarily for productive use. This estimation does not include the charging infrastructure required for powering transport-related PUE equipment.

There is an urgent need to mobilise investment for PUE equipment and appliances alongside energy systems to power PUE activities. These infrastructure and equipment investments should be implemented together with technical support to equip enterprises with technical expertise to identify the most profitable opportunities and facilitate routes to market. Given the high cost of PUE equipment and appliances, the financial support would need to be patient capital. This ensures that the investment is sustainable and can support long-term economic growth and development in rural SSA. The investment in PUE equipment and appliances alongside solar PV energy systems will support economic development, employment creation and productivity enhancements in remote areas.

1. PUE and its importance in rural sub-Saharan Africa

1.1 Background

The Powering Renewable Energy Opportunities (PREO) programme was launched in June 2020 and provides challenge funding and technical assistance for projects and companies engaged in supporting the productive use of energy (PUE). The energy demand driven by this support drives supply as renewable energy electrification becomes a viable option. Ultimately, the goal of the PREO programme is to stimulate economic development through access to energy.

Productive use of energy typically refers to energy demand (or consumption) by industries and enterprises. Specifically, PUE can include activities that generate revenue, increase productivity, enhance diversity, and create economic value through improvements in quality of life through, for example, electricity for education, healthcare, internet access and other social services. The German Agency for International Cooperation (GIZ) (2013) defines PUE as "agricultural, commercial and industrial activities involving energy services as a direct input to the production of goods or provision of services" (GIZ and EU Energy Initiative Partnership Dialogue Facility 2013).

To achieve the benefits from electrification, productivity-enhancing benefits require parallel support for the acquisition of appliances and equipment and complementary extension services to stimulate new types of economic activity. The financial support required to acquire PUE appliances and equipment is not usually considered in literature and policy surrounding energy access. To achieve the broader outcomes, financial support is required to ensure that enterprises, particularly farming enterprises, are involved in the productive consumption of energy. These broader outcomes are discussed in Section 2.

By 2030, the Sustainable Energy for All (SEforALL) initiative estimates that an annual investment of $40 billion, globally, is required to ensure universal energy access (IEA, 2021). Specifically, this investment will support modern energy access, defined as a "household" having reliable and affordable access to clean cooking facilities, a first connection to electricity, and then an increasing level of electricity consumption over time to reach the regional average. The initial, minimum level of electricity for rural households is assumed to be 250 kilowatt-hours (kWh), which, for example, could provide for use of a floor fan, a mobile telephone, and two compact fluorescent lights for five hours per day (IEA, World Energy Outlook 2011). By definition, the $40 billion annual investment does not consider the energy investment needed to power PUE equipment and appliances.

The purpose of this report is to estimate the capital required to maximise the productive use of energy in rural SSA. $1.2 trillion is required to facilitate investment in the acquisition and powering of PUE appliances and equipment in rural SSA over the 10 years, which translates to $120 billion per annum. The bulk of the capital investment is required by the agriculture and agro-processing sectors, which constitute a significant share of economic activity in rural areas. To estimate this market opportunity, a PUE Investment Model was developed to match the expected number of enterprises in rural SSA by 2030 to their PUE equipment and appliance needs.

1.2 Approach and methodology

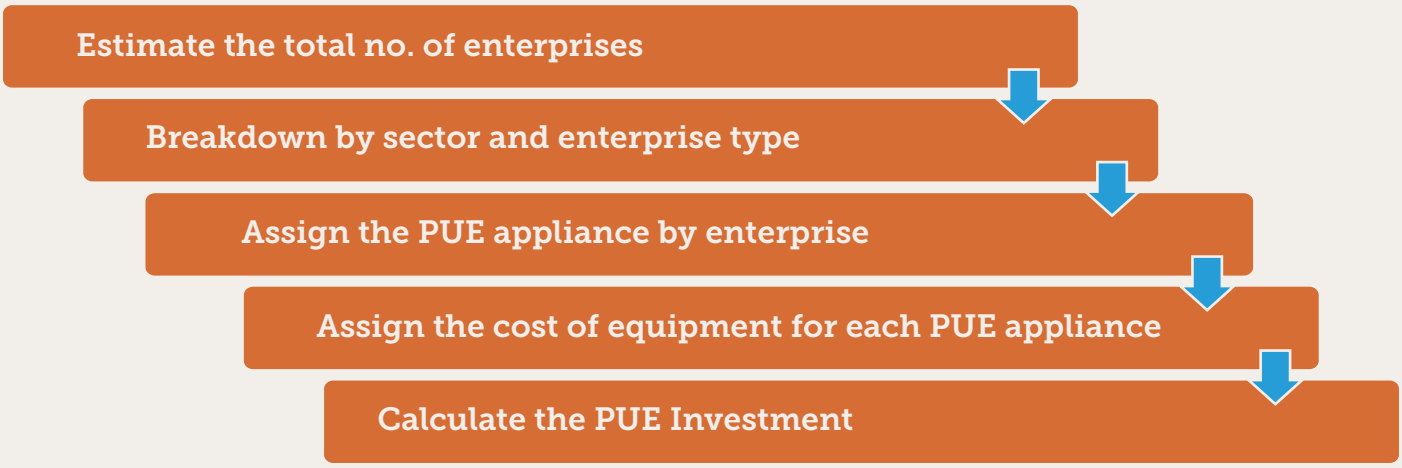
Limited research has been undertaken to calculate the PUE equipment and appliance capital investment required to support productive energy uses in rural SSA. A study by Lighting Global (2019) uses what they call the Dalberg Analysis to estimate the capital investment in SSA's agricultural sector, focusing on three processes – pumping, refrigeration and cooling, and processing. The study finds that the market opportunity for these three PUE products (linked to solar grids) amounted to $11.3 billion in 2018 (Lighting Global, 2019). The scale of the market opportunity identify in this study with a much narrower scope supports the estimate that has been calculated as a result of this study.

Our study employs a two-phased approach to calculate the market opportunity for PUE investment for rural SSA. The first phase involves the estimation of the number of enterprises in rural SSA (see Section 4). It is important to note that research on the number and type of enterprises operating in rural economies is scarce. A lot of the existing databases do not provide the variables required to estimate the PUE appliance and equipment investment. Ultimately, the report develops three approaches to estimate the number of enterprises in rural SSA: the methodology is summarised in Section 4.2.

The total number is disaggregated by the type of enterprise (or businesses), with the regional profile segmented into landlocked, and non-landlocked regions. Thereafter, each enterprise type is matched against its PUE appliances and equipment requirement, before assigning the retail prices for each PUE equipment and appliances (see Section 5).

In the second phase, the study controls for several assumptions to determine the market size by 2030. Importantly, two demand-side assumptions are relied on. Firstly, the study assumes that a proportion of the enterprises with electricity access had purchased PUE equipment by 2020. Secondly, of those firms without electricity access, none of them had purchased PUE equipment and appliances compatible with renewable energy, especially solar-powered energy. Furthermore, the study assumes a complete switch from fossil fuel-powered equipment and appliances to solar PV-powered PUE equipment and appliances. (Section 4). During this phase, the study also estimates the energy systems required to power the PUE equipment and appliances. fossil fuel-powered equipment and appliance to solar PV-powered PUE equipment and appliances.

Figure 1: An overview of the approach



The rest of the report is structured as follows:

- Section 2 briefly discusses the benefits of investing in PUE equipment and appliance.
- Section 3 discusses the key definitions of the terms employed during the study.
- Section 4 discusses the approach and methodology used to estimate the total number of enterprises in rural SSA.
- Section 5 provides the approach that was used to distribute the number of enterprises identified in Section 4.
- Section 6 presents the PUE investment model along with the expressions and assumptions used to calculate the market opportunity and energy systems investment.

2. The benefits of investing in PUE equipment and appliances

Existing literature on PUE investment has interrogated the link between energy consumption and economic activity. On the one end, research illustrates that electricity supply can be a financial burden on small businesses given the high costs associated with grid connection and electrical appliances, especially in marginalised rural communities (Booth, et al, 2018). In these studies, electricity usage hardly translated into higher enterprises profits. Of note, a study looking at villages in Benin concluded that the financial burden resulting from the investment in the connection and subsequent electricity bills could reduce firms' profitability, affecting long-term viability (Mayer-Trasch, Mukherjee and Reiche, 2013).

However, there is growing evidence that investing in PUE appliances and equipment can create opportunities to generate (and increase) income and support business expansion, which can both lead to higher income and job creation. Such positive outcomes can improve livelihoods, the ability to pay for the energy and improve the viability of any energy generation and supply model. For instance, enterprises that are reliant on energy e.g. services, welding, and fisheries, often register an improvement in sales and profit post-electrification (Mayer-Trasch, et al, 2013).

In rural economies, access to finance is highly limited, with most entities relying on cash-financed capital equipment. Furthermore, rural enterprises are often cash-constrained and are unable to save given volatile income streams. As such, there is an increasing tendency to either pool financial resources or buy and rent out PUE equipment (Lighting Global, 2019). Pooling resources reduces the financial burden for each farmer while renting the equipment provides a much-needed alternative income stream. The ability to apply either strategy depends on the sector: the agricultural sector is often organised into cooperatives where the necessary governance and accountability structures are in place to secure the investment. In the manufacturing sector, for example, it might be more difficult for welding enterprises to share a single grinding machine. Therefore, the format of shared or individual purchases is important in calculating PUE investment. Both strategies ensure that capacity utilisation is maximised, and the energy consumption is optimal.

The PUE appliances and equipment that are compatible with solar PV-powered mini-grids power output are at an early stage of development. Milling, threshing, and grating are the least mature PUE appliances and are still relatively energy intensive. Similarly, solar refrigeration and cooling appliances are still expensive and financially out of reach for most farmers. However, solar irrigation is relatively more advanced and increasingly becoming more affordable on a small scale. The nascency of the PUE appliance and equipment segment means that suppliers have not reached the level of scale and efficiency that supports low-cost production. Therefore, rural enterprises that are likely to invest in PUE equipment and appliances are those that can access patient capital or some form of grant funding.

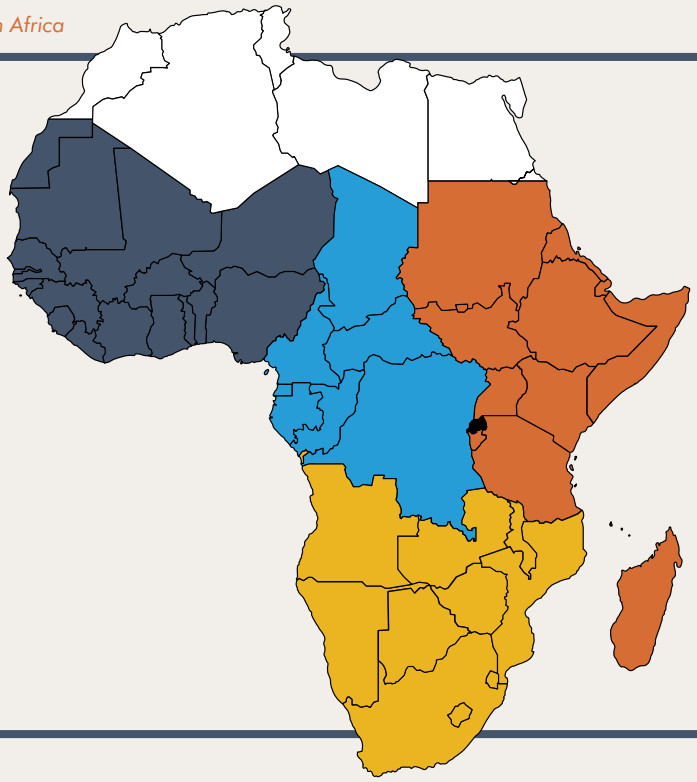
The full potential of the economic impact of electricity can only be exploited if certain necessary pre-conditions are fulfilled, such as a certain endowment for investment in electric appliances and access to markets, and transport infrastructure. Furthermore, PUE equipment and appliance acquisition need to be supported by extension services related to business development support skills development.

3. Key definitions of terms used in the analysis

3.1 What constitutes sub-Saharan Africa?

Sub-Saharan Africa consists of 51 countries in the east, west, central, and southern parts of Africa. This is illustrated on the map below. While the country coverage in the analysis will be based on data availability, three countries have been excluded upfront i.e. São Tomé and Príncipe, Reunion and Mayotte. Réunion and Mayotte are French regions, and data for São Tomé and Príncipe is unavailable in international databases.

Figure 2: Identifying sub-Saharan Africa



Furthermore, institutions group these countries differently. For instance, the International Monetary Fund (IMF) assigns Malawi, Mozambique Zambia, and Zimbabwe to Central Africa, while various country-level case studies assign them to Southern Africa. Furthermore, geographically, these countries are in the southern part of the continent and trade-wise, are part of the Southern African Development Community (SADC). For these reasons, those four countries have been reassigned to Southern Africa.

