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ENERGICA

ENERGY ACCESS AND GREEN TRANSITION COLLABORATIVELY DEMONSTRATED IN URBAN AND RURAL AREAS IN AFR**ICA**



D3.5. Capacity for local value chains and Circular Economy

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Nature of the Deliverable		
R	Document, report (excluding the periodic and final reports)	x
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patent filing, press & media actions, videos, etc.	
OTHER	Software, technical diagrams, etc.	

Dissemination Level		
PU	Public, fully open, e.g., web	x

CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information, as referred to in Commission Decision 2001/844/EC	

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I. PROJECT SUMMARY

The ENERGy access and green transition collaboratively demonstrated in urban and rural areas in AfrICA (ENERGICA) project is funded by the European Commission under the Horizon 2020 programme (H2020) and supported by the African Union. This project fosters the collaboration between partners from Europe (17) and Africa (11) in sustainable energy access and development in three demonstration sites in Africa.

The main objective of this project is to demonstrate the efficient implementation of renewable energy technologies (RETs) in three demonstration sites toward positive social, environmental, technical and economic impacts to meet the needs in the local contexts. Therefore, innovative technologies from high energy-efficiency and low carbon emission RETs are considered through a community-scale Integrated Community Energy Systems (ICESs) using a local Energy Transition Boards.

Specifically, the demonstration site of Madagascar will develop innovative nano grids in rural areas, Sierra Leone's demonstration will assess the low-tech efficient biogas production systems in peri-urban and urban areas; and the Kenya demonstration tailored solar-powered e-mobility solutions in urban areas.

II. OBJECTIVE AND EXECUTIVE SUMMARY

The ENERGICA project centres around three captivating demonstration sites, with unique energy challenges and great potential for producing and utilising green energy. This report consists of three separate parts namely Part A (Madagascar context), Part B (Sierra Leone context), and Part C (Kenya context). It makes up the deliverable 3.5 (D3.5) of the project ENERGICA funded by the EU Horizon 2020 under the grant agreement No. 101037428.

The deliverable describes the capacity for local value chains and circular economy model implementation and is developed by UAM, RISE and STIMA as part of task 3.3 of the Work Package 3 (WP3). It will also provide the results on local value chains and circular economy models' capacity at different scales up to ensure an enhanced uptake of environmentally compliant energy technologies in each context. The objective of the work package 3 is not only to develop capacity building programmes but also to ensure a sustainable ecosystem with reduced environmental impact and enhanced social impact for each demonstrator and the development of local value chains and circular economy models in these contexts.

This document outlines the techno economic feasibility of local value chain and circular economy in the three contexts. The report also identifies the implementation strategies and provides a business economy model for the three contexts. Therefore, the structure of the report is as followed: the report starts with a general introduction that gives the relevant background information to understand each context, then the first chapter (Part A) presents the Madagascar's demonstrator site which aims to create nano-grid solutions in the water-energy-food nexus. It provides vital support for clean energy access, rice farming, cooling and freezing systems for the fishing and local trading communities residing in the Diana Region. The second chapter (Part B) analyses the Sierra Leone context which tackles the challenges of biogas production and water purification systems in urban and peri-urban Freetown by implementing innovative waste recycling methods. The third chapter (Part C) indicates the Kenyan context which focuses on pioneering e-mobility solutions tailored specifically for the Boda-Boda sector (motorcycle taxis) in urban Nairobi, with plans for replication sites in the sub-urban areas of Kisumu City and Homa Bay counties. The batteries recycling and circular economy is investigated in the chapter. Finally, the report ends with a general conclusion that provides a summary of key findings and some recommendations for the implementation of the supply chain and circular economy model for each context.

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III. ACRONYMS

AC : Alternating Current

AD : Anaerobic Digestion

AfEMA : Association for Electric Mobility in Africa

BAK : Boda-Boda Safety Association of Kenya

BMZ : German Federal Ministry for Economic Cooperation and Development

BSC : Biogas Supply Chain

CBM : Circular Economy Model

CC : Carbon Credits

CE: Circular Economy

CEBM: Circular Economy Business Model

CEM: Circular Economy Model

CKD kits: Completely Knocked Down

CO_2: Carbon dioxide

DC: Direct Current

EAC: East African Community

EPRA: Energy and Petroleum Regulation Authority

EV: Electrical Vehicle

FWT: Freetown Waste Transformers

GHGS: Greenhouse Gas emissions

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit

ICES: integration of the community in the system through

IRENA: International Renewable Energy Agency

kg/h: kilograms per hour

kg/L: kilograms per liter

KPLC: Kenya Power and Lighting Company

kW: kilowatt

kWh/kg: kilowatt-hour per kilogram

LCOE: Levelized Cost of Electricity

m^3/h: cubic meter per hour

MSW: Municipal Solid Waste

MW: Megawatt

Nm^3/t: Normal cubic meter per ton

O&M costs: Operating and Maintenance costs

ODM: Original Design Manufacturer

PB: Payback Period

PREO: Powering Renewable Energy Opportunities

PV: Photovoltaic modules

NPV: Net Present Value

REEEP: Renewable Energy and Energy Efficiency Policy

RES: Renewable Energy Systems

RHA: *Rice Husk Ash*

SADC: Southern Africa Development Community

SL: Sierra Leone

TCO: Total Cost of Ownership

TUMI Transformative Urban Mobility Initiative

TWT: The Waste Transformer

USD: United States Dollar

WEF: Water-Energy-Food nexus

INTRODUCTION

The objective of this deliverable is to describe the capacity for local value chains and circular economy model implementation in each of the three contexts involved in the ENERGICA project.

The concept of a circular economy is gaining traction worldwide as a sustainable alternative to the traditional linear economic model of “take, make, dispose.” In a circular economy, resources are kept in use for as long as possible, extracting maximum value before recovering and regenerating products and materials at the end of their service life. The transition from linear to circular economy (CE) has urged researchers and policymakers to look at the materials end of life. This new paradigm could decrease pressure on ecosystems and resources by providing reclaimed building materials contained in post-consumer waste streams through recycling, repurposing and remanufacturing.

This report assesses the potential of local value chains in the three contexts and provides a relevant circular economy model (CEM) implementation to slow, close and narrow the material loop to sustain economic value chain as well as to decrease the effects on the environmental while delivering a strong local value chain in each of the three demonstration sites.

Therefore, three separate complementary sections are developed to analyse the potential of local value chain and circular economy for water-energy-food nexus in Madagascar context (Part A), biogas production and water purification in Sierra Leone context (Part B) and electrical mobility for Kenya context (Part C). Each section provides relevant information on the demonstration site, the local value chain and circular economy which emphasizes the reduction of material use through recycling, reusing, and repurposing waste. The methodology and the results are presented to demonstrate the techno economic feasibility of local value chain and circular economy in each of the three contexts.

ENERGICA

ENERGY ACCESS AND GREEN TRANSITION COLLABORATIVELY DEMONSTRATED IN URBAN AND RURAL AREAS IN AFR**ICA**



PART A, Capacity for local value chains and Circular Economy-Madagascar Context

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1.1. MADAGASCAR CONTEXT

1.1.1 Energy overview and concept of circular economy

Madagascar has one of the lowest electrification rates in the Southern Africa Development Community (SADC): 17% on average with many inequalities (more than 30% in urban areas and less than 5% in rural areas). In this sense, the development of nanogrid solutions supports Madagascar's 2015 Energy Policy targeting an acceleration of electrification rate through renewable energies to 54% by 2020, and 70% by 2030, which would be able to connect to the system 260,000 households annually. Moreover, grid solutions are not effective and affordable in Madagascar due to very low population density of 43.4 people/km^2. Despite its active Rural Electrification Agency promoting rural electrification and the government's policies advocating for protection against negative climate change shocks, the local energy supply remains (African Development Bank, 2019; UNDP, 2020).

At the moment, very inefficient and expensive Diesel-run micro rice-husking, polishing, and flour milling machineries are being used by the local population. The cold chain management for sea products is still an unsolved issue leading to a very low productivity of the artisanal fishing industry. Finally, the very low rate of access to clean water is a major source of health concerns throughout the region.

The concept of a circular economy is gaining traction worldwide as a sustainable alternative to the traditional linear economic model of "take, make, dispose." In a circular economy, resources are kept in use for as long as possible, extracting maximum value before recovering and regenerating products and materials at the end of their service life. This approach is particularly relevant for Madagascar, an island nation facing significant environmental and economic challenges.

In Madagascar, circular thinking can be applied to various sectors, including agriculture, waste management, and energy. Economically, adopting a circular economy can stimulate local industries and create jobs. By encouraging local manufacturing and maintenance of renewable energy systems (RES) and other technologies, Madagascar can reduce its dependence on imports and foster economic resilience. This shift can also attract investments and support from international organisations focused on sustainable development.

Circular thinking emphasises the reduction of material use through recycling, reusing, and repurposing waste. In Madagascar, agricultural by-products like rice husks and straws can be transformed into valuable resources, such as biomass fuel and compost. This not only minimises waste but also provides alternative income sources for local communities.

The social impact of a circular economy in Madagascar is profound. Improved access to clean energy and water can enhance living standards and health outcomes. Additionally, involving local communities in the development and maintenance of circular systems empowers them and fosters a sense of ownership and sustainability.

By embracing circular economy principles, Madagascar can address its environmental challenges, boost its economy, and improve the well-being of its people. This holistic approach ensures that resources are used efficiently and sustainably, paving the way for a resilient and prosperous future.

As the technologies need to be tailored to their specific contexts, the demonstrator started at the very beginning of specifications, technology design through co-creation processes with multiple stakeholders, commissioning, and operation of the solutions implementing local value chains, capacity building, and training programs to ensure impact through a quick and viable commercial take-up of the technological solution demonstrated. Here, possible goals and scope of techno economic feasibility have been discussed through consumption to waste generation reduction, use of co-products and improvement of the facilities.

1.1.2 Demonstration Site-Madagascar

The Madagascar demonstrator is part of the ENERGICA project, which aims to improve energy access and sustainability in various regions. In Madagascar, specifically the Diana region, the project focuses on addressing the low electrification rates and significant disparities between urban and rural areas.

The solutions developed for this region include:

- Solar nanogrids: These are already powering domestic and other non-productive users in over 150 villages.
- Agri-specific solutions: Development of small-sized electric rice huskers and adaptation of existing rice husking machines.
- Water-specific solutions: Water pumping, storage, and treatment devices.
- Cooling-specific solutions: Cooling devices for food and water refrigeration.

The Madagascar demonstrator focuses on delivering sustainable and affordable electricity to rural areas. This effort involves developing and constructing solar nano-grids in 120 rural villages, which will provide clean energy to over 45,000 households and businesses. Currently about 12,000 households are electrified though the solar nano-grids. The project aims to enhance living standards by powering homes, schools, health centres, and public spaces.

Nanogrids are a crucial component of this initiative, incorporating solar power plants and energy storage systems to ensure a reliable 24/7 power supply. These nanogrids can also trade surplus energy with one another through a local electricity market, optimizing energy use and reducing costs.

Additionally, the project emphasizes strengthening the local value chain by promoting local manufacturing and services. This approach encourages the production of components and maintenance services within the community, creating jobs and stimulating the local economy. For the moment, Nanoe has trained more than 200 local entrepreneurs to operate the nano-grids. The use of electricity to power agricultural machinery and other local industries further boosts productivity and economic growth.
Overall, these integrated efforts are designed to create a sustainable and resilient energy system that benefits the entire community in Madagascar.