Table 1: List of countries considered as SSA

Country	ILO Subregion - Detailed	Revised region
1. Angola	Central Africa	Southern Africa
2. Benin	Western Africa	Western Africa
3. Botswana	Southern Africa	Southern Africa
4. Burkina Faso	Western Africa	Western Africa
5. Burundi	Eastern Africa	Eastern Africa

Country	ILO Subregion - Detailed	Revised region
6. Cameroon	Central Africa	Central Africa
7. Cape Verde	Western Africa	Western Africa
8. Central African Republic	Central Africa	Central Africa
9. Chad	Central Africa	Central Africa
10. Comoros	Eastern Africa	Eastern Africa
11. Congo	Central Africa	Central Africa
12. Congo, Democratic Republic of the	Central Africa	Central Africa
13. Côte d'Ivoire	Western Africa	Western Africa
14. Djibouti	Eastern Africa	Eastern Africa
15. Equatorial Guinea	Central Africa	Central Africa
16. Eritrea	Eastern Africa	Eastern Africa
17. Ethiopia	Eastern Africa	Eastern Africa
18. Gabon	Central Africa	Central Africa
19. Gambia, The	Western Africa	Western Africa
20. Ghana	Western Africa	Western Africa
21. Guinea	Western Africa	Western Africa
22. Guinea-Bissau	Western Africa	Western Africa
23. Kenya	Eastern Africa	Eastern Africa
24. Lesotho	Southern Africa	Southern Africa
25. Liberia	Western Africa	Western Africa
26. Madagascar	Eastern Africa	Eastern Africa
27. Malawi	Eastern Africa	Southern Africa
28. Mali	Western Africa	Western Africa
29. Mauritania	Western Africa	Western Africa
30. Mauritius	Eastern Africa	Eastern Africa
31. Mayotte	Eastern Africa	Eastern Africa
32. Mozambique	Eastern Africa	Southern Africa
33. Namibia	Southern Africa	Southern Africa
34. Niger	Western Africa	Western Africa
35. Nigeria	Western Africa	Western Africa
36. Rwanda	Eastern Africa	Eastern Africa
37. Reunion	Eastern Africa	Eastern Africa
38. Saint Helena	Western Africa	Western Africa
39. Sao Tome and Principe	Central Africa	Central Africa
40. Senegal	Western Africa	Western Africa
41. Seychelles	Eastern Africa	Eastern Africa
42. Sierra Leone	Western Africa	Western Africa
43. Somalia	Eastern Africa	Eastern Africa
44. South Africa	Southern Africa	Southern Africa
45. South Sudan	Eastern Africa	Eastern Africa
46. Eswatini	Southern Africa	Southern Africa
47. Tanzania, United Republic of	Eastern Africa	Eastern Africa
48. Togo	Western Africa	Western Africa
49. Uganda	Eastern Africa	Eastern Africa
50. Zambia	Eastern Africa	Southern Africa
51. Zimbabwe	Eastern Africa	Southern Africa

3.2 Access to electricity and electrification solutions

The lack of access to electricity is severe in SSA, and even more acute in rural areas. Of the 600 million people living in rural SSA, the World Development Indicators estimated that 69% did not have access to electricity (see Figure 3). In other words, a large proportion of the rural population in rural SSA do not have access to electricity to undertake certain basic activities, such as lighting, refrigeration, and the running of household appliances, let alone operate a factory, run a shop, grow crops or deliver goods to consumers (World Bank, 2021).

In Southern and Central Africa, generation capacities are often insufficient (with frequent blackouts as a result) and electricity tariffs are hardly cost recovering, making the extension of electricity grids difficult. Conversely, many East African countries have excess electricity supply with not enough energy demand. Nonetheless, national governments, donors, and the private sector are investing in the national grid and off-grid systems to address rural electrification. Compared to extending the national grid, off-grid systems are more cost-effective and quicker to roll out in remote and rural areas.[1] Mini-grids and standalone systems can be a cost-effective option for ensuring that households and businesses have access to electricity.

In estimating the PUE capital investment, it will be important to recognise that the PUE equipment and appliances purchased by the enterprises will need to be compatible with mini-grids or off-grid systems, especially those powered by solar PV. Moreover, the capital investment estimate will need to consider the level of electrification in 2020 vis-à-vis 2030, and how that affects post-electrification growth. This is discussed further in Section 6.1.

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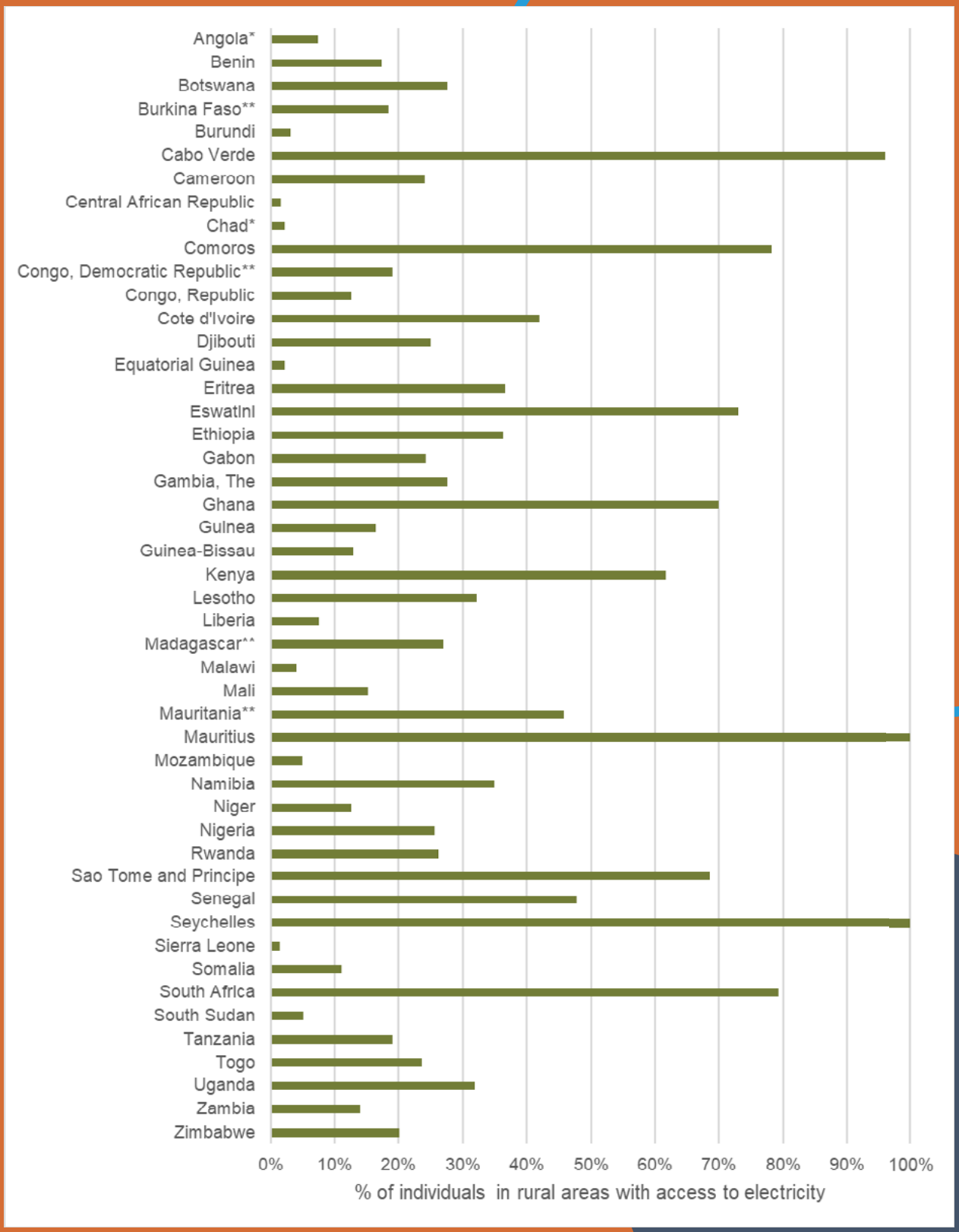
[1] *It should be noted that the most recent IEA scenarios state an investment requirement of $40bn/year between 2021 and 2030, coming down from $45bn year from the 2019 figures due to "huge progress in India and to the rapid decline of solar price."*

Figure 3: Share of rural population with access to electricity in SSA, 2019



Source: Analysis based on WDI.
*Notes: * Represents data from 2018. ** Represents national energy access rate*

3.3 Formal vs informal

The International Labour Organisation (ILO) refers to the informal economy as "all economic activities by workers and economic units that are – in law or practice – not covered or insufficiently covered by formal arrangements" (ILO, 2015, p. 11). In rural areas, informality usually refers to enterprises that are not registered under national law (Nagler & Naudé, 2017; Hilson, 2016; Rapsomanikis, 2015).

In rural Africa, the informal economy represents a significant proportion of economic activity, compared to the urban areas (ILO, 2015). In estimating the capital investment, it will be important to assume that most of the enterprises in the rural economy are informal and are likely to struggle to access asset financing for any purchases.

3.4 What is a micro, small and medium enterprise?

In rural SSA, economic activity is predominantly undertaken by micro, small and medium enterprises (MSMEs). Various studies and national classifications are used to categorise these MSMEs.

While there is no universal definition of MSMEs, many institutions use the following size categories:

- Micro enterprises have 0 to 9 employees
- Small enterprises have 10 to 49 employees
- Medium enterprises have 50 to 249 employees

Alternatively, enterprises (or firms) are deemed small and medium enterprises (SMEs) if they meet two of the following three requirements: (i) have less than 300 employees, (ii) have less than $15 million in assets, and (iii) have less than $15 million in annual sales.

According to Energy 4 Impact, another dimension worth considering for PUE investment relates to the enterprises' energy consumption per month. A distinction can be made between enterprises that consume less than 12kWh per month, and enterprises that consume more: the latter are categorised as productive consumers.[2] Using this approach, enterprises that fall within the productive users category include milling services, carpentry tools, egg incubation and water treatment services.

Nonetheless, enterprises located in rural areas are likely to be micro (80%) and small (20%) enterprises, with no medium-sized firms (DESA, 2017). This information will be useful in determining the type of equipment and appliances that will be purchased by the enterprises.

3.5 Standard Industry Classification

The standard industrial classification (SIC), as the name implies, are numerical codes that organise the industries that enterprises belong to as per their business activities. In the case of rural economies, there are various enterprises, which do not conform to the current SIC codes. For instance, enterprises offering services related to ironing, phone charging and popcorn making do not ordinarily fit into the SIC classification. However, it was important to match these enterprises to the closest industry as this aided the distribution of enterprises in Section 5.3.2.

[2] *Based on engagement with Energy 4 Impact.*

4. Estimating and distributing the number of enterprises in rural SSA

As illustrated in the introduction, the first step to estimating the PUE investment requirement is estimating the number of enterprises in rural SSA. The literature review presented below reveals the complexity of this endeavour. Estimations vary widely, meaning that pinpointing a reliable estimate is unlikely. Consequently, this section uses the results from the literature review and the models to provide a range within which the number of enterprises in rural SSA is likely to fall.

We conclude that depending on the methodology employed and the context, the number of enterprises in rural SSA varies. Furthermore, these estimates are quite different and difficult to compare. For this reason, we developed three models to estimate the number of enterprises in rural SSA that could benefit from PUE appliances and equipment – the Employment Model, the MSME Finance Model and the Value Chain Model. Using the existing literature and the three models, we are most confident that the study by Nagler and Naudé (2017) provides a reasonable estimate on the number of non-farming enterprises, while our Value Chain Model provides a sensible estimate of the number of farming enterprises in rural SSA.

4.1 Various approaches that have been used to estimate the number of enterprises

International institutions and peer-reviewed research have attempted to estimate the number of enterprises (by any definition) in SSA. These estimates produce stark results; mainly due to the scarcity of data on rural economies (Table 2). In this section, we briefly discuss several estimates on the total number of rural enterprises in rural SSA, by area (rural vs urban) level of formality (formal vs informal) and sector.

Table 2: Literature estimating the number of enterprises in SSA

Source	Methodology	Nature of enterprises	Area	Formal vs Informal	Sector	No. of enterprises
(IFC, 2013)	World Bank enterprise surveys	MSMEs only as per the WBs definition	Urban + rural	Formal	All	13,000,000
(SME Finance Forum, 2019)	Data from national offices	Micro, small, and medium enterprises	Urban + rural	Formal	All	80,860,786
(IFC, 2017)	Country data and enterprise surveys	MSMEs only as per the WBs definition	Urban + rural	Formal	Manufacturing and Services	44,200,000
(Wiggins & Keats, 2013)	No method disclosed	Smallholder farmers	Not disclosed	Not disclosed	Agriculture	33,000,000
McKinsey (2019)	No method disclosed	Smallholder farmers	Not disclosed	Not disclosed	Agriculture	380,000,000
(IFC, 2013)	World Bank enterprise surveys	MSMEs only as per the WBs definition	Urban + rural	Informal	All	28,000,000
(Hilso, 2016)	Extrapolates	Artisanal and small-scale miners	Urban + rural	Mostly informal	Mining	8,210,000
(Fjose, Grünfeld, & Green, 2010)	Extrapolated to 2020 using SMEs per 1 000	Small and medium enterprises	Rural	Formal	All	18,565,047
(Nagler & Naudé, 2017)	Survey data from six countries	Small-scale, self-employment	Rural	Mostly informal	NFE	80,490,000
(Fox, 2020)	Extrapolated from survey data	Small-scale, self-employment, no separation between household and enterprise assets	Rural	Mostly informal	NFE	59,324,724

Starting with the **formal enterprises in urban and rural regions in SSA**, the IFC (2013) estimates that there are 13 million formal enterprises in rural and urban SSA, while the SME Finance Forum (2019) places this estimate at nearly 81million in 2019. This would imply a growth of over 500% between 2013 and 2019, which far outstrips any reasonable population or GDP growth estimate during that period. These statistics were collated based on national statistics agencies, where each country's definition for MSME varies considerably. For instance, small enterprises in Kenya, Nigeria and Uganda have 10 to 49 employees, while Botswana has five to 29 employees, and South Africa has six to 50 employees. Lastly, not enough data is available to split the number of enterprises by region or sector. For these reasons, we find these estimates to not align with the objective of this study.

Limited information on the **number of enterprises in rural Africa across all the economic activities** is available. One outdated paper by Fjose, Grünfeld and Green (2010) captured the number of SMEs per 1,000 for eight countries – South Africa, Kenya, Tanzania, Ghana, Uganda, Mauritius, Botswana and Malawi – using the WDI Database Archives.[3] While the paper concludes that there is no correlation between the size of the country and the number of enterprises, we loosely match these eight countries to the rest of SSA. From this process, we estimate nearly 19 million enterprises in rural SSA in 2019. This estimate is relatively close to the IFC (2013), yet different from the SME Finance Forum (2019). However, we are unable to segment the rural enterprises to inform the estimation for this study.

To capture the **number of enterprises in rural SSA more reliably**, we split the enterprises in terms of farming and non-farming enterprises (NFEs).

The contribution of the agriculture sector towards gross domestic production and employment is well-documented, yet data on the **number of farming enterprises in rural areas is scarce**. A study by McKinsey estimates that at least 60% of the population of SSA are smallholder farmers (Goedde, Ooko-Ombaka, & Pais, 2019). By this, we can infer that there are over 380 million smallholder farmers in rural SSA.

This estimate differs from the International Fund for Agricultural Development (IFAD)'s approximation, which calculated 30 million smallholder farmers on the continent. Similarly, (NEPAD, n.d.) estimates that Africa has nearly 42 million farms, of which 80% of farms are less than 2ha in size. If we assume that one farm is held by one farmer, this provides an approximation of 42 million farmers in Africa (in rural and urban areas, both

[3]*The WDI Database Archives is available on the World Bank's website in beta version. However, the database does not yet include data on the number of enterprises. Available here https://databank.worldbank.org/source/wdi-database-archives-(beta).*

small-scale and large-scale). However, we could not validate the efficacy of these figures, given that there is no elaboration on the methodology for each study.

Nonetheless, we can conclude that McKinsey's estimate of 380 million farmers likely represents the uppermost bound on the number of farming enterprises in rural SSA.

Rural NFEs are defined by (Fox, 2020; Nagler & Naudé, 2017) as enterprises that:

- Are small-scale, self-employed or have less than five workers that are either household members or casual employees
- Are often not registered under national law, where the national law even excludes these businesses from registration requirements
- Do not separate between household and enterprise assets and finances
- Are mostly engaged in the retail trade sector, small-scale manufacturing (e.g. oilseed pressing or furniture making) or service provision (e.g. haircutting or repairs)

This definition aligns well with our understanding of economic activity in rural areas that would require PUE equipment and appliances.

To estimate the number of rural NFEs, Nagler and Naudé (2017) conducted household surveys across six countries in Southern and Eastern Africa: Ethiopia, Malawi, Niger, Nigeria, Tanzania and Uganda. Using weighted shares, the study estimates that 41.6% of enterprises have a non-farming enterprise; with each household having an average number of 1.36 NFEs. Using this approach, we estimate 84 million NFEs in rural SSA: see the calculation below in which we assume 4.5 family members per household (see (Population Reference Bureau, n.d.).

$$\textit{No. of NFEs in rural SSA} = \frac{\textit{639 million individuals}}{\textit{4.5 (assume mean HH size)}} \quad \textit{*41.63\% * 1.36 = 80,490,000}$$

Different from Nagler and Naudé (2017), Fox (2020) estimates that 40% to 50% of rural households have a household enterprise. Using this methodology, we can assume that there are at least 59 million NFEs in rural SSA. Both papers found that almost 40% of rural households operate an enterprise, though the average number of enterprises per household differs. Given that there is not enough information to sense-check the study by Fox (2020), we believe that Nagler and Naudé (2017) provide a reliable estimate of NFEs in rural SSA.

We can conclude from the data provided in this section, we are most confident that Nagler and Naudé (2017) provide a reasonable estimate on the number of non-farming enterprises, while McKinsey (2019) provides the ceiling for the number of farming enterprises.

4.2 Models developed by DNA

4.2.1 The Employment Model

The Employment Model uses employment data from the ILO to estimate the number of enterprises in rural SSA. This approach yields **an estimation of 115.2 million enterprises, of which 79.4 million are farming enterprises**. In this section, we discuss the employment model in detail.

To estimate the number of enterprises, we look toward official employment numbers in each respective country, proxied by the number of self-employed or employers. The ILO database classifies those employed into five broad categories. These can be defined as follows:

- **Employees** are those workers who hold the type of jobs defined as "paid employment jobs"
- **Employers** are those workers who, working on their own account or with one or a few partners, hold the type of jobs defined as a "self-employment jobs", on a continuous basis, one or more persons to work for them as employee(s)
- **Own-account workers** are those workers who, working on their own account or with one or more partners, hold the type of jobs defined as "self-employment jobs", and have not engaged on a continuous basis any employees to work for them
- **Members of producers' cooperatives** are workers who hold "self-employment jobs" in a cooperative producing goods and services
- **Contributing family workers** are those workers who hold "self-employment jobs" as own-account workers in a market-oriented establishment operated by a related person living in the same household

Based on these definitions, we proxy the number of enterprises using employers and own-account workers. While the inclusion of employers is self-explanatory, we would like to elaborate on the inclusion of own-account workers. As mentioned above, own-account workers include those employed that hold self-employment, though they may or may not employ others continuously. This definition aligns with existing literature, which points to the fact that rural enterprises are mostly characterised by self-employment. Given that own-account are not included in the "employer" category, it would be misleading to exclude them from the analysis. For this reason, the model uses the number of employers and own-account workers per industry to approximate the number of enterprises.

The ILO provides the following three data sets which are helpful for this estimation:

- Dataset 1: Number employed by industry and area[4]
- Dataset 2: Number employed by industry and status of employment[5]
- Dataset 3: Number employed by area and status of employment

[4] *Rural, Urban*
[5] *Employee, Employer, Own-account workers, Members of producers' cooperatives, Contributing family workers*

Ideally, we require a dataset that provides the number of employed by the sector, area, and status of employment. However, this tri-tabulation is not available. As such, we use the equation below to combine the information from each dataset available to estimate the number of enterprises in rural SSA.

The Employment Model can be expressed as follows:

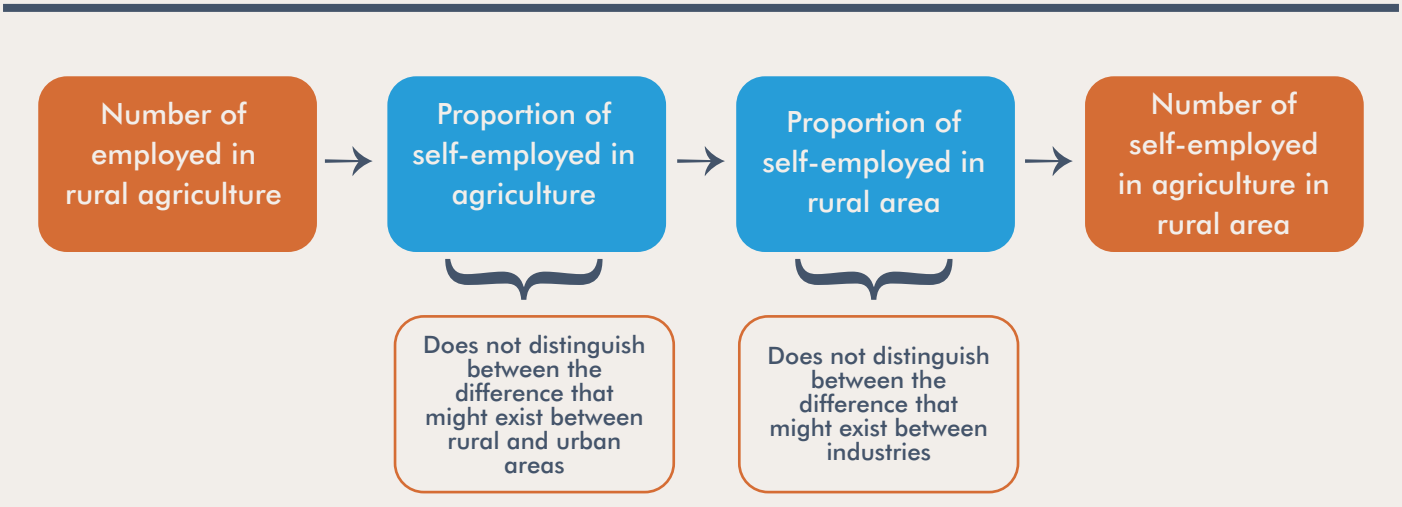
$$EN_{ri} \approx ER_{ri} = E_{ri} \times \left(\frac{ER_i}{E_i}\right) \times \left(\frac{ER_r}{E_r} \Big/ \frac{ER}{E}\right)$$

Where:

- EN_{ri} = Enterprises in rural area (r) in industry i which is approximately equal ($\approx$) to ER_{ri}
- ER_{ri} = Employer and own-account workers in a rural area (r) in industry i
- E_{ri} = Employed in a rural area (r) in industry i – Dataset 1
- $\frac{ER}{E_i}$ = Employer and own-account workers in industry i as a proportion of employed in industry i – Dataset 2
- $\frac{ER_r}{E_r}$ = Employer and own-account workers in rural areas (r)as a proportion of Employed in rural areas (r) – Dataset 3
- $\frac{ER}{E}$ = Employer and own-account workers as a proportion of Employed – Dataset 3

The equation makes two adjustments (illustrated below). It takes the number of employed in rural areas in an industry and multiplies it by the number of employers and own-account workers in the industry as a proportion of the total employed. This multiplication gives the number of employers and own-account workers in the industry if we assumed that the chances of being an employer and an own-account worker in an industry were independent of the area. As we do not want to make this assumption, we adjust this number by the chance of being an employer and an own-account worker in rural areas relative to the chance of being an employer and an own-account worker independent of the area.

Figure 4: Employment model: steps and limitations



Using the formula above, we estimate that there are 115.2 million enterprises in rural SSA (see Table 3 below). Of these enterprises, 79.4 million are predominantly involved in the agriculture sector, followed by 18.1 million in trade, transportation, accommodation and food, and business and administrative services, and 1.6 million in mining and quarrying, electricity, gas and water supply.

Table 3: No. of rural enterprises by industry using the Employment Model

Industry	No. of Enterprises
Agriculture	79,420,000
Manufacturing (including agro-processing)	7,660,000
Construction	2,160,000
Mining and quarrying, electricity, gas and water supply	1,640,000
Trade, transportation, accommodation and food, and business and administrative services	18,180,000
Public administration, community, social and other services and activities	5,940,000
Not classified	230,000
Total Enterprises	**115,220,000**

Source: ILO data, Authors own calculations

We highlight some of the key assumptions and limitations in our proposed employment model:

1. We are using the latest employment data for each respective country, which is often dated. For some countries, the latest data is 2011. In this regard, the WDI database on rural populations proved useful. We adjusted the ILO rural employment estimates with rural population growth rates to arrive at the latest period. This assumes that population and employment growth are perfectly correlated, and there may be exceptions in this regard.

2. The ILO data only has complete information for 33 countries and not the entire 48 countries in our analysis. As such, we extrapolated the numbers to the missing countries based on each country's rural population size, drawing from the WDI database on the rural population.

3. The ILO data is not available for the number of employers and own-account workers (enterprises) in rural areas per industry. This makes it difficult to know how accurate these proportions are.
    - For example, our calculation for "Proportion of employers and own-account workers (enterprises) in agriculture", does not distinguish between differences that might exist between rural and urban areas (see earlier Figure 4).
    - Further, within our calculation for "Proportion of employers and own-account workers (enterprises) in rural area", it does not distinguish between the difference that might exist between industries (see earlier Figure 4).

4.2.2 The Finance Model

The Finance Model uses financial data, specifically loan data, from various sources to estimate the total number of formal rural MSMEs. This approach yields an estimation of 120 million enterprises in rural SSA. In this section, we discuss the Finance Model in detail.

The Finance Model uses loan data to estimate the total number of formal rural MSMEs based on the proportion of lending made by commercial and microfinance institutions to MSMEs in rural areas. A country-by-country approach is taken due to the lack of worldwide or Africa-wide financial data.

The model is broken down into three steps.

1. Calculate the number of MSMEs in rural areas for "six representative countries" using financial data. The following six countries were selected: Kenya, South Africa, Ethiopia, Ghana, Zambia and Mauritius.

2. Calculate the total number of rural MSMEs in SSA by extrapolating the number of MSMEs per 1,000 individuals in rural areas for each of the six reference countries to the rest of SSA – the extrapolated countries – to find a total across all 48 countries (See Annexure 1).

3. Adjust the final value to account for informal enterprises to arrive at the final value.

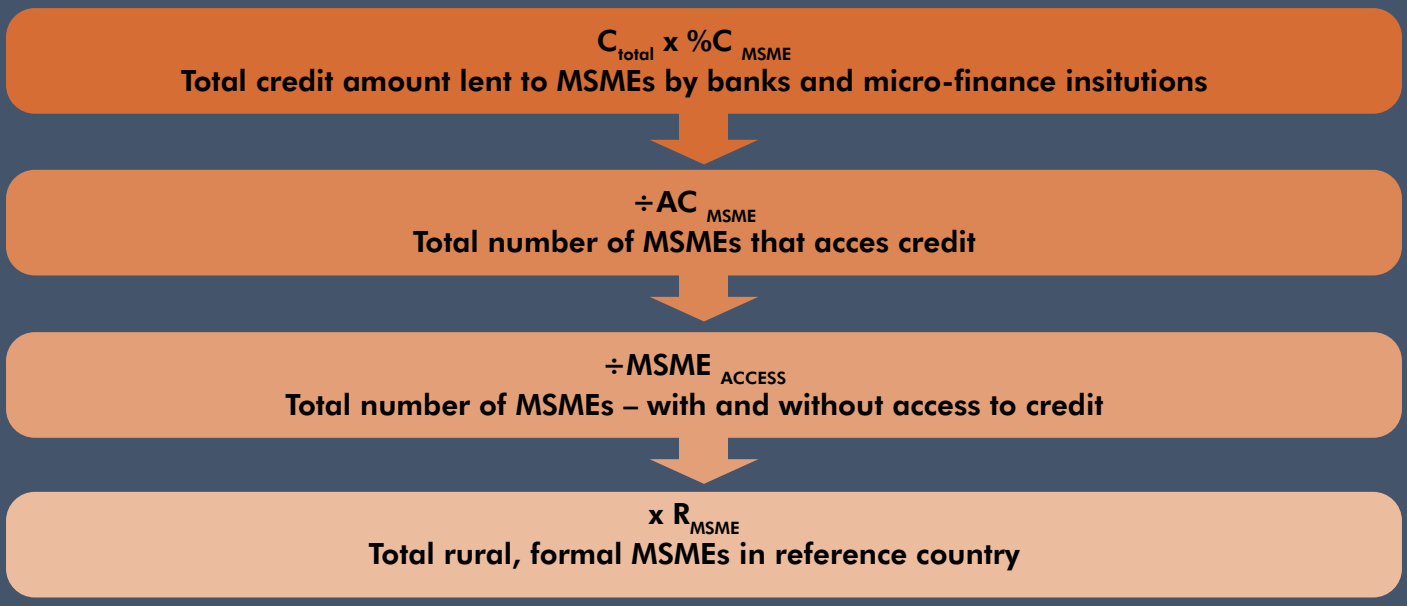
The total number of rural MSMEs per country for the "six representative countries" was calculated as follows:

$$R_{Total,i} = \{[(C_{Total} \times \%C_{MSME}) \div AC_{MSME}] \div MSME_{Access}\} \times R_{MSME}$$

Where

- $R_{Total,\ i}$ represents the total number of formal, rural enterprises in reference country i, I denote reference country 1 to 6
- C_{Total} represents Total Credit loaned to businesses in a representative country
- $\%C_{MSME}$ represents the proportion of total businesses that are MSME's
- AC_{MSME} represents the average amount of credit per MSME
- $\%MSME_{access}$ represents the percentage of MSME's with access to formal finance
- $\%R_{MSME}$ represents the percentage of MSME's that are rural
- $\%B_{informal}$ represents the percentage of informal MSME's in SSA

This approach can be represented graphically as follows:



Due to limited data availability for certain countries, certain assumptions were made. The first is that the average loan amount for a typical MSME is the same across all commercial banks and micro finance institutions. Second, a total loan amount was borrowed once by a single MSME. Thirdly, the average loan amount is based on the same period as the total loan amount. This stage of the calculation also needed to use proxies in certain instances. The first is that firm size can be used as a proxy for loan size and the second rural-urban employment split was used as a proxy for rural-urban MSME split.