1.2. METHODOLOGY

1.2.1. Goal and scope

In WP7 a thorough techno-economic assessment will be made of the demonstrations. The work done in this task can be seen as a complement to widen and improve the value chains of the demonstration cases.

In this task the techno-economic feasibility was studied to identify the potential for improving Water-Energy-Food (WEF) nexus in the short term and in the wider region as a part of upscaling strategies. In particular, the focus was on:

- Material consumption reduction
- Use of co-products
- Improved/better utilization of the facilities
- Waste generation reduction

An evaluation of the effect on techno-economic improvements in the above points will be made.

1.2.2. Definition of the local value chain

For the Madagascar context, the local value chains of the demonstration site are related to the WEF nexus whereby three co-products solutions are adopted namely the NanoHusk, the NanoCold and the NanoWater (See figure 1.3 below). Details description of the value and circular economy for each co-product is given the results sections.

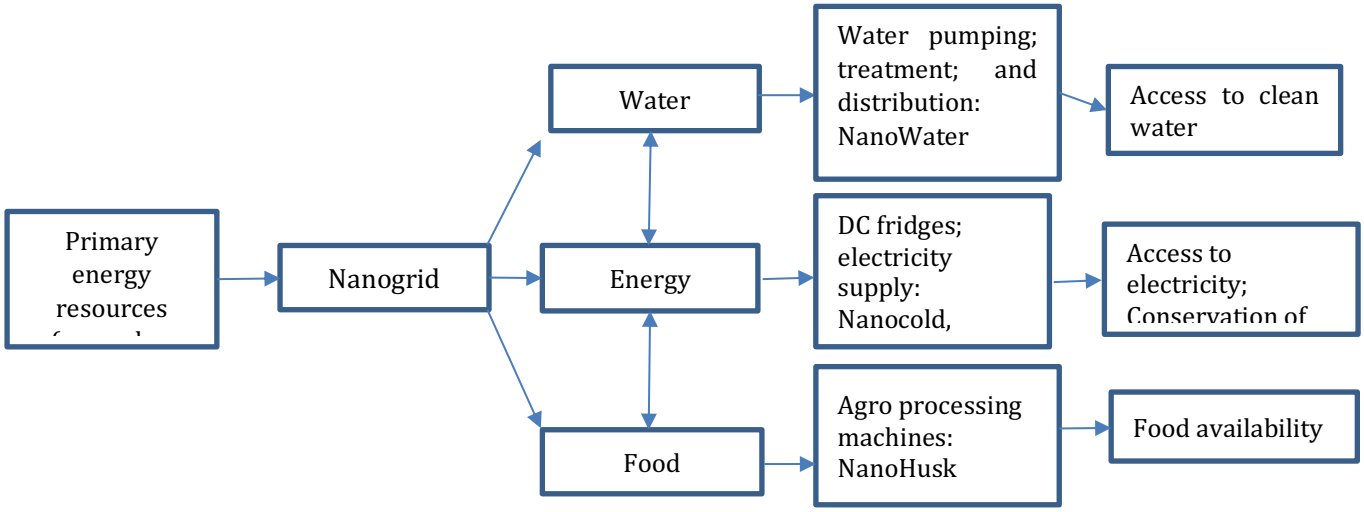


Figure 1. 1: *Local value chain for the Madagascar context*

1.2.3. Methodology for Madagascar context

The economic evaluation of the agricultural, water, and cooling solutions was conducted by calculating the anticipated costs and revenues based on specific case data provided in D4.3. This data included details on components, capacity, daily utilization, and other relevant factors. For the rice husking solution, additional insights were gathered from interviews conducted at the beginning of the project with 10 husking operations. These interviews provided valuable information on required capacity, monthly utilization, spare parts needs, operating costs, and product pricing.

The purchase prices of the components were supplied by Nanoé. For all three solutions, the annual costs for investment and equipment were calculated using the annuity method, with the depreciation period estimated for each equipment and an interest rate of 15% and 5% to reflect the expected rate of return from a pure private investor or from an eager investor which means an investor who is willing to expect lower profits. The costs were then expressed in US dollars, using an exchange rate of 1 USD= 4500 MGA.

This comprehensive approach ensures that the economic analysis reflects realistic operational conditions and market prices, providing a robust foundation for assessing the viability of these solutions in the local context. The integration of interview data, especially for the husking solution, allows for a more nuanced understanding of operational dynamics and potential financial outcomes, further enhancing the accuracy and relevance of the evaluation.

1.3. RESULTS

1.3.1. Agri-processing equipment/NanoHusk

1.3.1.1. Description of local value chains and innovative circular economy models for the productive nanogrids

NanoHusk's primary goal is to offer a local access point to husk rice and/or mill rice and other locally grown grains or roots (such as cassava and maize). This aims to replace the current diesel-powered hulling units.

The productive nanogrid will primarily power the retrofitted Direct Current (DC) rice hulling machine being prototyped by RISE as part of Task 4.2 of the ENERGICA project. It may also support other DC brushless agricultural machinery in the future. This equipment will be operated by a local entrepreneur experienced in managing a hulling unit. The entrepreneur will pay for this energy service via the Nanoé PAYG platform and provide hulling services to local farmers.

To ensure economic viability given the seasonal nature of rice production, additional energy services will be offered to maximize the nanogrid's usage. Besides connecting several neighboring households for domestic energy use through the Nanoé PAYG platform, NanoHusk will provide access to self-service, pay-per-use Alternating Current (AC) plugs. These AC plugs will allow community members to access AC power for domestic or professional purposes after prepayment through the Nanoé PAYG platform.

In D3.1 the value flows of the rice husking operation is well described in section 3.3.1. Farmers of the community deliver rice to the operator of the husking machine and pay for the husking service. The husks are sold as feed to small livestock or used by own livestock. The rice husking machine as well as spare parts (sieves) are purchased at the local market whereas fuel and lubricants are purchased from mobile distributors.

According to a survey made in the project, rice is mainly husked during May-July, and to a lesser extent in April, August, December and January. The survey also showed that the residual fraction consisting of a mixture of husk and flour is currently used for feeding of chickens and pigs after mixing with water. Currently, most husking machines are powered by diesel motors, specifically a Chinese single-cylinder four-stroke motor. This type of motor is prevalent in many applications. The rice husking machines are operated intermittently in batches, with no need to maximize capacity.

1.3.1.2. Technology, description of the equipment

The agri-specific solution, NanoHusk, is being developed as a productive nanogrid in the ENERGICA project. The NanoHusk solution is currently under development, and as of now, the concept developed for the container solution AgriWatt is being utilized. However, this approach may be revised, and any changes will be documented and updated in subsequent reports. It will contain the DC-electrical retrofitted rice husking machine and potentially other DC-electrical agricultural machinery in the future. This machinery will be operated by a local entrepreneur experienced in running a hulling unit. This entrepreneur will pay its access to this energy service to the nanogrid operator (i.e., a local entrepreneur trained and franchised by Nanoé) via Nanoé PAYG platform and sell hulling service to local farmers. According to the survey as part of Task 4.2, it is expected that the husking machine will typically be operated approximately 10 minutes when each customer arrives with a bag of rice.

Except for the rice husking the NanoHusk is designed to supply three other loads; interior and exterior LED lights, connection of up to 4 neighboring households as well as pay-per-use AC plugs. See D4.3 for more details.

Section 3.3.4 in D4.1 as well as section 1.4 of D4.3 describe the electrical layout of the NanoHusk as well as a list of the main components for the solar power supply system.

1.3.1.3. Construction of the NanoHusk, sourcing of parts

From D3.1, it was concluded that for containerized solutions, it is crucial to select equipment that can be locally sourced and ensure that repair parts are readily available. Additionally, the design of these solutions should be appropriate for the local context and compatible with existing engineering skills.

The main parts of the NanoHusk consists of the electrical nanogrid, PV-modules, batteries and the husking unit made up by the husking unit, the motor and the beltdrives and pulleys connecting them. A visual representation of the solution will be added to this report once the design is fully defined. Table 1 shows the specifications of the components, with its prices and lifetime.

Table 1. 1: *List of equipment, their sources, lifetime and prices.*

Equipment	Quantity	Source of supply	Lifetime (yr)	Total price (USD)
PV modules, trinasolar Vertex tsm400	16	Local supply	20	1980
Solar MPPT Regulator Victron Smart Solar MPPT rs 450/200	1	Local supply	10	1870
Batteries, Pylontech US2000	3	Standard batteries supplied locally	10	3080
Battery inverter, Victron Multiplus 2 48/5000/70-50	1	Local supply	10	858
Operators interface, Victron Cerbo GX	1	Local supply	10	330
DC/DC Converter, Victron Orion tr 48/24-12	1	Local supply	10	132
Smart nanogrid controller and user interface, Nanoe proprietary technology	1	Manufactured by Nanoe in Madagascar	10	165

Equipment	Quantity	Source of supply	Lifetime (yr)	Total price (USD)
48V DC energy meter, Ivy metering	1	Local supply	10	44
AC energy meter, Victron ET112	3		10	165
Arduino Mega 2560	1		5	28
5V Relay Module DC 5V 230V 4 Channels Arduino	1		5	6
Light led	1		7	22
Exterior AC Plugs	3		10	99
Metal stand for mounting the motor	1	Manufactured by local metal workshop	15	55
Rice husking machine	1	Imported, usually from China	10	1320
Motor and steering unit including switch/contact between battery and steering unit	1	Imported, usually from China	10	2200
Beltdrive and pulleys	1	Reconstruction/adaption to fit the electric motor. Can probably be made by local hard metal workshop	10	330



Figure 1. 2: *Layout of the husking machine including the brushless DC-motor and batteries as prototyped by RISE.*

1.3.1.4. Material consumption and spare parts

Consumables for the rice husking is fuel, in this case electricity, instead of diesel, and lubrication. Furthermore, the sieve (Figure 1.2) needs to be replaced in intervals due to worn out or break if stones or metals are present in the paddy.

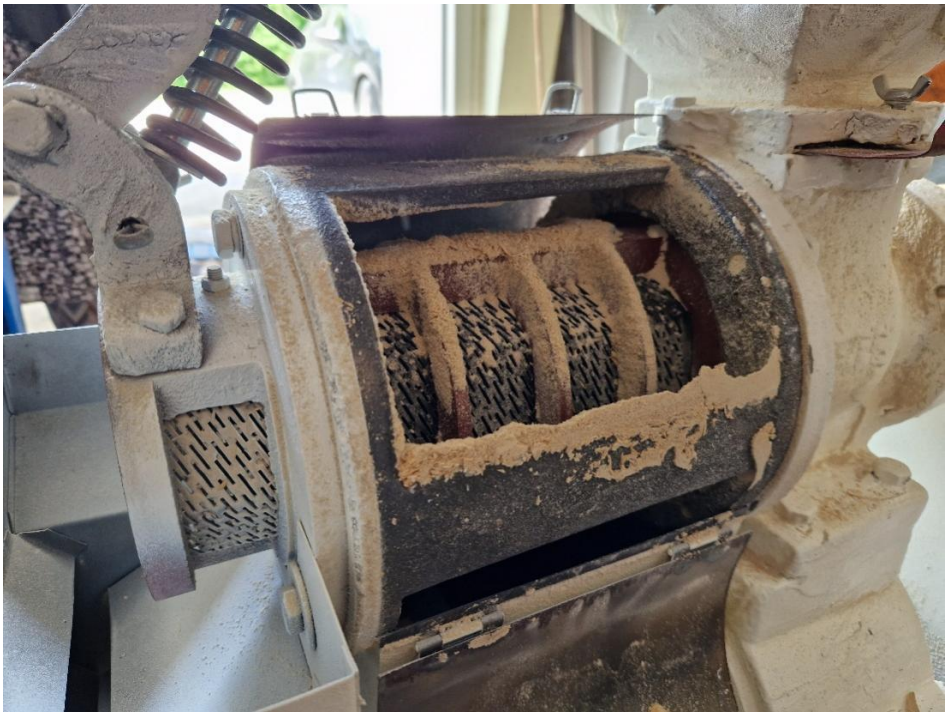


Figure 1. 3: *Sieve in the rice husking machine.*

The questionnaire to rice-huskers shows that on average each husker husked 89 000 tons of paddy per year (for the 10 interviewee) and approximately 26 000 kg of paddy was husked between changing sieves. The cost for a sieve was on average 27 200 MGA (approx. 6 USD). The corresponding value for lubrication was 18,1 times per year and 1900 MGA per time (approx. 0.4 USD). Since the need for lubrication is lower for electric motors compared with diesel powered lubrication consumption was assumed to be half.

If the design of the electric rice husking machines is based on available machines there exists capacity and knowledge to maintain and repair, both the husking unit and the solar installation. Nanoé will provide or make sure that local rice-husker repairmen are available both for the husking equipment and the electric and solar installations.

1.3.1.5. Running costs

Running costs include the energy (electricity) required for the engine/motor and the labor costs for operating the machine. Lab testing of rice husking, as presented in D4.2, indicates that electricity consumption varies between 17 and 28 Wh per kilogram of paddy. It is assumed that one person is required to run the NanoHusk during all day.

1.3.1.6. Co-products and residues

Besides the rice, the husking process of the paddy results in husks. According to interviews with rice husking entrepreneurs in the case study area of Madagascar 45% of the paddy ends up as husk.

1.3.1.7. Waste generation

Typically, rice husks constitute about 20% of the weight of the harvested rice (Rajaonarya et al., 2022). Considering that Madagascar produces around 4 million tons of rice annually, this amounts to approximately 800,000 tons of rice husks generated each year.

Rice husking generates several types of wastes that can also be considered by-products depending on its use:

- **Rice husks:** the harder outer shell of the rice grain.
- **Rice husk ash (RHA):** produced when rice husks are burned.
- **Rice bran:** the outer layer of the rice grain, which is removed during milling.

1.3.1.8. Economic analysis

Since the annual utilization of the solutions influence on the cost and income different cases were tested with varying daily capacity and based on the following specifications

- 15% interest rate (pure private investment) 5% interest rate (eager investment) and depreciation time equal to technical lifetime of each component, see table 1.
- Price hulling/husking 66.67 MGA/kg paddy (0.015 USD/kg) and sale mongo/husking residue 140 MGA/kg mongo (0.031USD/kg)
- 26 000 kg of paddy was husked between changing sieves (average value of survey)
- Energy consumption husking: 25 Wh/ kg paddy (based on measurement in lab tests)
- Husking capacity 250 kg/h (assumption based on measurement in lab tests)
- Labour costs 1 person 8h/day, 55 USD/month
- Public light will be provided free of charge to ensure site safety and allow people to use AC plugs at night.
- Neighbouring households, 0.3 USD/day
- AC plugs 2 USD/day

The tested cases with varying annual husking utilization were:

1) 7500 Wh available for husking operations daily. With energy consumption of 25 Wh/kg this gives 300 kg paddy per day. Assuming 300 working days per year the annual capacity was 90 000 kg paddy.
2) 2.5 h running timer per day as stated in D4.3. With the assumed hourly capacity of 250 kg paddy this gives 625 kg paddy per day and 187 500 kg paddy per year.

A summary of costs and income is shown in Table 1.2. With the above-mentioned specifications and preconditions, the NanoHusk shows a positive revenue (income higher than costs) for both daily utilization rates when the interest rate is 5% and for higher utilization rate (2.5 h/day) when interest rate is 15% .

Table 1. 2: *Summary of the costs and income (USD/yr) for the NanoHusk.*

	Pure private investment		Eager investment	
Cost (USD/yr)	7500 Wh/day	2.5 h/day	7500 Wh/day	2.5 h/day
Annuity cost, annual cost	2452	2452	1547	1547
Lubrication	4	8	4	8
Sieve	21	43	21	43
Repair maintenance	374	374	374	374
Labour 8h/day	600	600	600	600
Sum costs	3 450	3 476	2 546	2 572
Income				
Hulling	1307	2723	1307	2723
Sale mongo	1247	2599	1247	2599
Public light	0	0	0	0
Neighbouring household	100	100	100	100
AC plugs	730	730	730	730
Sum income	3 384	6 151	3 384	6 151
Revenue (income-costs)	-66	2 675	839	3 579

1.3.1.9. Capacity comparison with questionnaires husking operations

Figure 1.3 and Figure 1.4 show how the capacity of the NanoHusk fits the needs of the huskers participating in the survey done earlier in the project. Figure 1.4 compares the NanoHusk capacity with the husked amount expressed as average of the participating huskers per month. Figure 1.5 instead shows for each husker the variation between months. From Figure 1.4, it is clear that during the peak months of husking, May to July, the lowest capacity (called battery capacity only) of the NanoHusk will be too low for the requirement of the huskers seen as the average amount of paddy husked per month per plant in the survey. If the Nanohusk can be run 2.5 h per day the capacity will be sufficient when compared to the average of the amount husked per month.

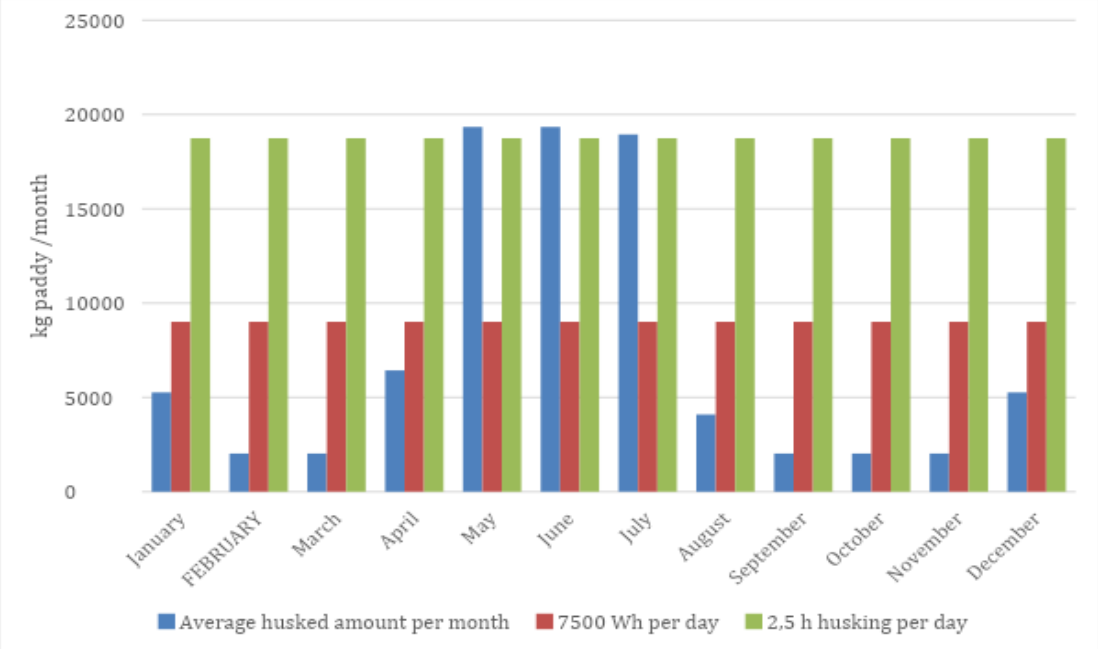


Figure 1. 4: *Monthly husking capacity for the solar powered NanoHusk compared with the average value of paddy husked each month by the 10 surveyed huskers. Two alternatives for husking capacity are presented; 7500 Wh/day and 2,5 h husking per day.*

If we instead look at the maximum and average capacity required by each husker considering the monthly variation in amount of paddy being husked the four largest huskers require more than 2.5 h husking capacity per day during the peak months.

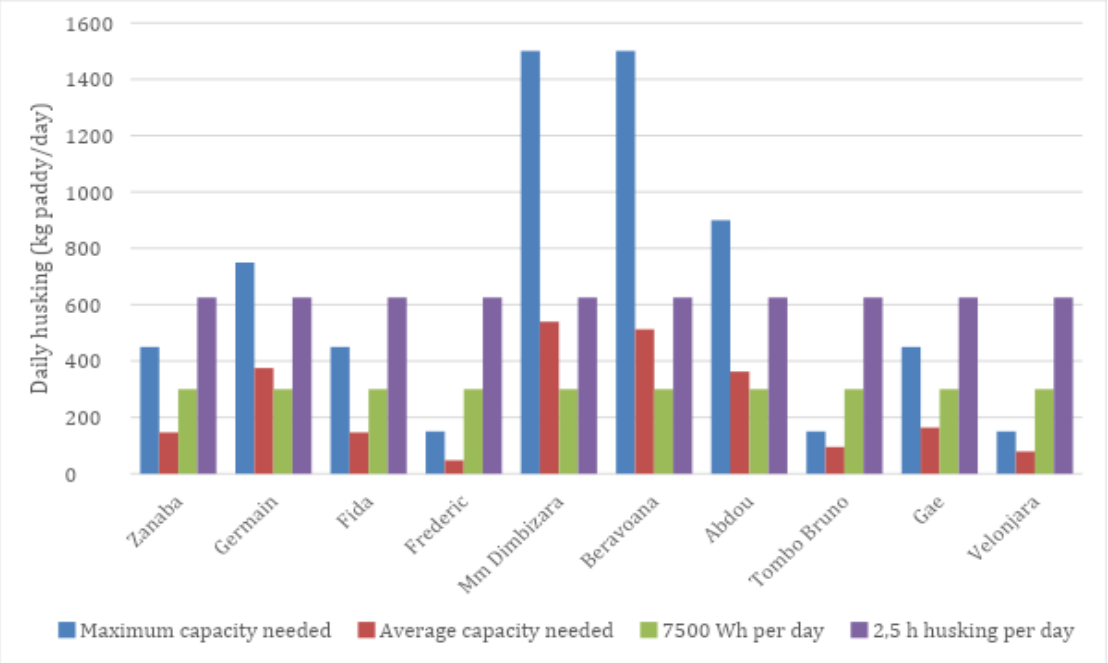


Figure 1. 5: *Maximum and average daily capacity of the 10 surveyed huskers compared with the daily husking capacity for the solar powered NanoHusk. Two alternatives for husking capacity are presented; 7500 Wh/dayl and 2,5 h husking per day.*

1.3.1.10. Benefits and potential improvements of the systems

1.3.1.10.1. Material consumption reduction

In the project innovative solutions were/will be developed for grid optimization aiming to reduce energy consumption and use of raw material such as PV panels and batteries. The solutions include grid congestion, voltage excursion rate and current excursion rate and will allow Nanoé to better operate the grids and manage its assets. This will lead to reduced CO2-emissions and use of copper and plastics. See D3.4 for more information.

1.3.1.10.2. Circular economy and use of co-products

The rice husking process generates significant amounts of waste, including rice husks, bran, and straw. Traditionally, these by-products are sometimes discarded, contributing to environmental pollution. However, adopting a circular economy approach transforms this waste into valuable resources, minimizing environmental impact and enhancing sustainability.