Extrapolated countries were matched to one of the six representative countries using two approaches. The first approach matched countries based on their rural population spread (low, medium, or high rural population) and dominant employment sector – agriculture or services. The second approach matched countries based on their rural population spread – low, medium, or high rural population – and financial sector penetration, classified as high or low. The key assumption for this calculation is that the six representative countries are a reasonable representation of their extrapolated countries.

The following step calculated the total number of formal, rural enterprises across 48 SSA countries by extrapolating the six reference countries calculated above (RTotal, i) following the extrapolation approaches outlined.

$$Total\ Enterprises_{formal} = \left\{\left(R_{Total,i} \div 1000\right) \times \left(R_{MSME,i} \div \left(R_{Total,i} \div 1000\right)\right) + \cdots + \left(R_{Total,48} \div 1000\right) \times \left(R_{MSME,i} \div \left(R_{Total,i} \div 1000\right)\right)\right\}$$

Where

- $R_{Total.i}$ represents rural population per country, *i* denotes country 1 to 48
- ($R_{MSME.i}$) represents Total Rural MSME's for reference country, i denotes country 1 to 6 of the reference countries

$$(R_{Total,i} / 1000) * ((R_{MSME,i})$$

Total Rural MSMEs per 1 000 people in reference country, country 1 to 6

$$\div R_{Total,i} /1000$$

Total Rural MSMEs in extrapolated country *i*

$$+\ldots + (R_{Total,48} / 1000) * ((R_{MSME.i}) / (R_{Total.i} / 1000)$$

Total rural, formal MSMEs across all SSA, from country 1 to 48

The final stage of the calculation accounted for the informal sector using the ILO statistic on the size of informal employment, where 44% of total employment is in the formal sector in SSA.

$$Total\ Enterpirses = Total\ Enterprises_{formal} \div 0.44$$

Using this approach, we estimated a total of 120 million enterprises in rural SSA. This estimate is relatively close to the estimate produced by the Employment Model (in Table 3). However, it is important to note that this model has three limitations.

1. The lack of complete data means that the country-by-country approach required strong assumptions and proxies.

2. A country-by-country approach means further assumptions need to be made when extrapolating across SSA, specifically that the six countries are a true representation of the number of enterprises in the extrapolate countries.

3. The model depends on two key assumptions: the size of the average loan amount per MSME and the percentage of MSMEs that have access to formal credit. For instance, the percentage of MSMEs that have access to credit are below 10% which means even a small deviation from this will have a major impact on the final number of MSMEs for the reference country – a 1% change could have a 15% or larger effect.

4.2.3 The Value Chain model

The Value Chain Model uses agriculture production data from the Food and Agriculture Organisation (FAO) to estimate the number of farming enterprises in rural SSA. This approach yields an estimation of 129.6-million farming enterprises. In this section, we discuss the Value Chain Model in detail.

The Value Chain model aimed to estimate the number of enterprises at each stage of each value chain in SSA using production data for all the primary economic activities – agriculture, forestry and fishing, and mining and quarrying. While a typical input-output model for SSA would have been ideal, this data is only provided in nominal US$, and there is no data available to calculate output information.

To calculate the total number of producers, by industry, in rural SSA two indicators were required: total output and average output per primary sector producer. This would then have been used to estimate the number of enterprises involved in downstream activities. Unfortunately, the execution of the Value Chain model was limited by:

1. Limited data on secondary and tertiary economic activities[6].
2. Difficulty in understanding the interaction of the value actors across the various stages along the value chain.
3. High level of informal and activities, which are often not captured in national accounts accurately.

Nonetheless, the model was useful in estimating the number of smallholder farmers. For the agriculture sector, the value chain model managed to estimate the number of smallholder farmers disaggregated by crops, animal, and fish output. The total number of agriculture producers in rural SSA was calculated as follows:

$$No.\,of\ smallholder\ farmers_r = rural\ \% * \left[\frac{Total\ output}{Average\ Yield * Farm\ size}\right]$$

Based on the calculation, the Value Chain model estimated a total of 129.6 million smallholder farmers in rural SSA (See Table 4). Compared to the data sources in the section above, the number of farming enterprises estimated by the Value Chain model is higher than IFAD's and NEPAD's estimations of 30 million and 42 million, respectively. However, our estimate is lower than McKinsey's large estimate of 380 million farmers. We believe that the Value Chain model's estimate provides a good indication of the number of farmers in rural SSA that would benefit from PUE investment.

[6] *Secondary sector refers to the business activities related to manufacturing, electricity, gas, steam and air conditioning supply, water supply, sewerage, waste management and remediation activities and construction. Tertiary sector refers to economic services such as trade, transportation, accommodation and catering, and business, financial and administrative services and social services include community, social and other services and activities.*

Table 4: No. of smallholder farmers using the Value Chain Model

Agriculture sector	No of smallholder farmers
Crop and livestock farming	123,970,000
Aquaculture and fish farming	5,670,000
Total	**129,640,000**

The total number of smallholder farmers should be interpreted considering the following assumptions:

1. The estimation assumes that 80% of total food production in Africa stems from smallholder farmer activity in rural areas (Lowder, et al, 2016; McKinsey, 2014). Using the high level "standard" rural percentage across the sectors is reasonable given that we are only presenting continent-wide conclusions.

2. The model calculated the average production per farmer by multiplying the mean yield per crop (t/ha) (from the Food and Agriculture Organisation (FAO)) by the mean farm size (ha) from several sources. Using average data for yield and farm size assumes that productivity for each crop is standardised within each country. This can result in an over-or under-estimation of producers.

3. Smallholder farmers produce a combination of crops and/or livestock and/or fisheries (Rapsomanikis, 2015). To minimise the probability of double counting, we made two assumptions:
   a. All the farmers are involved in the production of at least one cash crop and have livestock. For this, we defined cash crops as including fruit, oil crops, pulses, roots and tubers, sugar crops and cereals, excluding fibre crops, tree nuts and vegetables.
   b. Total number of fisheries.

4. The FAO collects crop production data from any commercial and non-commercial activity, including field or orchard and gardens, excluding harvesting and threshing losses and that form part of crop not harvested for any reason. Therefore, production includes the quantities of the commodity sold, consumed or autonomous consumption. The model assumes that 80% of agricultural activity is undertaken by smallholder farmers in rural areas (Lowder, et al, 2016, and McKinsey, 2014).

4.3 A discussion of the results

Admittedly, the most challenging aspect of this study was estimating the number of enterprises in rural SSA. There are various estimates of the number of enterprises, and the three models that we computed add to these variants. Most of the existing studies rely on national surveys or generalise country-level surveys to estimates the enterprise population in SSA, given the high cost associated with compiling a representative sample. As such, there is very little certainty about their level of accuracy.

All the estimates had different objectives, which differ from this study's objective. This study seeks to determine the PUE capital requirement in rural SSA. Our understanding is that rural SSA is characterised by small-scale, often household-based enterprises, mostly engaged in the agriculture value chain.

For this reason, we provide a range of possible estimates without a point estimate. Two of our models – the Employment Model and the Finance Model – arrive at very close estimates of 115.2 million and 120 million, respectively. We believe that these estimates are closer to the lower end of the enterprise population. However, the Employment Model relied on the more reputable ILO database, and in doing so, provides a more reasonable estimate.

Based on our analysis, we are more relatively more confident in two estimates on the farming, and non-farming enterprises. We believe that the representativity of the survey by (Nagler & Naudé, 2017) for non-farming enterprises, and the Value Chain Model's farming enterprises provide a more plausible approximation. These two estimates align with the objective of the assignment and provide the best estimates at the upper end.

Table 5: The limits for the total number of enterprises in rural SSA

Sector	Upper Limit, 2020	Lower Limit, 2020
Farming enterprises	129,640,000	79,240,000
Non-farming enterprises	80,490,000	35,810,000
Total	**210,130,000**	**115,220,000**

5. Distributing the enterprises by type, PUE equipment and appliances

5.1 Proportional distribution of enterprises

In the previous section, we identified the most plausible number of enterprises in rural SSA to be nearly 210 million enterprises. The next step in the analysis is to break down these headline numbers into industries, and subsequently into types of enterprises. Once we have the types of enterprises, we can then assign the PUE equipment and appliances based on each enterprises' needs.

To carry out this phase, three steps were applied to distribute the enterprises by industry, and enterprise type, as discussed below.

First, to capture the diversity of the rural economies in the calculation, we segmented each SSA country into two regions: landlocked (LL) and non-landlocked (NLL). A non-landlocked country loosely refers to countries where aquaculture and fish farming are dominant, and annual production is above 70,000 tonnes. Additionally, countries where aquaculture and fishing accounted for a non-negligible proportion of total agriculture output within that country, such as The Gambia, were categorised as non-landlocked. This means that even though a country may not be geographically landlocked it is still categorised as such based on its output from the aquaculture and fishing industry (see Table 6).

Table 6: Landlocked versus non-landlocked categorisation

Categorisation	Number of countries	Production range (tonnes)
Non-landlocked	33	75,000 – 2,000,000
Landlocked	15	0 – 60,000
Total	**210,130,000**	**115,220,000**

Second, the grouped countries were assigned percentage distributions based on employment numbers across three sub-sectors: agriculture, mining and quarrying, and manufacturing, trade and services. These percentage distributions were based on the ILO's data, which segments employment by sector (see Table 7).

Table 7: Sectoral distribution (%) using employment data for the upper and lower limits for enterprises

Sub-sector	Landlocked distribution	Non-landlocked distribution
Agriculture	59%	73%
Mining and quarrying	1%	1%
Manufacturing and trade and services	**40%**	**26%**
TOTAL	**100%**	**100%**

Finally, each country grouping was further disaggregated to determine the number of enterprises per SIC classification. To do this, we used a combination of existing research (particularly the study by McPherson, 1991, which was processed and updated[7]), survey data provided by Energy 4 Impact and FAO output data.

[7]*The McPherson (1991) case study was selected after extensive desktop research which showed that most studies did not provide a granular breakdown on the types and distribution of enterprises in rural SSA.*

From this information, we identified 29 industries in rural SSA as per the ILO's standard industry classifications (see Table 8). These industries were further broken down into 69 types of enterprises (see Annexure 2). Most of the enterprises are involved in agriculture, followed by manufacturing activities such as carpentry and, lastly, services. This industry representation aligns well with a lot of the existing research on the types of economic activities that are prevalent in rural economies (Fox, 2020; Goedde, Ooko-Ombaka, & Pais, 2019; McPherson, 1991).

Table 8: Final industry weights for rural SSA, split by landlocked and non-landlocked

ILO standardised industry classification	Non-landlocked	Landlocked
01 - Crop and animal production, hunting and related service activities	73%	59%
08 - Other mining and quarrying	1%	2%
10 - Manufacture of food products	1%	1%
11 - Manufacture of beverages	2%	3%
14 - Manufacture of wearing apparel	1.20%	1.90%
15 - Manufacture of leather and related products	0.40%	0.60%
15 - Manufacture of textiles	2.60%	3.90%
15 - Manufacture of wearing apparel	0.30%	0.40%
16 - Manufacture of wood and products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	7.20%	11.00%
20 - Manufacture of chemicals and chemical products	0.00%	0.00%
23 - Manufacture of other non-metallic mineral products	1.50%	2.20%
25 - Manufacture of fabricated metal products, except machinery and equipment	0.40%	0.60%
31 - Manufacture of furniture	0.10%	0.10%
33 - Repair and installation of machinery and equipment	0.10%	0.20%
34 - Electricity, gas, steam and air conditioning supply	0.10%	0.10%
36 - Water collection, treatment and supply"	0.10%	0.10%
35 - Electricity, gas, steam and air conditioning supply	1.40%	2.10%
36 - Water collection, treatment and supply"	0.10%	0.10%
41 - Construction of buildings	1.40%	2.10%
46 - Wholesale trade, except for motor vehicles and motorcycles	0.00%	0.00%
47 - Retail trade, except for motor vehicles and motorcycles	3.10%	4.70%
49 - Land transport and transport via pipelines	0.20%	0.30%
52 - Warehousing and support activities for transportation	0.60%	0.90%
56 - Food and beverage service activities	0.90%	0.80%
63 - Information service activities	0.80%	1.20%
86 - Human health activities	0.40%	0.60%
87 - Residential care activities	0.00%	0.00%
90 - Creative, arts and entertainment activities	0.10%	0.20%
93 - Sports activities and amusement and recreation activities	0.10%	0.20%
95 - Repair of computers and personal and household goods	0.10%	0.10%
96 - Other personal service activities	1.30%	2.60%

5.2 PUE equipment and appliances

Each enterprise, depending on the type of economic activities that can be electrified, requires specific PUE appliances and equipment. Importantly, the power for the PUE equipment and appliances was limited to 5000W to ensure compatibility with mini-grids or standalone systems, given that the rural areas will likely be electrified using off-grid systems.