In a circular economy, these by-products are repurposed to create new products, reducing waste and promoting resource efficiency. Key strategies include:

- Energy Generation: biomass fuel to generate electricity and heat, providing a renewable energy source.
- Bio-based Products: conversion into oils, proteins, and other bio-based materials for use in food, cosmetics, and pharmaceuticals.
- Agricultural Applications: conversion into compost or utilization as animal feed, enhancing soil fertility and supporting livestock farming.

By integrating these practices, the rice husking process not only reduces waste but also creates a sustainable value chain that benefits the environment and the economy as shown in Figure 6.

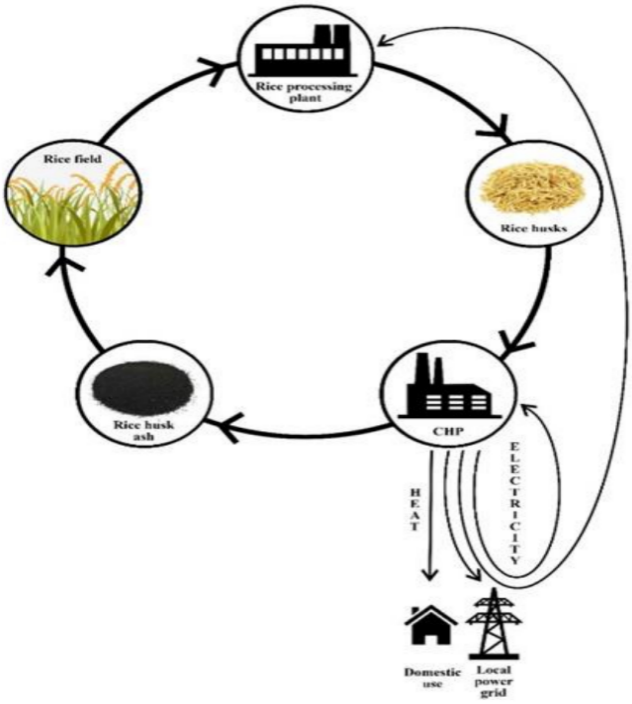


Figure 1. 6: *Circular economy solutions for the management of rice processing. Source: Vaskalis, et al. (2019).*

In rice production three main residues are generated, straw, husk and bran. Whereas the straw remains on the field the husk and bran is generated during husking and milling of the rice. Depending on the type of rice husking machine, if it is a one or two step husking machine, the husks are separated into bran and flour fraction and a husk fraction. According to a review made by Sanoja-Lopez et al. (2024), there is a large potential to use these residues to produce energy, raw material for bioplastics as well as high-value products.

1.3.1.10.3. Rice husks

Rice is one of the main crops in Madagascar, producing approximately 4 million tonnes of paddy rice and about 160,000 tonnes of rice husk annually. Husking occurs year-round, primarily from April to July. Generally, 1 kg of paddy rice yields 0.55 kg of polished rice and 0.45 kg of rice husk residues. These husks are currently used as fodder and have a market value between 200 and 300 MGA/kg. Recently, rice husks have also been used as biofuel on a small scale, reducing the reliance on forest wood.

Rice husks can be repurposed in various innovative ways. Compressed rice cakes made from rice husks provide a cost-effective, nutritious feed for livestock. This recycling method offers farmers an additional income source and reduces dependence on expensive commercial feeds. Additionally, rice husks can be used to produce biogas, a sustainable energy source that helps reduce reliance on wood and charcoal, which are major contributors to deforestation. Composting rice husks creates organic fertilizer, managing waste effectively and providing a valuable resource for agriculture. Furthermore, new stoves that burn rice husks instead of wood or charcoal have been introduced. These stoves are more efficient and environmentally friendly, helping to reduce deforestation and offering a cheaper fuel alternative.

The chemical composition of the rice husk makes it promising for industrial application to produce materials. Its composition varies depending on where it has been grown but generally it contains 25-35% cellulose, 18-21% hemicellulose, 26-31% lignin and 15-25% silica. Its porous structure makes it interesting for adsorbent materials and another application is to extract silica from the rice husk (Sanoja-Lopez et al., 2024).

1.3.1.10.4. Rice bran oil

Rice bran, the outer layer of the rice grain that is separated during husking and milling of the rice and it has significant potential for various uses. The bran makes up approximately 9% of the total weight during rice production (Sanoja-Lopez et al., 2024). After extracting the oil, the remaining husk cake can be used as fodder. A major fraction of rice bran contains 12%-18% oil, depending on its geological origin, with a fatty acid content and composition similar to that of peanut oil, making it a healthy cooking oil. The retail price range for sunflower oil in Malagasy Ariary is between 13,274.34 and 26,548.67 MGA/kg. Therefore, rice bran oil could be a potential economic co-product if the necessary infrastructure for production is established in Madagascar.

In addition to its use as a cooking oil, rice bran can be used as a nutrient-rich feed supplement for livestock. The extracted rice bran oil can also be utilized in the production of biodiesel. Furthermore, rice bran contains antioxidants and other bioactive compounds that can be incorporated into health supplements and skincare products (Sanoja-López et al., 2024).

1.3.1.10.5. Biochar

Rice husks can be used to produce biochar which is a low-cost renewable resource. Biochar is a valuable soil amendment that can improve the productivity and sustainability of agricultural fields. Biochar can also be used for the remediation of water and soil.

1.3.1.10.6. Rice Husk Ash (RHA)

Rice husk ash is often used in construction materials like cement. The use of RHA in cement not only reduces construction costs but also addresses the environmental issue of agricultural waste disposal (Rajaonarya et al., 2022).

Due to its high silica content, RHA can be used to improve soil structure and fertility. Further, it can be used as a filtration medium to remove impurities from water (Malhotra et al., 2013).

All these possibilities can reduce waste and improve the sustainability of their farming practice while generating additional income and reducing unemployment rates.

1.3.1.10.7. Improved utilization of the facilities

Prolonged season

In Madagascar, the prolonged season for husking and milling crops like cassava, maize, and rice can be influenced by various factors, including climate, agricultural practices, and crop varieties.

Rice is a staple food in Madagascar, with significant production and processing activities. Planting typically occurs during the rainy season, with harvesting and milling following the growth cycle.

Cassava is a highly resilient crop to climate variations, making it reliable throughout the year. It can be intercropped with maize, legumes, or trees to enhance productivity and environmental benefits. Farmers typically plant cassava during the short rainy season (October to December) to avoid higher infection rates from diseases like cassava brown streak disease.

Maize is a versatile crop that can be grown in various climates and soil types, making it suitable for different regions in Madagascar. It is commonly intercropped with cassava and other crops to maximize land use and improve soil health. The harvesting period for maize can vary but generally aligns with the main growing seasons, ensuring a steady supply for milling.

1.3.1.10.8. Additional agri-specific equipment

The rice husking is quite concentrated during the harvesting season which means that the NanoHusk solution will not be evenly utilized throughout the year. If the same equipment could be used for other crops or if other equipment could be added to the container the utilization could increase.

In particular, if the rice bran should be valorized a mill would be valuable to add to the equipment. The Kenyan company Agsol (2023) offers innovative solutions for off-grid and nanogrid farming, particularly through their solar-powered milling equipment. The MicroMill is a versatile machine capable of processing grains like maize, sorghum, and millet, as well as tubers like cassava. It is 2.5 times more efficient than other small electric mills and 70% more profitable than diesel-powered mills when operated in solar format. Adaptable to various power sources, including solar, mini-grid, grid, or e-bike, the MicroMill features an automatic feed control mechanism and is practically maintenance-

free. Similarly, the hammer mill and rice mill are designed to operate efficiently using solar power, reducing reliance on fossil fuels. Their robust design ensures durability in tough environments, making them suitable for rural and off-grid areas. These mills generate economic benefits by creating income, improving labor efficiencies, and providing a platform for other commercial activities.

Agsol MicroMill is shown in Figure 6 and the specifications are given in Table 3.

Table 1. 3: *Specification of the Agsol MicroMill.*

Type	**Hammer mill**
Capacity	45-75 kg/h
Energy consumption	60-80 kg/kWh
Motor rating	1 kW
Size	300x200x500 mm
Weight	6.5 kg



Figure 1. 7: *Solar powered small-scale mill from Agsol.*

Solar-powered mills contribute to sustainability by reducing environmental impact through the replacement of diesel and other fossil fuels. They are affordable and quickly pay for themselves, making them accessible to smallholder farmers. These mills enhance local economies, reduce manual labor, and provide social benefits such as improved education and health.

1.3.1.10.9. Waste generation reduction

The waste generated in rice husking not only poses environmental challenges but also represents a loss of potential resources. Reducing waste generation in the rice husking process is essential for promoting sustainability and enhancing the efficiency of rice production. By implementing innovative technologies and practices, Madagascar can transform rice husking waste into valuable by-products, contributing to environmental conservation and economic growth.

1.3.1.10.10. Maintenance of solar panel

Regular maintenance and repair can help prolong the lifespan of solar panels and prevent them from becoming waste. Panels can be checked often for any signs of damage, corrosion, dirt, or shading. Further, keeping the panel surface clean from dust or debris can increase its performance.

1.3.1.10.11. Energy optimization

In order to husk the rice efficiently, it is important to reach the optimal speed of the DC motor connected to the rice husking machine. At the trial period, it has been found that at lower rotation speed, the power supply from the motor was not enough to run the husker at a large enough capacity (flow of rice into the cleaning unit). The flow of rice into the cleaning unit is adjusted by changing the size of the inlet or the pressure of the outlet valve. If the inlet is small the throughput capacity is low and the rice stays too long in the cleaning cylinder resulting in a large degree of paddy ending up as rice flour and a low yield of cleaned rice.

1.3.2. Water equipment/ NanoWater

1.3.2.1. Description of local value chains and innovative circular economy models for the productive nanogrids

1.3.2.1.1. Technology, description of the equipment

This productive nanogrid NanoWater is a light building-integrated solution that should mainly provide a local point of access to clean water. Thereby the goals are to decrease the walking distance to the nearest access to water (and particularly of children and females often in charge of these chores), increase sanitary conditions in the village, limit the rivers pollution (laundry and vehicles are currently washed in nearby rivers) and create a new economic activity in these rural villages.

Water fountains, often solar power, already exist in some villages but their investment costs are high which hinders the spreading. The NanoWater solution aims at drastically decreasing the investment cost by building smaller and more optimised installations taking benefits of the synergies between energy and water production and distribution (D4.3).

The productive nanogrid will power both the water fountain and neighbouring domestic users. Furthermore, a public light will be installed on top of the nanogrid wood poles to light up the fountain and its surroundings during night. The water fountain will be operated by a local entrepreneur who will sell drinkable water. The entrepreneur will pay its access to this energy service to the nanogrid operator (i.e. a local entrepreneur trained and franchized by Nanoé) via Nanoé PAYG platform.

NanoWater will support three types of loads:

1.3.2.1.2. Domestic Households

The system will provide 24 Vdc power to neighboring households, similar to other Nanoé domestic users. Based on data from over 6,500 domestic users connected through more than 1,500 nanogrids deployed by Nanoé in the project area, the average consumption per household is approximately 100 Wh/day. Load patterns are predictable, with peak consumption occurring at sunset and early night. Depending on the geographical conditions at the NanoWater deployment sites, up to four domestic users could be connected to this productive nanogrid, with a total average consumption of 0.4 kWh/day.

1.3.2.1.3. Public Lighting

A public light will be installed on top of the nanogrid's wooden poles to illuminate the fountain and its surroundings at night. A 30-watt, 24 Vdc LED spotlight will automatically turn on during the night.

1.3.2.1.4. Submersible Pump

The nanogrid will also power a 24Vdc submersible pump capable of pumping at least 2 m^3 of water per day from a 15-meter well-head to the fountain tank, such as the SHURFLO 9325 series. This pump will add flexibility to the nanogrid. Its operation—starting and stopping—will be controlled by the nanogrid's smart energy management system to minimize PV curtailments and the depth of discharge of the nanogrid's battery pack while ensuring the water pumping service level subscribed to by the operator. Although the pump's load profile will not be used in the system sizing simulation, the available energy to power it will be an output of the system.

1.3.2.1.5. Technologies

The NanoWater solution is designed with several key components to provide efficient and reliable water access.

1. Water Tank (1 m^3): The system features a water tank with a capacity of 1 cubic meter. This tank is central to storing and managing the water that is collected and distributed.
2. Water Tap: Positioned for easy access, the water tap allows users to draw water from the system. It is strategically placed to ensure convenient use for both domestic and public needs.
3. Nanogrid Controller Interface: The nanogrid controller interface is an essential component for managing and monitoring the energy distribution and operation of the water system. This interface ensures that all system functions are efficiently controlled and optimized.
4. Water Retention Area: This area is designed to capture and retain water, ensuring that there is a steady supply available for the tank and tap. It helps in managing water flow and prevents overflow.
5. Water Well: Located below the fountain, the water well is a crucial part of the system, supplying water to the tank. It is designed to access groundwater and ensure a reliable source of water for the entire setup.

Together, these components, shown in Figure 7, form an integrated system that supports efficient water management and accessibility.

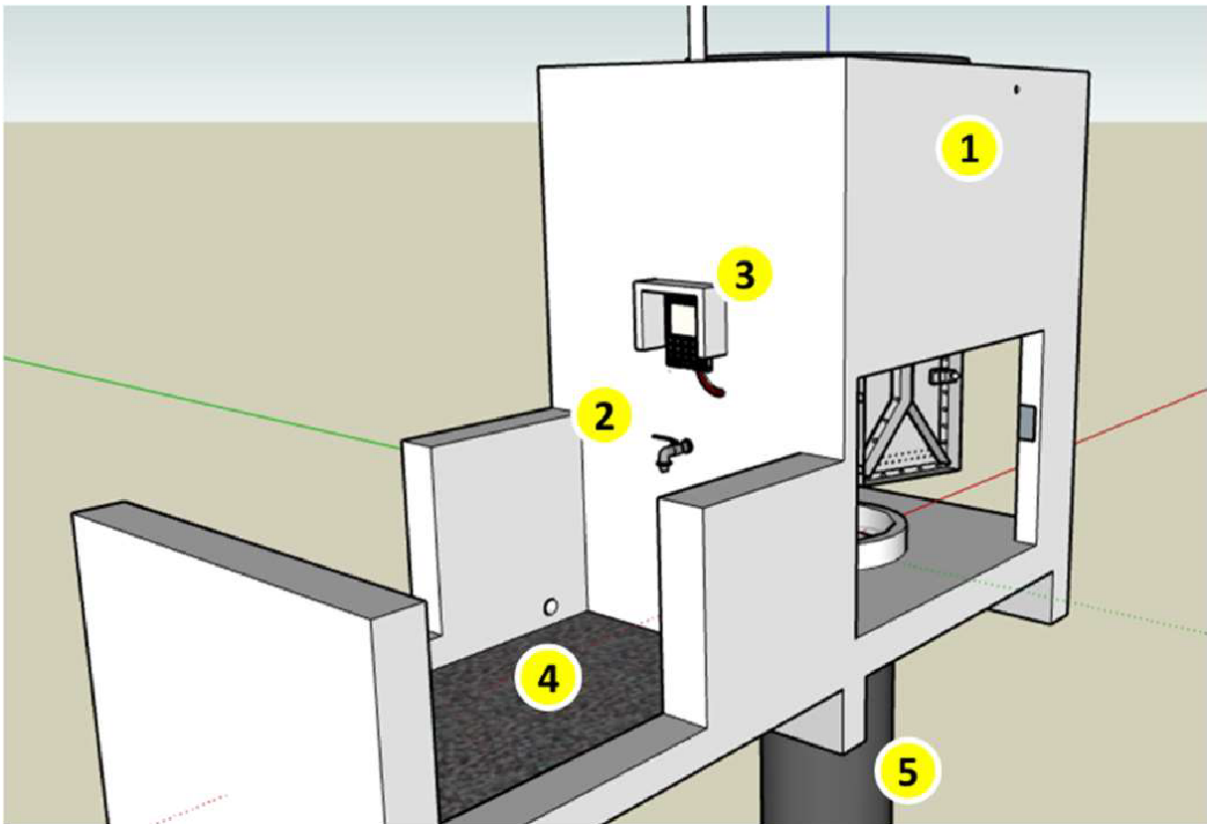


Figure 1. 8: *Layout of the NanoWater solution where 1) water tank 1 m^3, 2) water tap, 3) Nanogrid controller interface, 4) water retention area and 5) water well below the fountain.*

The electrical layout and main components are given in section 3.1 in D4.1. Existing roofs and buildings will be used to install solar modules, batteries and controllers.

1.3.2.1.6. Construction and sourcing of parts

The components of the NanoWater are presented in Table 4, with the respective prices in US dollars and the lifetime considered for each equipment.

Table 1. 4: *List of components for the NanoWater.*

Equipment	Quantity	Source of supply	Life time (yr)	Total price (USD)
Batteries, Victron AGM 130 Ah	2	Standard batteries supplied locally	5	792
PV modules, Victron Bluesolar	2		15	286
Smart nanogrid controller and user interface	1	Manufactured by Nanoe in Madagascar	10	165
Light Led	1		7	22
Submersible pump, 9325 Shurflow	1	Supplied locally by Gaïa	10	
Pump Controller	1	Manufactured by Nanoe	10	22

1.3.2.1.7. Material consumption and spare parts, maintenance and repair

Nanoé will provide or make sure that local repairmen are available both for the water pumping equipment as well as the electric and solar installations.

Maintenance of the pump: Choosing the right size of the pump based on the consumption would make the water pumping efficient. Also, proper installation with experts is necessary to avoid any installation error. Use of energy-efficient motor and use of high-quality cables will be necessary to run the system efficiently and sustainably. Regular checking of voltage and current is necessary to avoid high temperatures in the motor. Furthermore, make sure the water tap is not leaking dripping water.

1.3.2.1.8. Economic analysis

Since the annual utilization of the solutions influence on the cost and income different cases were tested with varying daily capacity and based on the following specifications

- 5% interest rate and 5 yr depreciation time (annuity factor 0,23097)
- 15% interest rate (pure private investment) 5% interest rate (eager investment) and depreciation time equal to technical lifetime of each component, see table 4.
- Neighbouring households, 0.3 USD/day
- Public light will be provided free of charge to ensure site safety and allow people to fill the buckets at night.
- Water fountain 1 m3/day 0.5 USD/day

Table 1. 5: *Costs and income for the NanoWater solution*

	Pure private investment	**Eager investment**
Total annual cost (USD/yr)		
Equipment annual cost, annuity cost	328	236
Maintenance	146	146
Total annual cost	473	381
Income		
Water fountain, 1 m3/day	183	183
Public light	0	0
Neighbouring households	110	110
Total annual income	292	292
Revenue (income-costs)	-181	-89

For both alternatives with higher and lower interest rate (pure private and eager) expected costs are higher than the income. Some kind of investment support of subsidy could be one solution to reach profitability.

1.3.2.2. Benefits and potential improvements of the systems

The social impact of NanoWater systems in the local value chain is significant:

- Improved Health: Access to clean water reduces waterborne diseases, improving overall community health.
- Economic Opportunities: Local manufacturing and maintenance create jobs and boost the local economy.

- Community Empowerment: Training local technicians and involving communities in the management of water systems fosters self-reliance and sustainability.

These improvements make NanoWater systems a promising solution for addressing water scarcity and quality issues, particularly in underserved regions.

1.3.3. Cooling equipment/NanoCold

1.3.3.1. Description of local value chains and innovative circular economy models for the productive nanogrids

The NanoCold solution is a light-building solution whose main purpose is to provide access to freezing and refrigeration of food and beverages. This productive nanogrid will power both the grocery fridge/freezer and neighbouring domestic users. The grocery owner will pay its access to this cooling service to the nanogrid operator (i.e. a local entrepreneur trained and franchized by Nanoé) via Nanoé PAYG platform and sell refrigerated goods, ice and/or fridge spaces to the local population. The NanoCold layout is shown in Figure 8.

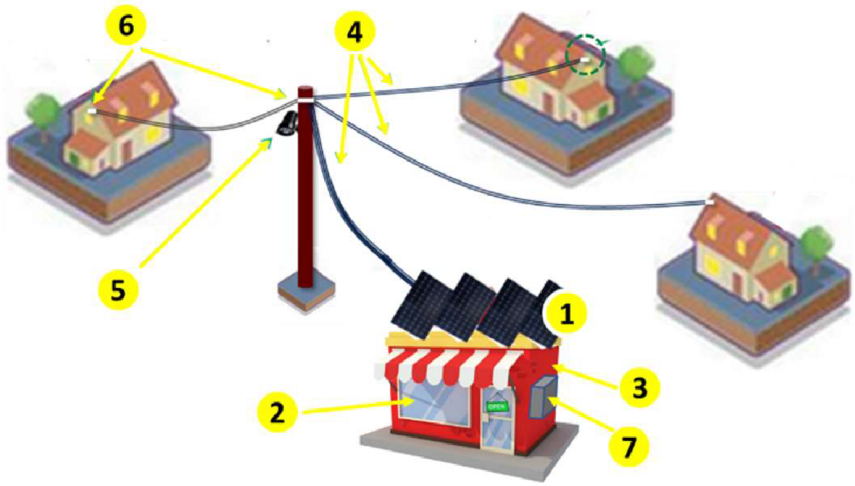


Figure 1. 9: *Layout of the NanoCold solution where 1) solar modules, 2) fridge located inside the grocery store 3) batteries and controller 4) distribution cables 5) public ligntning, 6) anchoring cables and 7) nanogrid user interface.*

1.3.3.1.1. Technologies

Cooling services is one the most prominent needs for productive uses in most rural regions of Madagascar. Indeed, over 60% of the population works in the field and almost 20% lives from fishing and sea products. The existing cooling services are through local shops, ice blocks and personal petrol or diesel run freezer. The cold chain management for sea products is still an unsolved issue leading to a very low productivity of this artisanal industry.

1.3.3.1.2. Materials Consumption

This fridge must be used as a flexibility feature of the nanogrid. Indeed, the on-off function of the fridge compressor should be piloted by the nanogrid smart energy management system to minimize PV curtailments and the nanogrid battery pack depth of discharge while guaranteeing the level of cooling service subscribed by the grocery owner. This action has been already identified in the energy sizing simulation and reported in D4.2.

1.3.3.1.3. Sourcing of Parts

In the social survey (D 2.1), it was found that more than two-thirds of the respondents surveyed lack access to cooling and freezing services. The people are interested in accessing both services and they are willing to pay is $94.61. They plan to use these services for making ice blocks, cooling beverages, and preserving meat and fish.

It has been identified in the D4.2 that the demand for refrigeration and freezing services in groceries is very important since most of them currently lack access to this service and fully rely on expensive and inefficient alternatives (e.g. buying ice blocks from the nearest city that is often several hours away and fit them in unpowered cool boxes). The productive nanogrid will power both the grocery fridge/freezer and neighboring domestic users. The grocery owner will pay its access to this cooling service to the nanogrid operator (i.e. a local entrepreneur trained and franchized by Nanoé) via Nanoé PAYG platform and sell refrigerated goods, ice and/or fridge spaces to the local population. The cooling service that will be sold to the grocery owner will be defined by a daily fee depending on the temperature settings and that will allow variations in subscription that are briefly described in D 4.2. So, there is a very good scope in solar-powered cooling services that can produce additional income to the local people and help in reducing unemployment rate.