The PUE equipment and enterprise was also assigned a current retail price based on the data provided by Energy 4 Impact, and secondary sources. The secondary sources included well-established suppliers of PUE equipment and appliances, such as Bosch and Lorentz, and start-ups that are still in the process of achieving scale, such as SunDanzer. The retail prices are tabulated below.

Table 9: PUE Equipment and Appliance, wattage and retail price

PUE equipment and appliance	Shared or individual purchase	Equipment wattage (watts)	Retail price (USD)
Air conditioner	Individual	1 130	569
Blow dryer	Individual	-	26
Brooder	Individual	360	526
Chaff cutter	Individual	-	431
Computer	Individual	-	354
Decoder	Individual	8.8	53
Solar dryer	Shared	-	2,964
Egg incubator	Individual	-	1,179
Electric drill	Individual	550	30
Electric fan	Individual	4	23
Electric grinder	Individual	650	33
Electric planning tool	Individual	650	78
Freezer (cold chain solution)	Individual	280-800	2,195
Fridge	Individual	-	438
Fish dryer	Individual	-	2,964
Grinding machine	Individual	-	590
Hair clippers	Individual	-	59
Hairdryer	Individual	2 200	110
Hair straightener	Individual	-	59
Huller - cereal	Individual	800	3,000
Huller -rice	Individual	250	1,675
Iron	Individual	2 00	34
Milling/grinding machine	Individual	-	1,769
Oil press	Individual	810	2,200
Oven	Individual	1 920	1,749
Phone charger	Individual	6.8	20
Phone repair machine	Individual	-	354
Popcorn maker	Individual	-	177
Power saw	Individual	-	1,769
Printer	Individual	-	236

PUE equipment and appliance	Shared or individual purchase	Equipment Wattage	Retail price
Projector	Individual	50	136
Radio	Individual	-	59
Satellite dish	Individual	-	23
Security lights	Individual	20	34
Sewing machine	Individual	-	590
Soldering machine	Individual	48	156
Speaker	Individual	80	271
Thresher	Individual	100	500
TV	Individual	5.5	159
Water heater	Individual	1 500	151
Water pump	Shared	-	1,651
Water purifier	Shared	85	1,236
Welding machine	Individual	-	115
UV Lamp	Individual	-	590
Fishing boat motor	Individual	-	4,000
Motorbike motor and battery	Individual	-	1,000
Tuk-tuk motor and battery	Individual	-	2,000

In the next section, we detail the approach used to calculate the market opportunity for the PUE equipment and appliances.

6. The PUE Investment Model

6.1 Mathematical expression and assumptions

The PUE Investment Model estimates the market opportunity for PUE equipment and appliances in rural SSA required to maximise the benefits from electrification. The acquisition of PUE equipment and appliances needs to be complemented by an investment in solar PV systems that match the energy requirement for each PUE equipment and appliance.

To calculate the market opportunity, we use the following expression:

$$Total\ PUE\ investment\ required = \sum_i p_i q_i e_i + \frac{\sum_j p_j q_j e_j}{5}$$

Where

- p_i = price (unit cost) of not commonly shared equipment of type *i*.
- q_i = quantity of not commonly shared equipment of type i required per enterprise that uses it
- e_i = number of enterprises that use not commonly shared equipment of type *i*
- p_j = price (unit cost) of commonly shared equipment of type *j*.
- q_j = quantity of commonly shared equipment of type *j* required per enterprise that uses it
- e_j = number of enterprises that use commonly shared equipment of type *j*
- The commonly shared equipment is assumed to be shared among five enterprises (one workday per week per enterprise)

To calculate the cost of investment in solar PV energy systems, we use the following expression:

$$Total\ investment\ in\ solar\ PV\ energy\ systems = \sum_i kW_i\, d_{PV} p_{PV} q_i$$

Where

- kW_i = energy system power for equipment of type *i*.
- d_{pv} = design factor for energy systems, which is equal to 1.4kW
- p_{pv} = price (unit cost) of a solar PV system cost at $/kW, which is equal to $1300 per kW.
- q_j = number of PUE equipment and appliances that require energy systems

A summary of the unit cost of energy systems required to power PUE equipment and appliances, by type is provided in Annexure 3.

The PUE Investment Model relies on key demand-side assumptions that are related to access to PUE equipment and appliances that are compatible with solar PV energy systems and access to electricity.

1. The World Bank's WDI assumed that 31% of the rural population in SSA had access to electricity in 2019. By extension, we assume that only 31% of enterprises had access to electricity in 2019. We highly doubt that this statistic had changed materially in 2020. Therefore, we assume that access to electricity among enterprises in rural SSA was 31%.

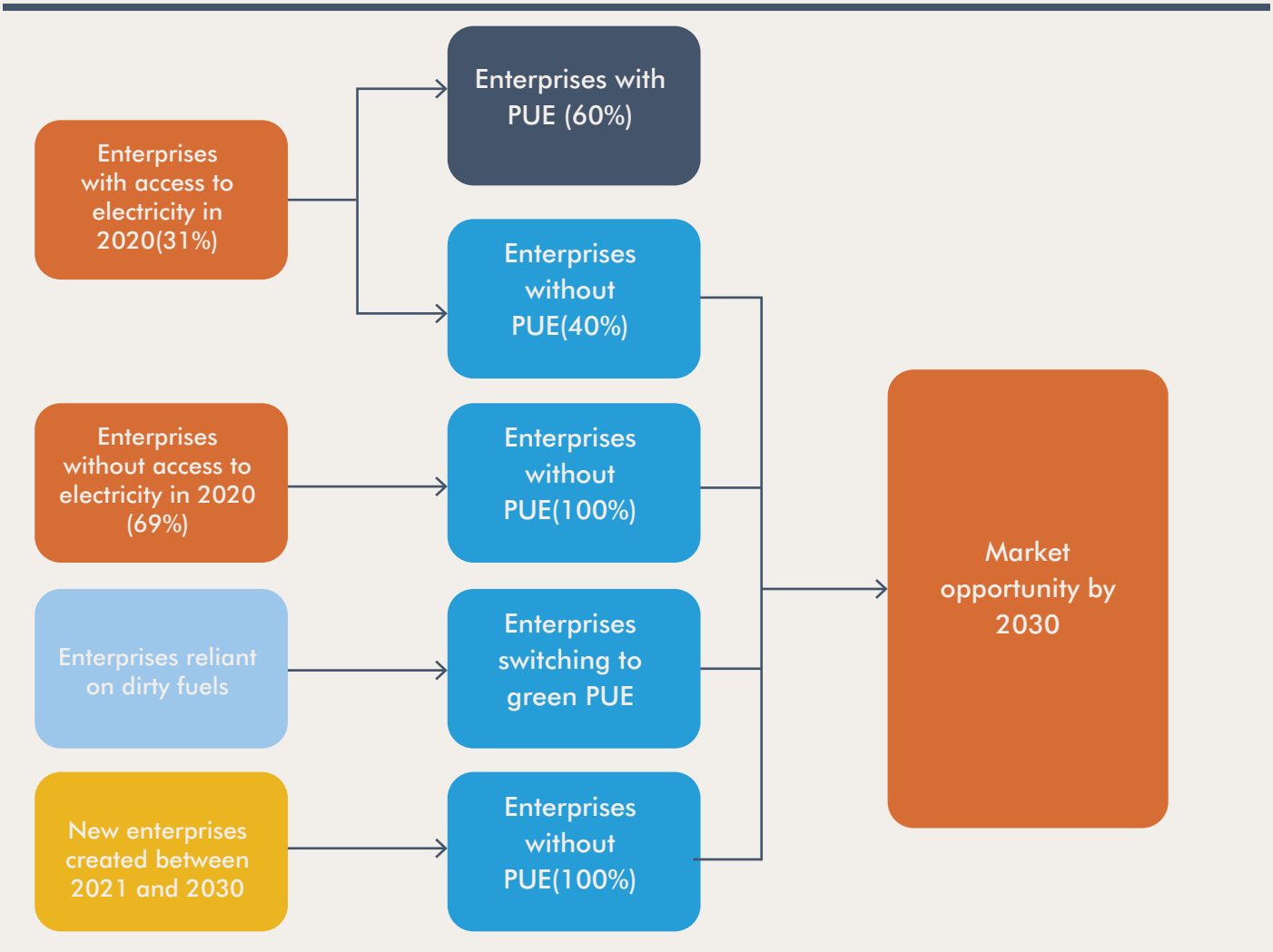
2. Among the 31% of firms that have access to electricity, 60% are likely to have connected to the grid (drawing on findings from Mayer-Trasch, Mukherjee and Reiche, 2013). We extend this assumption and presume that enterprises that are connected to the grid can afford to purchase PUE equipment and appliances, otherwise, they would not have invested in grid connection.

3. If 69% of enterprises did not have access to electricity, we further assume that none of them had invested in PUE equipment and appliances. All these firms will need to purchase PUE equipment and appliances by 2030.

4. In rural areas, enterprises are likely to have invested in PUE equipment and appliances that are powered by fossil fuels. As solar PV energy systems gain more traction, enterprises are likely to switch to more sustainable energy sources.

5. Between 2020 and 2030, we expected the number of enterprises in rural SSA to increase by 3% year-on-year based on rural population growth rates. These additional new firms will not have access to PUE equipment and appliance.

The interaction of these variables is summarised in Figure 5 below and represents the market opportunity for PUE equipment and appliances in rural SSA by 2030.



Source: DNA Economics' representation

These demand-side assumptions, and additional demand- and supply-side assumptions are tabulated below. All the assumptions were incorporated in the PUE Investment Model are listed in Table 10.

Table 10: The key assumptions in calculating the PUE Investment Model

Demand-side assumptions		
	31% of enterprises have access to electricity	In 2020, 31% of the rural population had access to electricity (see Section 3). As such, we assume that 31% of enterprises had access to electricity.
	60% of the enterprises in electrified areas have access to PUE	Once firms have access to electricity, 60%, on average, connect to the grid (Mayer-Trasch, Mukherjee, & Reiche, 2013). We assume that this 60% represents enterprises that have acquired PUE equipment and appliances.
	Some PUE equipment and appliances will be purchased as shared investments	Rural enterprises tend to share the cost for big-ticket items (Section 1.2). Based on the data, three appliances, a solar dryer, water pumps and purifiers, meet the shared purchase criteria. We assume that five enterprises will share the appliance, allowing each business access once a day per workweek.
	The number of enterprises is expected to increase post-electrification.	Several studies indicate that post-electrification, the total number of enterprises is expected to increase. For the rural enterprises, we apply a growth rate of 3% per annum until 2030, in line with the historical rural population average growth rate.
	Enterprises will make once-off purchases for PUE equipment and appliances	The investment in PUE equipment and appliances will result in the growth and expansion of the enterprises. However, given the excess capacity post-purchase, it is highly unlikely that the same enterprise will invest in additional PUE equipment and appliances, especially similar PUE capital. This is even more reasonable as these enterprises will probably serve the same, relatively small market.
	Enterprises will switch to green PUE equipment and appliances	Renewable, decentralised solutions are fast gaining traction in rural areas, with enterprises switching from diesel- or paraffin-powered solutions towards green solutions, especially solar PV systems. As such, we expect the enterprises to switch towards PUE equipment and appliances that are compatible with solar PV systems.
Supply-side assumptions		
$40 billion	$40 billion is required for global universal energy access	SEforALL estimates an annual investment of $40 billion for universal access is only for low tier energy access meant for lighting. This estimation is based on IEA scenarios (SE4All, 2015).
	Each PUE equipment or appliance requires a PV system	We assume that each PUE equipment or appliances will require a solar PV system that matches the equipment or appliances' energy requirements.
	Costs associated with setting up charging infrastructure are excluded	The calculation does not include the costs associated with setting up charging infrastructure that will be required for electric motorboats, motorbikes and tuk-tuks.
	PUE equipment and appliances below 5000W	The list of appliances and their corresponding costs that have been sourced are productive use appliances, which can connect to a microgrid or mini-grid.
	Declining costs in PUE equipment and appliances	As the ability to scale production and efficiency improves, the cost of PUE equipment and appliances is likely to decline (Section 1.2). However, given the uncertainty of when this will happen, we calculate the PUE based on 2021 retail prices.
	Retail prices excluding credit costs	Most MSMEs across Africa have limited access to credit, especially within rural areas. According to the 2017 Global Findex database, borrowing rates among rural adults to start, operate, or expand a farm or business only ranged from 1% to 13%.