1.3.3.1.4. Construction and Sourcing of parts

Table 6 shows the equipment or the NanoCold solution in Madagascar.

Table 1. 6: *List of equipment for the NanoCold system.*

Equipment	Quantity	Source of supply	Life time (yr)	Total price (USD)
Batteries, Victron AGM 130 Ah	4	Standard batteries supplied locally	5	1584
PV modules, Victron Bluesolar	4	Supplied localy	15	286
Smart nanogrid controller and user interface	1	Manufactured by Nanoe in Madagascar	10	165
NanoCold Controler	1	Manufactured by Nanoe	10	22
Sideboard fridge/freezer, Steca PF- 166H	1		10	1100 (cost not supported by Nanoe : Freezer purchased by the final user)

1.3.3.1.5. Economic analysis

Since the annual utilization of the solutions influence on the cost and income different cases were tested with varying daily capacity and based on the following specifications

- 15% interest rate (pure private investment) 5% interest rate (eager investment) and depreciation time equal to technical lifetime of each component, see table 6.
- Neighbouring households, 0.3 USD/day
- Public light will be provided free of charge to ensure site safety
- Price/fee for access to grocery fridge/freezer: 5°C to 0°C = 20 USD/month, -5°C To -10°C = 32 USD/month, -10°C to -15°C = 49 USD/month

Table 1. 7: *Cost and income for the NanoCold solution*

	Pure private investment	Eager investment
Total annual cost (USD/yr)		
Equipment annual cost, annuity cost	559	418
Total annual income	**559**	**418**
Income		
Freezer/fridge max	511	511
Public light	0	
Neighbouring households	110	110
Total annual income	**621**	**621**
Revenue (income-costs)	**62**	**203**

As can be seen in table 7, for both alternatives with higher and lower interest rate (pure private and eager) expected income is higher than the cost.

1.3.3.2. Benefits and potential improvements of the systems

An implementation of techno-economic optimization can limit the unmet electrical load (i.e. partial or total shedding) to a maximum of 5% over the year and can ensure excess energy (i.e. energy available for water pumping and lighting) of at least 1 kWh/day on average. Also, a default management of an automatic system can be implemented to reclosing routine when short circuits are detected at the load side.

1.4. CONCLUSION AND RECOMMENDATIONS

The evaluation of local value chains and circular economy capacity in Madagascar reveals significant advancements and potential areas for further development in various sectors:

1. Solar Nanogrids: The implementation of solar nanogrids in over 150 villages highlights a successful model for decentralized energy provision. These grids effectively power both domestic and other non-productive users, demonstrating the viability of renewable energy solutions in rural settings.
2. Agri-specific Solutions: The development of small-sized electric rice huskers and the adaptation of existing rice husking machines signify progress in agricultural mechanization. These innovations are aligned with the needs of local farmers and contribute to increased agricultural productivity and efficiency.
3. Water-specific Solutions: Advances in water pumping, storage, and treatment technologies address critical needs for clean and reliable water sources. These solutions are essential for improving community health and supporting sustainable agricultural practices.
4. Cooling-specific Solutions: Cooling devices for food and water refrigeration are crucial for preserving perishables, especially in hot climates. This technology supports the food supply chain and reduces waste, contributing to food security and sustainability.

Based on the findings, the following recommendations are proposed to enhance the capacity of local value chains and promote a circular economy in Madagascar:

- Expand Solar Nanogrid Coverage: Continue to scale the deployment of solar nanogrids to additional villages. Focus on integrating storage solutions to ensure reliable power supply during varying weather conditions and nighttime.
- Enhance Economic Viability: Develop financial models that improve the affordability and economic appeal of these technologies. This could include innovative financing options like microfinancing, pay-as-you-go models, and cooperative ownership structures to reduce upfront costs and spread financial risk. Additionally, building partnerships with financial institutions to offer low-interest loans can further facilitate technology adoption among small-scale users and businesses.
- Enhance Agri-specific Technology Development: Support research and development for more sophisticated agri-specific technologies that cater to the nuances of local agriculture. Promote training programs for farmers to maximize the benefits of new machinery, and explore opportunities for local manufacturing to reduce costs and increase accessibility.
- Strengthen Water Infrastructure: Invest in robust water management systems that not only provide essential services but also contribute to the resilience of communities against climate variability. Encourage the use of solar-powered water solutions to align with renewable energy goals.
- Policy Support and Incentives: Advocate for supportive policies that encourage investment in these technologies. This includes subsidies for renewable energy solutions, tax incentives for local manufacturing of equipment, and grants for research into sustainable technologies.
- Circular Economy Integration: Promote a circular economy approach by encouraging the reuse and recycling of materials, particularly in the manufacturing of new devices. Develop local recycling programs to handle end-of-life products and reduce environmental impact.

By implementing these recommendations, Madagascar can significantly enhance its local value chains, improve sustainability, and foster economic growth in alignment with environmental conservation goals.

1.5. REFERENCES

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ENERGICA

ENERGICA

ENERGY ACCESS AND GREEN TRANSITION COLLABORATIVELY DEMONSTRATED IN URBAN AND RURAL AREAS IN AFR**ICA**



PART B, Capacity for local value chains and Circular Economy –Sierra Leone Context

2.1 SIERRA LEONE CONTEXT

2.1.1 Energy overview and circular economy

Many developing countries from Africa are facing generally weak electricity supply system in urban, semi-urban and rural areas. According to IRENA (2015), the percentages of population not having access to electricity are respectively 75%, 77% and 53% in Central, East and West Africa [1]. Sierra Leone is one of these West African countries where the energy access is very low especially in rural areas. The number of people connected to the grid is roughly at about 150,000 customers. Therefore, more than 80% of the populations do not have access to electricity through grid connected network. Only 17% have grid connection and 2 to 3% are connected to mini grid, solar and portable home energy systems [2].

The total installed capacity is estimated to 113 MW in 2019 in which up of 75 MW are coming from hydropower, 4 MW from solar and 34 MW from bio-energy [3]. Therefore, the ambition and target goals of the country are to increase the rate of electricity access from 13% (2013) to 92% (2030), and the penetration of renewable energy level from 43,464 GWh (2013) to 111,780 GWh (2030) [4]. In this way, the renewable bioenergy produced through biogas plant can contribute to improve the energy access if developed at larger scale in the country.

The CE in biogas production is gaining great attention in many countries worldwide [5]. The utilisation of waste in biodigesters to produce bioenergy improves the energy demand for local communities and enterprises and sustains the waste management and reduces the pressure on ecosystem. In this regard, the renewable bioenergy and bioproducts (fertilizers) are valorised [6]

This report aims to provide a relevant circular economy business model for a sustainable production of a low-tech biogas and environmentally friendly biofertilizer in the SL context. This helps to improve the RE share through the bio-energy production, to reduce the GHGs emission and to improve water quality and the agricultural productivity. Indeed, while contributing to enhance the local economies, the CEBM promotes decentralized energy systems to mitigate GHGs emission and minimize the impact of the environment. In addition, the sustainability pathway for business and policy-making community passes through a crucial CE [6].

2.1.2 Demonstrator site – Sierra Leone (SL)

In the Sierra Leone context, a biodigester through anaerobic digestion (AD) is used to transform organic waste into biogas which can be converted into electricity, heat and biofertilizer. The process AD breaks down the chemical bonds in the organic materials into a primarily mixture of methane (CH4) and carbon dioxide (CO2) that constitutes the produced biogas. However, the composition of biogas strongly varies and depends on the types of feedstock used as well as the specific conditions of the biodigester. Anaerobic Digestion can be used, as renewable bioenergy to generate electricity to improve the access to clean energy; as cooking fuel to replace wood and charcoal in rural areas; as fertilizer for agricultural practices; as waste management asset to reduce landfill:ecosystem degradation and GHGs emission. Sereval types of biodigesters exist including: the plug-flow biodigester; the fixed-dome biodigester; the floating-drum biodigester; the horizontal biodigester, etc []. their performance is strongly related to the type of feedstock(wet/dry) and the operating temperature.

In the demontrator site of SL context, a small-scale biogas plant for local food waste streams is developed and implemented by the The Waste Transformer (TWT, Netherland) in collaboration with the Freetown Waste Transformers (FWT, SL) which conducts the operating activities in urban area of Freetown. The aim is to create sustainable local food waste management in a circular economy manner to support local emerging economic activities for jobs creation and local entrepeneurs. The biodigester used in SL context is a modular biodigester design (see figure1). It is equipped to process from 300 to 350 kg of food waste/day or more. The larger version has five digestion tanks and can process up to 1750 kg per day. (see Table 1). The Freetown Waste Transformers have developed a mobile application available on playstore to reorganise and coordinate the waste collection efforts between waste collectors, the customers and the users of the application. In this regards many challenges of food waste management are getting sustainable solutions. Biogas for cooking, electricity/heat generated and digestate (fertilizers) are the main streams derived in this context.

In addition, solar reactors for water treatment using municipal wastewater streams will be also implemented for the context of Sierra Leone. Indeed, photocatalytic solar reactors have been introduced since the late 1980s. They are primarily designed for water or surface treatment, decontamination and disinfection ([14]; [15]).



***Figure 2. 1**: The TWT biodigester system installed in Freetown Sierra Leone*[1]

2.2 METHODOLOGY

The method used for the techno-economic feasibility study for local value chain and Circular model in the SL context is mainly by assessing potential of organic waste resources in SL and the evaluation of some indicators on the technical and economical dimensions of the biogas and water purification systems.

[1] https://www.thewastetransformers.com/about/

2.2.1 Assessment of potential of organic waste resources

The feasibility of biogas production and water purification systems suggests the inclusion of technical and economic aspects of the whole supply chain. Hence, for a sustainable design and planning of biogas projects, these aspects should be carefully addressed. Some of the most important technical aspects are the capacity factor and the calorific value of the biowaste. For instance, the conversion efficiency of a technology determines the amount of the products that can be obtained per unit of biomass input. Higher calorific values are associated with higher heat/power output. Besides the calorific value, the capacity factor also influences the techno economic feasibility of producing bioenergy and bio products. Table below summarizes the techno economic indicators used for feasibility study of the biogas production in SL. The other economic indicators are described in detail in subsequent sections.

Table 2. 1: *techno-economic indicators for feasibility study of biogas production*

Indicators	Definitions	Units	References
Capacity factor	The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period.	%	US Energy Information Administration
Net heat/power output	The amount of heat/power obtained at the end of the process. The heat used during the process is subtracted from the total heat/power that could be obtained	kW	US Energy Information Administration [10]
Calorific value	Calorific value refers to the heating power of the waste [2].	kWh/kg	

2.2.2 Estimation of the techno-economic indicators

The following indicators are evaluated:

a) Biogas potential

The total amount of biogas that can be theoretically estimated considering the biogas yield is given by the following formula:

$\dot{m}_{biogas} = \dot{m}_{biowaste} \times \gamma$

Where:

$-\dot{m}_{biogas}$: is the mass flow of biogas (m^3/h);

$-\dot{m}_{biowaste}$: is the mass of biowaste (kg/h);

[2] https://www.inciner8.com/blog/waste-management/6-waste-terms-what-they-mean

– γ: is the biogas yield. (100 Nm^3 for a methane content of 61% in: general estimation literature for biowaste).

b) Cost of Biogas

It is possible to estimate the biogas cost by linking these steps of the biogas chain and summing up the needs for investment, operation and maintenance cost.

Revenues: bioproduct selling, carbon credit

a. Electricity generated from biogas

$$E\left(\frac{kWh}{year}\right) = \dot{m}_{biogas} \times Energy\ content_{biogas} \times \eta_{el}$$

Where:
– $\dot{m}_{biogas}$ is the amount of biogas per year
– $Energy\ content_{biogas}$ is the low calorific value of biogas
– η_{el} is the electricity efficiency

c) Organic fertiliser

The calculation of organic fertiliser is based on the mass balance of the digestate. The volume of the mass treated after AD process remains with 90 to 95% of their original volume

d) Economic Analysis of biogas and water purification system

- **Net Present Value (NPV)**

The NPV is the sum of the present value of money moved into and out of an investment project. It determines the present rate of the total investment cost, considering the changes in the value of the capital over time. For a project to be feasible or profitable, the NPV should be higher or equal to zero (0)

$$NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where:

i is the discount rate
– N is the total number of periods
– R_t is the cash flow in year t

- **Internal Rate of Return (IRR)**

IRR is the value when the present value of the costs and the present value of the benefits are equal. It is also the discount rate at which the NPV is zero [11].

$$IRR = NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} = 0$$

- **Payback Period**

The Payback Period (PB) is the length of time required to recover the costs invested for the biogas plant. The costs include the operating and maintenance cost.

$$PB = \frac{Total\ amount\ invested}{Estimated\ Annual\ Cash\ Flows}$$

- **Levelized Cost of Electricity (LCOE)**

The LCOE is an indicator for the price of electricity or heat required for a project where the revenues would equal costs, including making a return on the capital invested equal to the discount rate [12]. It is expressed as follow

$$LCOE = \frac{\sum_t \quad ((I_t + O\&M_t + B_t - C_t + D_t) \times (1+i)^{-t})}{\sum_t \quad (E_t \times (1+i)^{-t})}$$

Where:

– I_t: is the investment cost in year t

– $O\&M_t$: is the operation and maintenance cost in year t

– B_t: is the cost of producing the biowaste in year t

– C_t: is the carbon credit

– D_t: is the decommissioning cost in year t at the end of the lifetime of the plant

– E_t: is the electricity produced in years t (kWh)

2.3. RESULTS

2.3.1. *Definition of local value chains and innovative circular economy models*

2.3.1.1. *Definition of the local value chain in SL context*

The biogas supply chain (BSC) comprises five main phases including biomass feedstock sourcing (P1), transportation(P2), pre-processing (P3), biogas production (P4), and distribution (P5)(see figure 2.2). Each process receives a main input and produces a main output. All these outputs are physical products, except for the output of the transportation process, which is the distance covered between the biomass feedstock producer and the biogas producer. There are also four primary inputs (gasoline, workforce, electricity and other biomass), four types of waste (CO_2, N_2O, CH_4 and NH3) and three by-products sold as a value-added (solid digestate, liquid digestate and heat). During the phase P1, the biomass feedstock is collected or produced from farms or dumping sites, which is then loaded into trucks to be transported into the biogas production site (P2). Then, the biomass feedstock is pre-processed or sorted to get rid of undesirable compounds (P3). Then, the feedstock is macerated and

mixed to form a blend to increase the biogas yield before it is converted into biogas and digestate by means of anaerobic digestion (AD). Then, the biogas obtained is distributed for combined heat and power generation to produce electricity and heat. As by product, bio-fertilizers will be extracted to improve the soil quality and thereby increase the agricultural yield. The Water produced during the supply chain will be purified by a water purification component using the electricity produced by the biogas plant. The electricity and heat produced will be used for water purification.

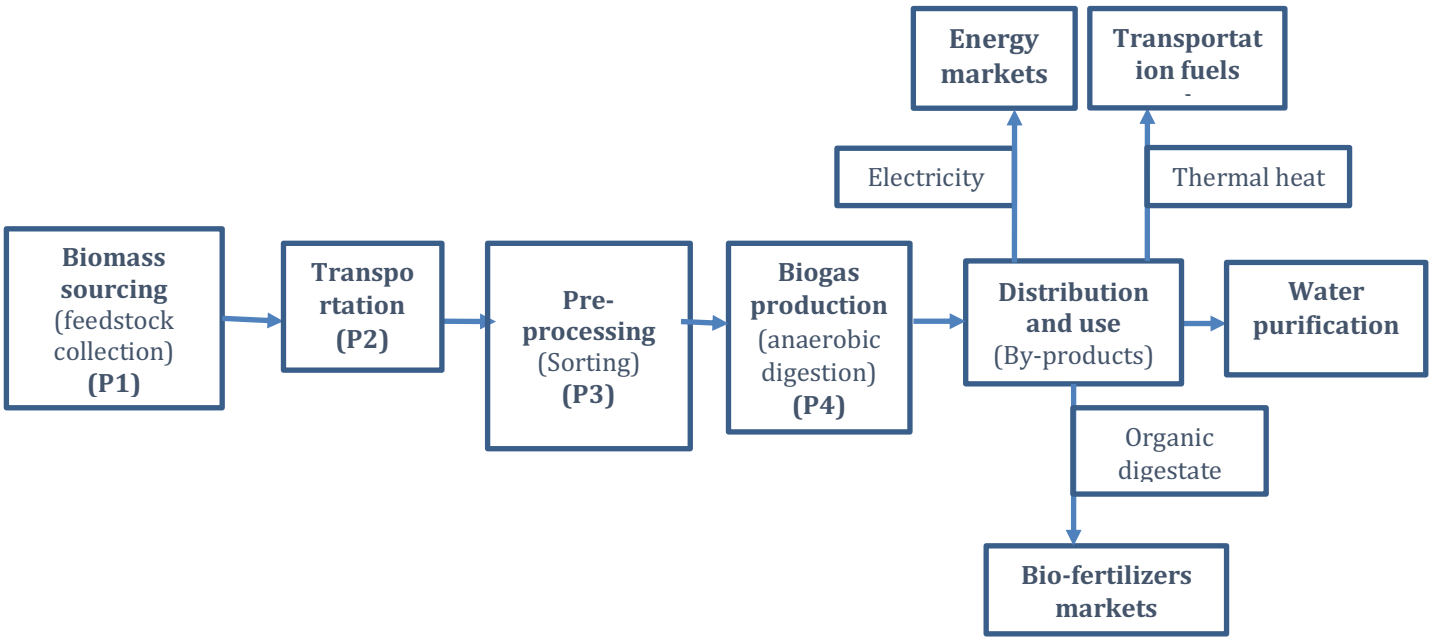


Figure 2. 2: *summarizes the main process of the biogas supply chain.*

2.3.1.2. Potential of local value chains

The production and use of bioenergy has gained a lot of interest in the scientific and decision-making arena as it can potentially reduce the greenhouse gas emissions (GHGS). For the local value chain of the biogas production and water purification, this report will be interested in the amount of biomass available as primary energy supply without compromising the supply for food crops as well as the human resources available for the sustainable production of the biogas. The variables such as the municipal waste production per capita, the food waste production day, Recycling rate of municipal waste, agricultural waste, the End of Life (EoL) recycling input rate for Sierra Leone will be assessed. Thus, both technical and economic potential of biogas production in Sierra Leone will be highlighted.

For instance, regarding the biomass potential in SL, there is a huge potential of biomass resources. Indeed, the annual total waste from crops (rice husks and straw) is estimated to 656,400 tons, amounting to a total generation of 2,706 GWh (REEEP, 2012). In addition to municipal waste and agricultural residues, the sugarcane farms could be also promoted for the production of the biogas. Indeed, there is also a potential of 32 MW of biofuels that can be produced from sugarcane (REEEP, 2012). In addition to the available biomass in the country, there are also viable biomass production systems in Sierra Leone implemented by The Waste Transformer (TWT), Addax bioenergy and among others. Moreover, many associations and women groups are also present for the biowaste collection.

In terms of economic potential, a recent initiative led by Addax bioenergy, the construction of a biomass fuelled power plant and sugarcane ethanol refinery in the country will be an important asset for the implementation of the local biogas plant and water purification system. Indeed, the power plant is expected to produce 90 million litres of ethanol annually and will be powered entirely through the conjoined biomass station, which will also feed renewable power into the national grid system. The biogas production has also the potential to reduce the carbon emissions that will have a positive implication leading to some additional costs.

2.3.1.3. Innovative circular economy models

The implementation of the Circular Economy Model (CBM) might include various elements as depicted in the Figure 2.3 below. Local Value Chain creation is concerned with the key stakeholders or partners (the network of actors that make the business model work, of which can take the form of strategic alliance, joint ventures, buyer-supplier relationships, or coopetition), key activities to be carried out (to show the most important things to be done to make the business model work), and key resources (Essential assets for the local value creation, market and technical maintenance, and revenue creation). Hence, for each context, the different elements mentioned above will be used in building the business model to reach the objectives stated in the grant agreement.

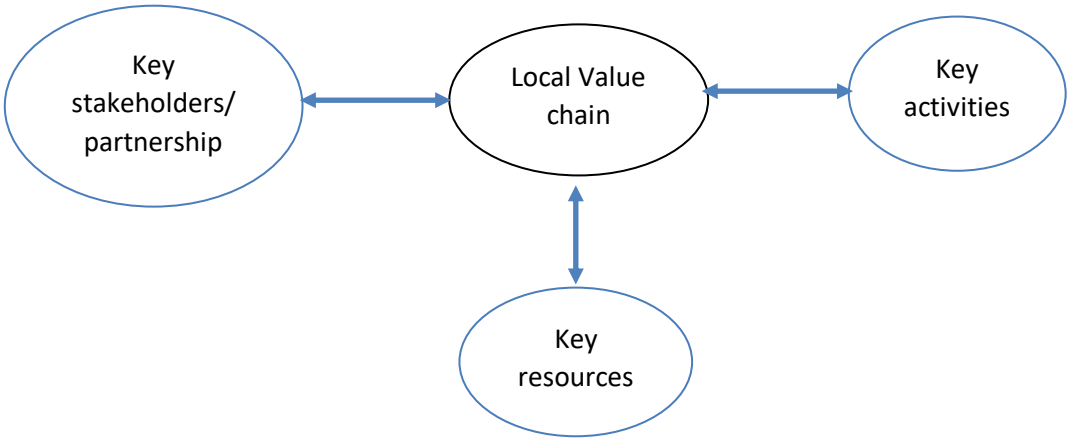


Figure 2. 3: *Local value Creation Circular business model*

The economic business model will consist of assessing the costs (raw material cost and biogas production cost) and the revenues (biofertilizers sales). The different elements of the local value chain are :

- **Stakeholders/Partners**

Several partners including farmers, market women, retailers, agricultural agencies, as well as municipalities could be involved in the sustainable implementation of the biogas plant.

- **Activities**

Various activities should be undertaken in the development of the biogas plant. These activities might include but are not limited to Bioproducts management; managing chains; sales, transportation, lobbying, etc. Hence, the cost and the revenues related to these activities should be incorporated in the business model

- **Resource availability**

The availability of resources is very important for the implementation of any project. Hence, for an effective local value chain for the biogas production, the following key resources are necessary:

- **Local Expertise:** this entails technical knowledge and bakery application of a partner that complements. In addition, the availability of machinery and equipment, technologies and local technical personnel. Moreover, subsidies from the Ministry of Agriculture largely supported the execution of the project. Hence, the impact of local expertise on the performance of the costs and revenues.
- **Biomass resources**
  To quantify the potential for biogas production, the following metrics including, Sewage, agricultural waste, food waste, municipal waste per day, will be used.