6.2 The PUE Market Opportunity

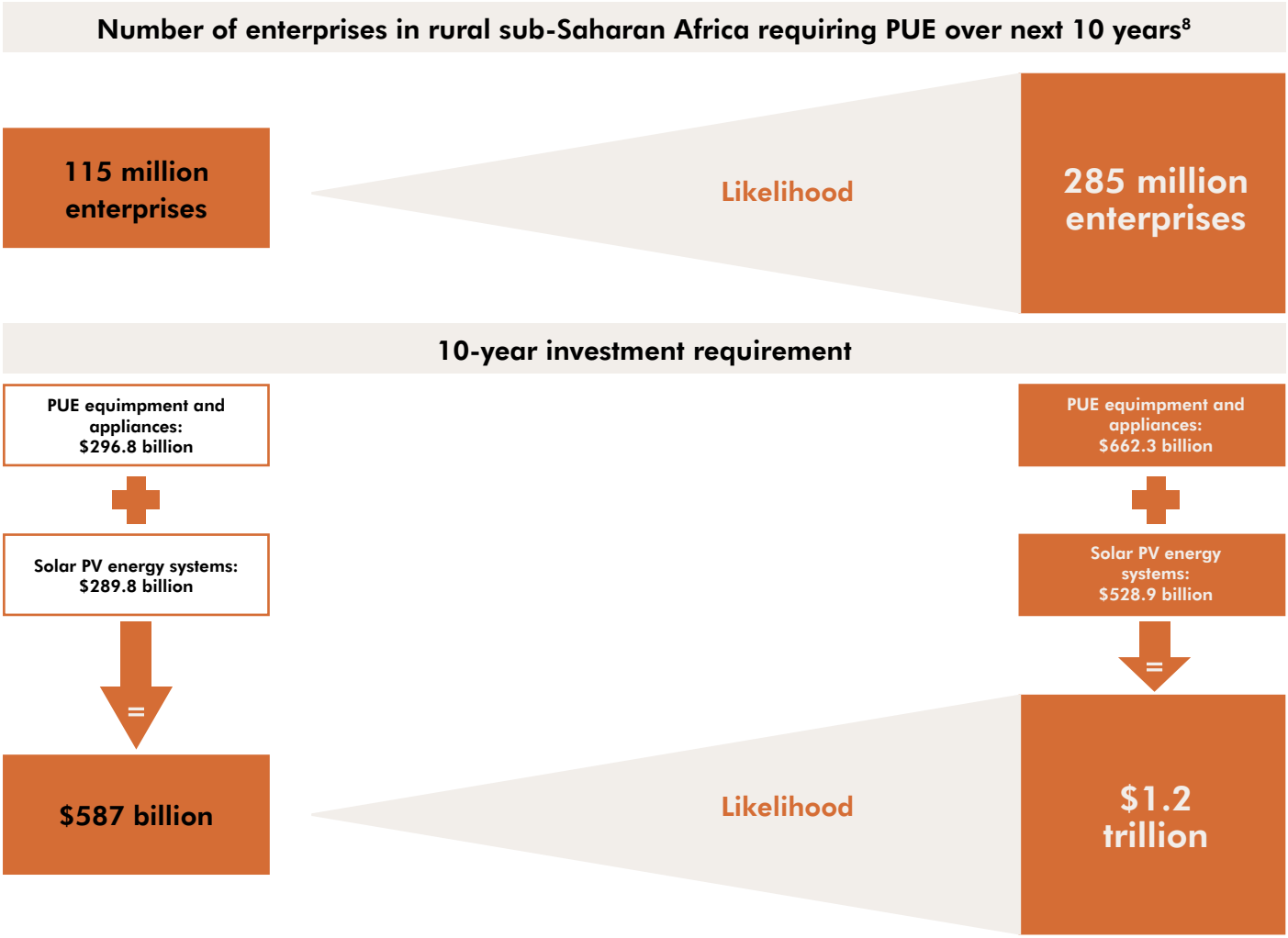
At least $1.2 trillion is required to facilitate investment in the acquisition and powering of PUE appliances and equipment in rural SSA over the next 10 years, which translates to $120 billion per annum. Of this, $662.3 billion is required for the acquisition of PUE equipment and appliances, while the remaining $528.9 billion will facilitate investment in solar PV energy systems to power the equipment and appliances: Notably, the investment for solar PV energy systems excludes charging systems, which would require large-scale energy investments. While this investment amount is informed by careful economic modelling, it carries a level of uncertainty. We are most confident that these estimates are indicative of the considerable investment required to support economic development in rural economies.

"$1.2 trillion over the next 10 years is required to facilitate investment in the acquisition and powering of PUE appliances and equipment in rural SSA, which translates to $120 billion per annum."

With all the information reviewed and presented, it is most prudent to consider the PUE equipment and appliance market opportunity in rural SSA to be $662.3 billion over the next 10 years or $66.2 billion per year. The acquisition of PUE equipment and investment need to be supported by an investment in solar PV energy systems of $528.9 billion over the next 10 years, or $52.9 billion per year.

Figure 6 summarises the results. We are confident that the actual required investment amount lies within the range presented in section 4.2. However, due to the reasons provided in section 4.2, we believe that the larger amount is likely to be more accurate.

Figure 6: Summary of results



Source: DNA Economics Analysis

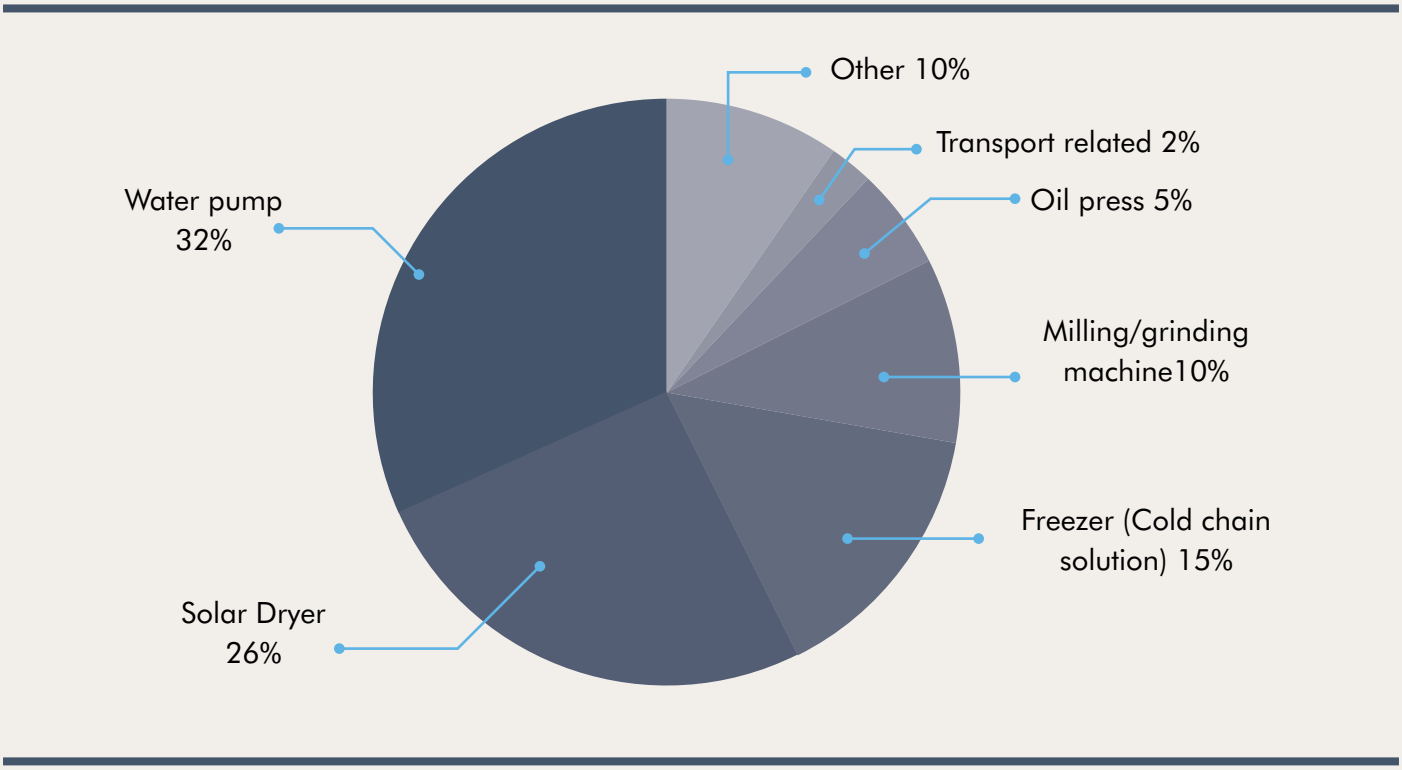
If South Africa is excluded from the analysis, the investment requirement for acquiring and powering PUE equipment and appliances decreases by 2.6% (equal to a total decline of $30.6 billion over the next 10 years).

- A breakdown of the investment required for acquiring and powering PUE equipment and appliances rural SSA is tabulated in Annexure 4A (upper limit) and Annexure 4B (lower limit)
- Without SA, a breakdown of the investment required for acquiring and powering PUE equipment and appliances rural SSA is tabulated in Annexure 5A (upper limit) and Annexure 5B (lower limit)

The agriculture value chain accounts for the largest opportunity for the PUE capital investment. From the 47 PUE equipment and appliance identified, the water pump, solar dryer, freezer, milling machine and the oil press account for 88% of the value of the market opportunity. These products are mainly used in the agriculture and agro-processing sectors, which accounts for nearly 75% of rural economic activity.

[8]*These numbers are different to those presented in Section 4.2 because these include the assumption in Section 5 and an estimated growth rate in the number of enterprises over the next 10 years.*

Figure 7: Market Opportunity by 2030 of $651.2 billion, broken down by PUE type



Source: DNA Economics Analysis

The capital required to meet the PUE equipment and appliance market opportunity in rural SSA is relatively large. Given the high cost of PUE equipment and appliance, the financial support would need to be patient capital.

References

Booth, S., Li, X., Baring-Gould, I., Kollanyi, D., Bharadwaj, A., & Weston, P. (2018). *Productive use of Energy in African micro-grids: Technical and Business Considerations*. Energy 4 Impact in USAID-NREL Partnership. Retrieved from https://energy4impact.org/productive-use-energy-african-micro-grids-technical-and-business-considerations-0

Chirambo, D. (2018). Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030. *Renewable and Sustainable Energy Reviews*(94), 600-608. Retrieved from https://www.aler-renovaveis.org/contents/lerpublication/dumisani-chirambo_2018_towards-the-achievement-of-sdg-7-in-sub-saharan-africa-creating.pdf

Fjose, S., Grünfeld, L. A., & Green, C. S. (2010). *Identifying SME roles and obstacles to SME growth*. MENON-publication. Retrieved from https://www.norfund.no/archive/Bilder/Publications/SME%20and%20growth%20MENON%20.pdf

Fox, L. (2020). *Informal household enterprises in sub-Saharan Africa – livelihoods for rural transformation*. RURAL21 The International Journal for Rural Development. Retrieved from https://www.rural21.com/english/current-issue/detail/article/informal-household-enterprises-in-sub-saharan-africa-livelihoods-for-rural-transformation.html?no_cache=1

Global, L. (2019). *The Market Opportunity for Productive*. World Bank Group.

Goedde, L., Ooko-Ombaka, A., & Pais, G. (2019). *Winning in Africa's agricultural market*. McKinsey. Retrieved from https://www.mckinsey.com/industries/agriculture/our-insights/winning-in-africas-agricultural-market

Hilso, G. (2016). *Artisanal and small-scale mining and agriculure: Exploring their links in rural sub-Saharan Africa*. International Institute for Environment and Development. Retrieved from https://pubs.iied.org/sites/default/files/pdfs/migrate/16617IIED.pdf

Hilson, G. (2016). *Farming, small-scale mining and rural livelihoods in Sub-Saharan Africa: A critical overview*. The Extractive Industries and Society, 3(2), 547-563.

IFAD. (n.d.). *The field report*. Retrieved from IFAD: https://www.ifad.org/thefieldreport/

IFC. (2013). *Closing the Credit Gap for Formal and Informal Micro, Small and Medium Enterprises*. IFC. Retrieved from https://documents1.worldbank.org/curated/en/804871468140039172/pdf/949110WP0Box380p0Report0FinalLatest.pdf

IFC. (2017). *MSME FINANCE GAP: ASSESSMENT OF THE SHORTFALLS AND OPPORTUNITIES IN FINANCING MICRO, SMALL AND MEDIUM ENTERPRISES IN EMERGING MARKETS*. IFC. Retrieved from https://documents1.worldbank.org/curated/en/653831510568517947/pdf/121264-WP-PUBLIC-MSMEReportFINAL.pdf

ILO. (2015). *Transition from the Informal to the Formal Economy Recommendation*, 2019 (no. 2014). Geneva: ILO. Retrieved from https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---actrav/documents/publication/wcms_545928.pdf

Lighting Global. (2019). *The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa*. Washington, D.C.: International Finance Corporation. Retrieved from http://www.fao.org/in-action/kore/publications/publications-details/en/c/1247224/

Mayer-Trasch, L., Mukherjee, M., & Reiche, K. (2013). *Measuring Impacts of Electrification on Small and Micro-Enterprises*. Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Retrieved from http://www.produse.org/?lang=eng&page=5

McPherson, M. A. (1991). *Micro and Small Scale Enterprises in Zimbabwe: Results of a Country-Wide Survey.* USAID.

Nagler, P., & Naudé, W. (2017). Non-farm entrepreneurship in rural sub-Saharan Africa: New empirical evidence. *Food policy,* 67, 175-191. Retrieved from https://www.sciencedirect.com/science/article/pii/S0306919216303876

NEPAD. (n.d.). *Agriculture in Africa: Transformation and outlook*. NEPAD. Retrieved from https://www.nepad.org/caadp/publication/agriculture-africa-transformation-and-outlook

Population Reference Bureau. (n.d., July 13). *Average household size*. Retrieved from PRB: https://www.prb.org/international/indicator/hh-size-av/map/country

Rapsomanikis, G. (2015). *The economic lives of smallholder farmers*. Rome: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/3/i5251e/i5251e.pdf

SE4All. (2015). *Scaling Up Finance for Sustainabel Energy Investments: Report of the SE4All.* Sustainable Energy for All, Bank of America Merrill Lynch, BNDES and the World Bank. Retrieved from https://www.seforall.org/sites/default/files/l/2015/09/SE4All-Advisory-Board-Finance-Committee-Report.pdf

SME Finance Forum. (2019). *MSME Economic Indicators.* SME Finance Forum. Retrieved from https://www.smefinanceforum.org/data-sites/msme-country-indicators

Wiggins, S., & Keats, S. (2013). *Leaping and Learning: Linking smallholders to markets in Africa*. London: Agriculture for Impact, Imperial College and Overseas Development Institute. Retrieved from https://cdn.odi.org/media/documents/8401.pdf

World Bank. (2021). *World Development Indicators.* World Bank. Retrieved from https://databank.worldbank.org/source/world-development-indicators#

Annexure 1: MSME Model extrapolated countries

Country	Matching country, finance	Matching country, sector
Angola	South Africa	Ghana
Benin	Nigeria	Zambia
Botswana	Ghana	South Africa
Burkina Faso	Kenya	Ethiopia
Burundi	Kenya	Kenya
Cameroon	Ghana	Ghana
Central African Republic	Nigeria	Zambia
Chad	Ethiopia	Kenya
Comoros	Kenya	Kenya
Equatorial Guinea	South Africa	Ghana
Eritrea	Ethiopia	Kenya
Eswatini	Kenya	Ethiopia
Ethiopia	Ethiopia	Ethiopia
Ghana	Ghana	Ghana
Guinea	Kenya	Kenya
Guinea-Bissau	Zambia	Zambia
Kenya	Kenya	Kenya
Lesotho	Kenya	Kenya
Liberia	Nigeria	Zambia
Madagascar	Zambia	Zambia
Malawi	Kenya	Kenya
Mali	Nigeria	Zambia
Mauritania	Ghana	Ghana
Mauritius	Nigeria	Mauritius
Mozambique	Ethiopia	Kenya
Namibia	Zambia	Mauritius
Niger	Kenya	Kenya
Nigeria	Nigeria	Nigeria
Rwanda	Kenya	Kenya
Senegal	Zambia	Zambia
Sierra Leone	Zambia	Mauritius
Somalia	Zambia	Zambia
South Africa	South Africa	South Africa
South Sudan	Ethiopia	Kenya
Togo	Nigeria	Zambia
Uganda	Kenya	Kenya
Zambia	Zambia	Zambia
Zimbabwe	Ethiopia	Kenya
Cabo Verde	Ghana	Ghana
Congo, Dem. Rep.	Zambia	Zambia
Congo, Rep.	South Africa	Ghana

Annexure 1: MSME Model extrapolated countries

Country	Matching country, finance	Matching country, sector
Cote d'Ivoire	Zambia	Zambia
Gabon	South Africa	Ghana
Gambia, The	South Africa	Ghana
Seychelles	Ghana	South Africa
Tanzania	Ethiopia	Kenya
Djibouti	Ghana	South Africa
Saint Helena	Kenya	Ethiopia

Annexure 2: Enterprise sectoral distribution for rural SSA

Sector	Sub-Sector	Industry	Enterprise	Non-landlocked	Landlocked
Primary	Agriculture	Livestock farming	Beef and buffalo meat	1.70%	1.30%
Primary	Agriculture	Crop farming	Cereals, total	15.80%	12.90%
Primary	Agriculture	Livestock farming	Eggs, primary	0.50%	0.10%
Primary	Agriculture	Fishing	Fish, seafood	2.00%	0.30%
Primary	Agriculture	Crop farming	Fruit, primary	10.20%	7.20%
Primary	Agriculture	Livestock farming	Meat, poultry	0.60%	0.30%
Primary	Agriculture	Crop farming	Oil crops	7.20%	5.40%
Primary	Agriculture	Crop farming	Pulses, total	2.00%	2.50%
Primary	Agriculture	Crop farming	Roots and tubers, total	24.60%	15.20%
Primary	Agriculture	Livestock farming	Sheep and goat meat	1.00%	1.00%
Primary	Agriculture	Crop farming	Sugar crops, primary	7.20%	12.60%
Secondary	Mining and quarrying	Mining	Artisanal small-scale mining	1.20%	1.50%
Secondary	Electricity, gas and water supply	Electricity, gas and water supply	Water treatment facility	0.10%	0.10%
Secondary	Electricity, gas and water supply	Electricity, gas and water supply	Water collection and supply	0.10%	0.10%
Secondary	Construction	Construction	Bricklaying	1.40%	2.10%
Secondary	Manufacturing	Food products	Abattoir	0.10%	0.20%
Secondary	Manufacturing	Food products	Cereal milling	0.30%	0.50%
Secondary	Manufacturing	Food products	Bread, biscuits and cake baking	0.10%	0.10%
Secondary	Manufacturing	Food products	Oil pressing	0.10%	0.20%
Secondary	Manufacturing	Food products	Fish processing – filleting, packaging and canning	0.10%	0.20%
Secondary	Manufacturing	Food products	Milk processing – chilling	0.00%	0.00%
Secondary	Manufacturing	Food products	Milk processing – bulking, quality control and packaging	0.00%	0.00%
Secondary	Manufacturing	Beverages	Beer brewing	2.20%	3.40%
Secondary	Manufacturing	Clothing, textiles and apparel	Dressmaking	0.40%	0.60%
Secondary	Manufacturing	Clothing, textiles and apparel	Tailoring (incl sewing machines)	0.80%	1.30%
Secondary	Manufacturing	Clothing, textiles and apparel	Knitting	2.30%	3.40%

Annexure 2: Enterprise sectoral distribution for rural SSA

Sector	Sub-Sector	Industry	Enterprise	Non-landlocked	Landlocked
Secondary	Manufacturing	Clothing, textiles and apparel	Tailoring (incl sewing machines)	0.8%	1.3%
Secondary	Manufacturing	Clothing, textiles and apparel	Knitting	2.3%	3.4%
Secondary	Manufacturing	Clothing, textiles and apparel	Weaving	0.2%	0.2%
Secondary	Manufacturing	Clothing, textiles and apparel	Crocheting	0.2%	0.2%
Secondary	Manufacturing	Clothing, textiles and apparel	Shoe work and repairs	0.3%	0.4%
Secondary	Manufacturing	Leather and related products	Leather work	0.4%	0.6%
Secondary	Manufacturing	Wood and wood products	Grass, cane and bamboo processing	5.1%	7.8%
Secondary	Manufacturing	Wood and wood products	Coal and wood production	0.1%	0.2%
Secondary	Manufacturing	Wood and wood products	Wood carving	1.3%	1.9%
Secondary	Manufacturing	Wood and wood products	Carpentry	0.7%	1.1%
Secondary	Manufacturing	Furniture	Furniture making	0.1%	0.1%
Secondary	Manufacturing	Chemical and chemical products	Chemical production	0.0%	0.0%
Secondary	Manufacturing	Non-metallic mineral products	Pottery work	0.7%	1.0%
Secondary	Manufacturing	Non-metallic mineral products	Brick making	0.8%	1.2%
Secondary	Manufacturing	Fabricated metal products	Welding (incl tin smithing and metal workshop)	0.4%	0.6%
Secondary	Manufacturing	Artistry	Art or artefact production	0.1%	0.2%
Secondary	Manufacturing	Repair and installation of machinery and equipment	Auto repair	0.1%	0.1%
Secondary	Manufacturing	Repair and installation of machinery and equipment	Electrical repair	0.0%	0.0%
Secondary	Manufacturing	Repair and installation of machinery and equipment	Radio/TV repair	0.0%	0.0%

Annexure 2: Enterprise sectoral distribution for rural SSA

Sector	Sub-Sector	Industry	Enterprise	Non-landlocked	Landlocked
Secondary	Manufacturing	Repair and installation of machinery and equipment	Phone repair	0.0%	0.0%
Tertiary	Trade	Wholesale and retail trade and repair of motor vehicles and motorcycles, incl. rental	Retailers of farming machinery and equipment e.g. tractors	2.0%	3.1%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Wholesaler	0.0%	0.0%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Grocery – retail shop	0.5%	0.7%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Retailer of farm products, inputs and implements	0.00%	0.00%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Retail kiosk	0.5%	0.8%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Retailer of farm products, inputs and implements	0.0%	0.0%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Butchery	0.0%	0.0%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Stationers/ bookstore	0.0%	0.0%
Tertiary	Trade	Wholesale trade, except of motor vehicles and motorcycles	Retail hardware	0.0%	0.0%
Tertiary	Trade	Accommodation and catering services	Food catering	0.0%	0.1%

Annexure 2: Enterprise sectoral distribution for rural SSA

Sector	Sub-Sector	Industry	Enterprise	Non-landlocked	Landlocked
Tertiary	Trade	Accommodation and catering services	Popcorn	0.0%	0.0%
Tertiary	Trade	Accommodation and catering services	Restaurant	0.1%	0.1%
Tertiary	Trade	Accommodation and catering services	Bar/pub/shebeen or bottle store	0.4%	0.4%
Tertiary	Trade	Community, social and other services and activities	Traditional healer	0.2%	0.3%
Tertiary	Trade	Community, social and other services and activities	Clinic	0.2%	0.3%
Tertiary	Trade	Community, social and other services and activities	Hair salon or barber	0.1%	0.1%
Tertiary	Trade	Warehousing and support activities for transportation	Distributors and agents for farming produce	0.6%	0.9%
Tertiary	Trade	Community, social and other services and activities	Ironing	0.0%	0.0%
Tertiary	Trade	Warehousing and support activities for transportation	Cold storage unit	0.4%	0.3%
Tertiary	Trade	Community, social and other services and activities	Cyber cafe	0.4%	0.6%
Tertiary	Trade	Community, social and other services and activities	Phone charging and mobile money points	0.4%	0.6%
Tertiary	Trade	Community, social and other services and activities	Entertainment hall and video show	0.1%	0.2%
Tertiary	Trade	Community, social and other services and activities	Photo and printing shop	0.1%	0.1%
Tertiary	Trade	Transportation	Transport services – motorbikes	0.1%	0.1%
Tertiary	Trade	Transportation	Transport services – tuk-tuks	0.1%	0.2%
Other	Other	Other	Other	1.3%	2.6%

Annexure 3: The unit cost of energy systems required to power PUE equipment and appliances, by type

Equipment	Comment on energy requirement	Median Power Rating (watts)	Energy System Power (kWp)	Energy system cost (USD)
Air conditioner	Requires PV system	1 130	1.582	2 057
Blow dryer	Requires PV system	1 900	2.660	3 458
Brooder	Requires PV system	360	0.504	655
Chaff cutter	Requires PV system	2 200	3.080	4 004
Computer	Requires PV system	100	0.140	182
Decoder	Requires PV system	9	0.013	16
Solar dryer	PUE retail price already includes a PV system	-	-	-
Egg incubator	Requires PV system	80	0.112	146
Electric drill	Requires PV system	550	0.770	1 001
Electric fan	Requires PV system	55	0.077	100
Electric grinder	Requires PV system	650	0.910	1 183
Electric planning tool	Requires PV system	650	0.910	1 183
Cold chain storage solution	Requires PV system	540	0.756	983
Fridge	Requires PV system	100	0.140	182
Solar fish dryer	PUE retail price already includes a PV system	-	-	
Grinding machine	Requires PV system	4 000	5.600	7 280
Hair clippers	Requires PV system	11	0.015	20
Hair dryer	Requires PV system	1 000	1.400	1 820
Hair straightener	Requires PV system	100	0.140	182
Huller – cereal	Requires PV system	2 200	3.080	4 004
Huller – rice	Requires PV system	2 200	3.080	4 004
Iron	Requires PV system	1 000	1.400	1 820
Milling/ grinding machine	Requires PV system	4 000	5.600	7 280
Oil press	Requires PV system	810	1.134	1 474
Oven	Requires PV system	1 920	2.688	3 494
Phone charger	Requires PV system	7	0.010	13
Phone repair machine	Requires PV system	850	1.190	1 547
Popcorn maker	Requires PV system	800	1.120	1 456
Power saw	Requires PV system	1 200	1.680	2 184
Printer	Requires PV system	50	0.070	91

Annexure 3: The unit cost of energy systems required to power PUE equipment and appliance, by type

Equipment	Comment on energy requirement	Median Power Rating (watts)	Energy System Power (kWp)	Energy system cost (USD)
Projector	Requires PV system	50	0.070	91
Radio	Requires PV system	50	0.070	91
Satellite dish	Requires PV system	20	0.028	36
Security lights	Requires PV system	20	0.028	36
Sewing machine	Requires PV system	30	0.042	55
Soldering machine	Requires PV system	48	0.067	87
Speaker	Requires PV system	80	0.112	146
Thresher	Requires PV system	2 200	3.080	4 004
TV	Requires PV system	70	0.098	127
Water heater	Requires PV system	1 500	2.100	2 730
Water pump	Requires PV system	370	0.518	673
Water purifier	Requires PV system	500	0.700	910
Welding machine	Requires PV system	250	0.350	455
UV Lamp	Requires PV system	300	0.420	546
Fishing boat motor	Large-scale PV system: Not to be priced			
Motorbike motor and battery	Large-scale PV system: Not to be priced			
Tuk-tuk motor and battery	Large-scale PV system: Not to be priced			

Annexure 4A: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – upper limit

Equipment	Energy System Power (kWp)	Energy system cost (USD)	Energy costs, Upper limit	Energy costs, Lower limit
Air conditioner	1 445 465	822 339 387	2 972 742 936	3 795 082 323
Blow dryer	433 639	11 274 626	1 499 525 198	1 510 799 823
Brooder	1 950 471	1 025 655 345	1 277 948 810	2 303 604 155
Chaff cutter	24 033 904	10 369 908 649	96 231 752 448	106 601 661 097
Computer	4 264 121	1 508 987 211	776 070 059	2 285 057 269
Decoder	1 084 099	57 457 226	17 757 535	75 214 762
Solar dryer	77 202 011	169 844 424 405	-	169 844 424 405
Egg incubator	1 950 471	2 300 483 401	283 988 624	2 584 472 025
Electric drill	7 805 510	236 038 622	7 813 315 504	8 049 354 127
Electric fan	10 913 259	246 748 794	1 092 417 260	1 339 166 054
Electric grinder	1 084 099	35 927 028	1 282 488 656	1 318 415 684
Electric planning tool	5 926 406	463 089 344	7 010 937 986	7 474 027 331
Cold chain storage solution	44 902 069	98 560 040 603	44 129 753 032	142 689 793 635
Fridge	9 118 404	3 994 590 582	1 659 549 594	5 654 140 176
Solar fish dryer	3 736 104	11 072 391 905	-	11 072 391 905
Grinding machine	1 084 099	639 314 632	7 892 237 883	8 531 552 516
Hair clippers	650 459	38 357 577	13 022 193	51 379 770
Hair dryer	216 820	23 850 169	394 611 894	418 462 064
Hair straightener	216 820	12 785 859	39 461 189	52 247 048
Huller – cereal	867 279	2 601 836 665	3 472 584 669	6 074 421 333
Huller – rice	867 279	1 452 692 138	3 472 584 669	4 925 276 807
Iron	3 541 389	119 840 597	6 445 327 605	6 565 168 201
Milling/grinding machine	38 024 238	67 271 341 730	276 816 455 060	344 087 796 790
Oil press	16 751 500	36 853 299 684	24 695 061 088	61 548 360 772
Oven	144 546	252 811 796	505 103 225	757 915 020
Phone charger	4 842 307	98 395 681	61 690 993	160 086 674
Phone repair machine	72 273	25 572 441	111 806 703	137 379 144
Popcorn maker	144 546	25 573 163	210 459 677	236 032 840
Power saw	6 360 045	11 252 001 132	13 890 338 675	25 142 339 807
Printer	2 095 924	494 407 508	190 729 082	685 136 590
Projector	722 732	98 219 334	65 768 649	163 987 983
Radio	1 084 099	63 929 295	98 652 974	162 582 269
Satellite dish	867 279	20 034 142	31 568 952	51 603 094
Security lights	2 746 383	93 294 635	99 968 347	193 262 982

Annexure 4A: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – upper limit

Equipment	Energy System Power (kWp)	Energy system cost (USD)	Energy costs, Upper limit	Energy costs, Lower limit
Sewing machine	5 420 493	3 196 627 367	295 958 921	3 492 586 288
Soldering machine	144 546	22 549 251	12 627 581	35 176 832
Speaker	3 961 977	1 074 488 258	576 863 902	1 651 352 160
Thresher	867 279	433 639 444	3 472 584 669	3 906 224 113
TV	5 893 614	936 436 339	750 846 432	1 687 282 771
Water heater	72 273	10 941 446	197 305 947	208 247 393
Water pump	127 237 081	210 096 922 182	17 136 290 097	227 233 212 279
Water purifier	6 793 685	8 394 004 975	1 236 450 602	9 630 455 577
Welding machine	1 300 918	149 384 452	591 917 841	741 302 293
UV Lamp	174 529	102 925 137	95 292 973	198 218 109
Fishing boat motor	3 736 104	14 944 415 148	-	14 944 415 148
Motorbike motor and battery	218 848	218 847 870	-	218 847 870
Tuk-tuk motor and battery	364 746	729 492 899	-	729 492 899
TOTAL		**662 297 590 074**	**528 921 820 131**	**1 191 219 410 205**

Annexure 4B: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – lower limit

Equipment	No. of equipment	Market opportunity	Energy costs	Total investment
Air conditioner	783 510	445 746 817	1 611 367 183	2 057 114 000
Blow dryer	235 053	6 111 380	812 813 535	818 924 915
Brooder	1 088 117	572 186 122	712 934 006	1 285 120 127
Chaff cutter	12 993 564	5 606 333 137	52 026 230 982	57 632 564 119
Computer	2 311 355	817 942 393	420 666 654	1 238 609 047
Decoder	587 633	31 144 532	9 625 423	40 769 956
Solar dryer	42 753 188	25 340 840 889	-	25 340 840 889
Egg incubator	1 088 117	1 283 379 141	158 429 779	1 441 808 920
Electric drill	4 230 955	127 944 090	4 235 186 312	4 363 130 402
Electric fan	5 915 502	133 749 509	592 141 790	725 891 299
Electric grinder	587 633	19 474 147	695 169 470	714 643 618
Electric planning tool	3 212 392	251 016 313	3 800 259 771	4 051 276 085
Cold chain storage solution	24 728 648	54 279 382 120	24 303 315 147	78 582 697 267
Fridge	4 981 415	2 182 258 327	906 617 548	3 088 875 875
Solar fish dryer	2 105 926	6 241 164 836	-	6 241 164 836
Grinding machine	587 633	346 538 749	4 277 965 972	4 624 504 721
Hair clippers	352 580	20 791 620	7 058 644	27 850 264
Hair dryer	117 527	12 927 919	213 898 299	226 826 218
Hair straightener	117 527	6 930 540	21 389 830	28 320 370
Huller – cereal	470 106	1 410 318 452	1 882 305 027	3 292 623 480
Huller – rice	470 106	787 427 802	1 882 305 027	2 669 732 830
Iron	1 919 600	64 959 268	3 493 672 210	3 558 631 478
Milling/grinding machine	20 946 458	37 057 845 903	152 490 217 545	189 548 063 448
Oil press	9 244 706	20 338 352 286	13 628 544 972	33 966 897 258
Oven	78 351	137 035 943	273 789 822	410 825 765
Phone charger	2 624 759	53 335 110	33 439 434	86 774 544
Phone repair machine	39 176	13 861 472	60 604 518	74 465 990
Popcorn maker	78 351	13 861 863	114 079 093	127 940 956
Power saw	3 447 445	6 099 116 457	7 529 220 110	13 628 336 567
Printer	1 136 090	267 992 238	103 384 178	371 376 416
Projector	391 755	53 239 522	35 649 716	88 889 238
Radio	587 633	34 652 700	53 474 575	88 127 274
Satellite dish	470 106	10 859 452	17 111 864	27 971 316
Security lights	1 488 669	50 570 102	54 187 569	104 757 671
Sewing machine	2 938 163	1 732 723 127	160 423 724	1 893 146 851

Annexure 4B: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – lower limit

Equipment	Energy System Power (kWp)	Energy costs, Upper limit	Energy costs, Lower limit	
Soldering machine	78 351	12 222 760	6 844 746	19 067 505
Speaker	2 170 864	588 738 414	316 077 850	904 816 264
Thresher	470 106	235 053 075	1 882 305 027	2 117 358 103
TV	3 210 141	510 059 299	408 971 960	919 031 258
Water heater	39 176	5 930 781	106 949 149	112 879 930
Water pump	70 258 272	116 012 144 319	9 462 384 024	125 474 528 342
Water purifier	3 682 498	4 549 947 452	670 214 669	5 220 162 121
Welding machine	705 159	80 973 434	320 847 448	401 820 882
UV Lamp	95 156	56 116 183	51 955 024	108 071 207
Fishing boat motor	2 105 926	8 423 704 571	-	8 423 704 571
Motorbike motor and battery	118 677	118 676 862	-	118 676 862
Tuk-tuk motor and battery	197 795	395 589 540	-	395 589 540
TOTAL		**296 841 170 966**	**289 844 029 624**	**586 685 200 591**

Annexure 5A: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – upper limit, excluding SA

Equipment	No. of equipment	Market opportunity	Energy costs	Total investment
Air conditioner	1 414 711	804 843 322	2 909 494 957	3 714 338 279
Blow dryer	424 413	11 034 747	1 467 621 350	1 478 656 097
Brooder	1 892 297	995 064 503	1 239 833 151	2 234 897 654
Chaff cutter	23 540 899	10 157 191 639	94 257 759 106	104 414 950 745
Computer	4 173 398	1 476 882 049	759 558 418	2 236 440 467
Decoder	1 061 033	56 234 768	17 379 727	73 614 495
Solar dryer	75 070 001	165 154 002 180	-	165 154 002 180
Egg incubator	1 892 297	2 231 869 979	275 518 478	2 507 388 457
Electric drill	7 639 440	231 016 672	7 647 079 666	7 878 096 338
Electric fan	10 681 069	241 498 975	1 069 175 027	1 310 674 002
Electric grinder	1 061 033	35 162 646	1 255 202 470	1 290 365 116
Electric planning tool	5 800 316	453 236 671	6 861 773 505	7 315 010 176
Cold chain storage solution	43 736 263	96 001 097 439	42 983 999 345	138 985 096 784
Fridge	8 903 436	3 900 417 362	1 620 425 401	5 520 842 763
Solar fish dryer	3 612 975	10 707 485 532	-	10 707 485 532
Grinding machine	1 061 033	625 712 596	7 724 322 895	8 350 035 490
Hair clippers	636 620	37 541 483	12 745 133	50 286 615
Hair dryer	212 207	23 342 734	386 216 145	409 558 879
Hair straightener	212 207	12 513 828	38 621 614	51 135 442
Huller – cereal	848 827	2 546 480 075	3 398 702 074	5 945 182 149
Huller – rice	848 827	1 421 784 709	3 398 702 074	4 820 486 782
Iron	3 466 042	117 290 872	6 308 197 031	6 425 487 903
Milling/grinding machine	37 033 980	65 519 407 030	269 607 377 005	335 126 784 035
Oil press	16 306 175	35 873 585 926	24 038 563 806	59 912 149 732
Oven	141 471	247 432 981	494 356 665	741 789 646
Phone charger	4 739 282	96 302 218	60 378 457	156 680 675
Phone repair machine	70 736	25 028 362	109 427 908	134 456 270
Popcorn maker	141 471	25 029 070	205 981 944	231 011 014
Power saw	6 224 729	11 012 603 933	13 594 808 295	24 607 412 228
Printer	2 051 331	483 888 510	186 671 137	670 559 647
Projector	707 356	96 129 623	64 369 357	160 498 980
Radio	1 061 033	62 569 138	96 554 036	159 123 174
Satellite dish	848 827	19 607 897	30 897 292	50 505 188
Satellite dish	848 827	468 155	19 607 897	10 814 377

Annexure 5A: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – upper limit, excluding SA

Equipment	No. of equipment	Market opportunity	Energy costs	Total investment
Security lights	2 687 951	91 309 702	97 841 423	189 151 125
Sewing machine	5 305 167	3 128 616 031	289 662 109	3 418 278 139
Soldering machine	141 471	22 069 494	12 358 917	34 428 411
Speaker	3 865 103	1 048 216 020	562 759 043	1 610 975 063
Thresher	848 827	424 413 346	3 398 702 074	3 823 115 420
TV	5 759 836	915 180 285	733 803 061	1 648 983 345
Water heater	70 736	10 708 656	193 108 072	203 816 728
Water pump	123 833 240	204 476 418 092	16 677 860 780	221 154 278 872
Water purifier	6 649 142	8 215 414 407	1 210 143 920	9 425 558 327
Welding machine	1 273 240	146 206 154	579 324 217	725 530 371
UV Lamp	170 517	100 559 252	93 102 524	193 661 775
Fishing boat motor	3 612 975	14 451 900 759	-	14 451 900 759
Motorbike motor and battery	214 164	214 164 133	-	214 164 133
Tuk-tuk motor and battery	356 940	713 880 445	-	713 880 445
TOTAL		**644 662 346 241**	**515 970 379 607**	**1 160 632 725 848**

Annexure 5B: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – lower limit, excluding SA

Equipment	No. of equipment	Market opportunity	Energy costs	Total investment
Air conditioner	780 258	443 896 605	1 604 678 699	2 048 575 304
Blow dryer	234 077	6 086 013	809 439 698	815 525 710
Brooder	1 081 965	568 951 135	708 903 269	1 277 854 404
Chaff cutter	12 941 429	5 583 838 280	51 817 480 872	57 401 319 151
Computer	2 301 761	814 547 267	418 920 545	1 233 467 812
Decoder	585 194	31 015 257	9 585 470	40 600 727
Solar dryer	42 527 728	25 207 205 094	-	25 207 205 094
Egg incubator	1 081 965	1 276 123 260	157 534 060	1 433 657 320
Electric drill	4 213 393	127 413 018	4 217 606 845	4 345 019 863
Electric fan	5 890 948	133 194 340	589 683 920	722 878 260
Electric grinder	585 194	19 393 314	692 283 952	711 677 266
Electric planning tool	3 199 058	249 974 391	3 784 485 604	4 034 459 995
Cold chain storage solution	24 605 364	54 008 773 473	24 182 151 512	78 190 924 985
Fridge	4 958 682	2 172 299 494	902 480 159	3 074 779 652
Solar fish dryer	2 092 905	6 202 575 928	-	6 202 575 928
Grinding machine	585 194	345 100 331	4 260 208 935	4 605 309 266
Hair clippers	351 116	20 705 318	7 029 345	27 734 662
Hair dryer	117 039	12 874 258	213 010 447	225 884 705
Hair straightener	117 039	6 901 773	21 301 045	28 202 817
Huller – cereal	468 155	1 404 464 484	1 874 491 931	3 278 956 415
Huller – rice	468 155	784 159 337	1 874 491 931	2 658 651 268
Iron	1 911 632	64 689 634	3 479 170 630	3 543 860 264
Milling/grinding machine	20 841 739	36 872 578 529	151 727 856 393	188 600 434 922
Oil press	9 197 612	20 234 747 400	13 559 120 280	33 793 867 680
Oven	78 026	136 467 132	272 653 372	409 120 504
Phone charger	2 613 864	53 113 726	33 300 633	86 414 359
Phone repair machine	39 013	13 803 935	60 352 960	74 156 895
Popcorn maker	78 026	13 804 325	113 605 572	127 409 897
Power saw	3 433 135	6 073 800 165	7 497 967 725	13 571 767 890
Printer	1 131 374	266 879 852	102 955 049	369 834 902
Projector	390 129	53 018 534	35 501 741	88 520 275
Radio	585 194	34 508 863	53 252 612	87 761 474
Satellite dish	468 155	10 814 377	17 040 836	27 855 212
Security lights	1 482 490	50 360 195	53 962 647	104 322 842
Sewing machine	2 925 968	1 725 530 917	159 757 835	1 885 288 752
Soldering machine	78 026	12 172 026	6 816 334	18 988 360

Annexure 5B: The investment requirement for acquiring and powering PUE equipment and appliances over the next 10 years – lower limit, excluding SA

Equipment	No. of equipment	Market opportunity	Energy costs	Total investment
Speaker	2 160 620	585 960 120	314 586 259	900 546 380
Thresher	468 155	234 077 414	1 874 491 931	2 108 569 345
TV	3 195 994	507 811 468	407 169 620	914 981 088
Water heater	39 013	5 906 163	106 505 223	112 411 387
Water pump	69 898 315	115 417 775 116	9 413 905 050	124 831 680 167
Water purifier	3 667 213	4 531 061 471	667 432 733	5 198 494 204
Welding machine	702 232	80 637 328	319 515 670	400 152 998
UV Lamp	94 731	55 865 991	51 723 383	107 589 374
Fishing boat motor	2 092 905	8 371 621 096	-	8 371 621 096
Motorbike motor and battery	118 182	118 181 556	-	118 181 556
Tuk-tuk motor and battery	196 969	393 938 521	-	393 938 521
TOTAL		**295 338 618 226**	**288 474 412 727**	**583 813 030 952**

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