2.3.1.4. Channels: Social media, Website

The Figure2.4 below shows the schematic description of a potential CBM for the SL context

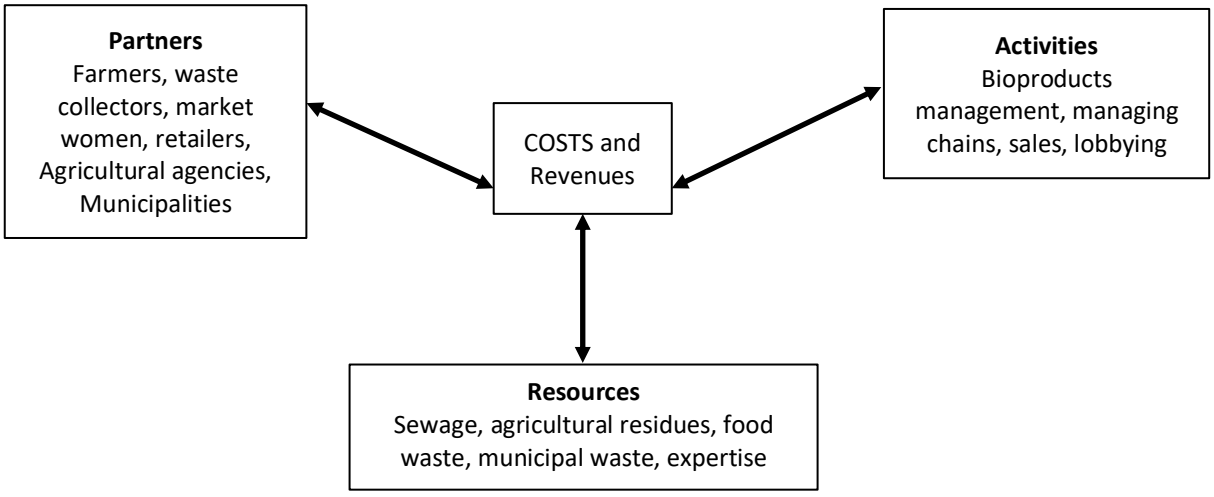


Figure 2. 4: *Local value Chain Circular business model for Biogas production*

In this business model, we are seeking to achieve the following techno economic benefits by increasing the nutrients availability, using more efficient distribution technique, and lowering the distribution cost, as well as investment support.

The investment requirements and the operating and maintenance cost will be specified at each step of the supply chain:

- Biogas plant
- Biogas transportation through local gas pipelines
- Measurement equipment's

- Gas dryers
- Instruments for pressure elevation

2.3.1.5. Techno-economic feasibilities study for SL context

This section presents the estimations of the amounts of biogas and organic fertilizer that can be generated by treating the municipal solid waste (MSW) using the AD. The calculations are made considering the total potential of organic biowaste that can be produced daily as well as by considering a treatment of 350 kg/daily.

2.3.1.6. Biomass energy potential

Figure 2.5 shows the share of total waste that could be generated annually in SL. From the figure it is noticeable that about 80% are organic waste that could be potentially use for the biogas production. The other remainder (non-organic) include

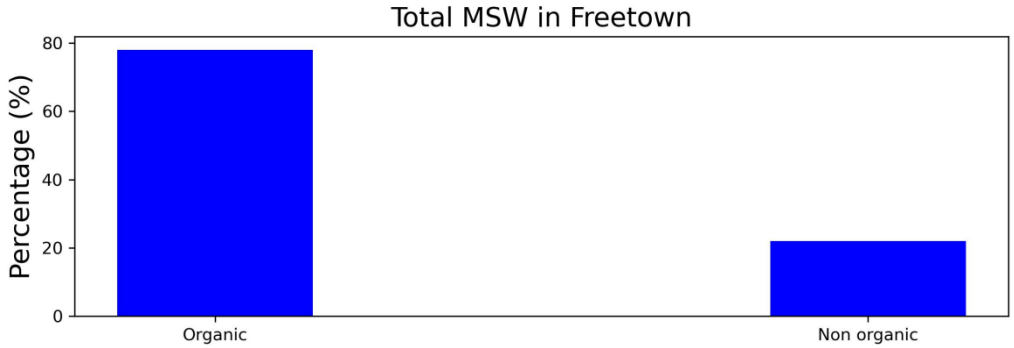


Figure 2. 5: *share of organic and non-organic waste in Sierra Leone*

2.3.1.7. Biogas production potential

The total amount of biogas produced annually using a daily organic load rate of 350 kg is estimated at 20235 m^3 while the methane production is 12402 m^3. The amount of biogas produced per tonne of waste was estimated 0.115 t/t of biowaste. This value was calculated considering a biogas density of 1.15 kg/Nm^3 which is the average value found in literature for biogas produced from AD processes [6], [7], [8]. A summary of these results can be seen in Table 2.2 below

Table 2. 2: *Key characteristics for the Biogas system*

Biogas characteristics	**Values**	**Units**
Biogas yield	176	Nm^3/t of biowaste
Biogas density	1.15	Kg/ Nm^3
Biogas estimated production per ton of biowaste	0.182	t biogas/t of biowaste
Total biogas produced	20 235	Nm^3/year
Methane content	61.3	%
Total methane produced	12402	Nm^3/year

The biogas yield is estimated to 176 Nm^3/t of biowaste, a value that is slightly higher than that found in literature which is 100 Nm^3/t of biowaste [9]. This indicates the technical potential of biogas production over the area.

2.3.1.8. Electricity and heat production from biogas

The electricity generated based on a daily feedstock of 350 kg is estimated to 102 kWhe per day with about 22.61 kWhe consumed by the biogas plant ("Self-Use" Electrical Load of Biogas Plant) resulting to a net daily electricity production of 79 Kwh. Hence, the annual total electricity that could be produced can be estimated to 28,835 kWhe/year. On the other hand, the daily total heat production is estimated to 211 kWh_{th} where about 70 kWh_{th} is consumed by the biogas plant resulting to a net heat output of 141 kWh_{th}. Corresponding to a total annual net heat production of 51465 kWh_{th}. Based on these values, the energy content of the biogas is estimated to be 5.65 Kwh/ Nm^3; this value is comparable to that found in literature which is about 6 kWh/Nm3 [9].

2.3.1.9. Organic fertiliser production

The amount of organic fertilizer is the amount of digestate production outflow, which is estimated to be 325.5 Litres a day where 10 kg represent the solid fraction and 316 liters the liquid one. Furthermore, by assuming a waste density of 0.53 kg/L, the total amount of digestate to be composted is estimated to 177.48 kg/day, resulting in an annual value of 64 780 kg a year of biofertilizer to be sold. Moreover, the daily net outputs of Nitrogen, Phosphorus, and Potassium are respectively 1.6163875 kg; 0.25725 kg; 0.77175kg. Hence, the annual values are 589.98; 93.90 and 281.70 kg a year.

2.3.1.10. Economic analysis

The sections hereunder present the economic analysis. Two different scenarios summarized in the Table below are considered:

Table 2. 3: *Scenarios description and business model*

	Scenario 1	**Scenario 2**
Description	The biogas plant is a concessionary company responsible for treating the waste. The collection and transport operations are assumed to be done by a local transportation company operating in Freetown.	The biogas plant is a concessionary company on charge of the collection, transport and treatment of the biowaste
Business model	In this scenario, the waste treatment company could be a new private concessionary company or the municipality of the city of Freetown.	The company that could be suitable for this scenario is an existing company of the Freetown city with an experience in this matter and has the equipment for the transportation of waste in the city.

Hence, for each scenario various considerations will be made by including or not the carbon credits (CC) and water purification component.

2.3.1.11. Investments costs, O & M costs, and transportation costs

The CAPEX for both scenarios 1 and 2 are estimated based on investment cost per kilowatt of electricity, operating and maintenance cost and transportation cost. The administrative costs are included in the O&M cost. According to the literature the investment costs of a biogas plant per kilowatt is about 5000 euro while the annual maintenance cost is considered to be about 2 % of the total investment cost. The costs related to the transportation of the biowaste are also included in calculation of the capex expenditure of the biogas plant. The inclusion of these resulted in a total cost of 72,000 and 75,000 euro per kW for scenarios 1 and 2 respectively.

2.3.1.12. Incomes generated

The incomes generated annually from each scenario come mainly from the electricity sales, biofertilizer sales, as well as the revenues from the carbon credits (CC). The incomes for Scenarios 1 and 2 are presented in Table 2.5

Table 2. 4: *Annual Incomes of various scenarios*

Income	**Scenario 1.1 (with CC)**	**Scenario 1.2 (without CC)**	**Scenario 2.1 (with CC)**	**Scenario 2.2 (without CC)**
Electricity sales	4325	4325	4325	4325
Biofertilizer sales	47346	47346	47346	47346
Revenues from CC	432	-	432	-
Transport fee	-	-	15,500	15,500
Total (Euro/year)	**52103**	**51671**	**67603**	**67171**

Figure 2.6 shows the distribution of the incomes per source. For each of the four scenarios, the biofertilizer sales are the main contributor of the total income with a share of over 90% while the electricity sales contribute with values of 6.4 to 8.4 % of the income depending on the scenarios. Regarding the transportation fees, about 23 % of the total income comes from it and less than 1% from the carbon revenues. In the cases of Scenarios 1.1 and 1.2, the income from transport is not considered.

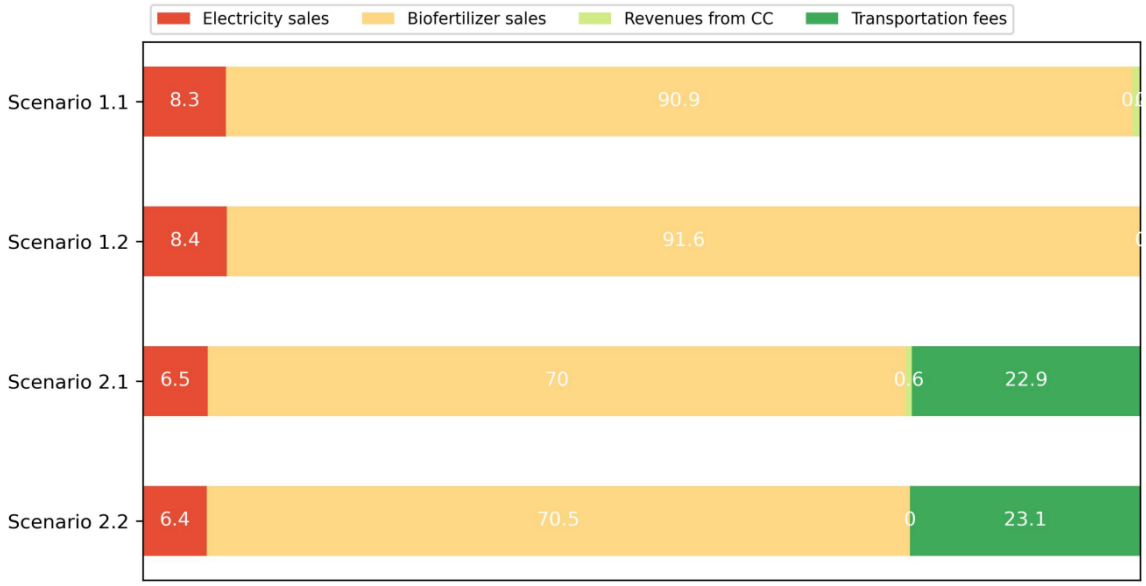


Figure 2. 6: *Income distribution from different sources*

2.3.1.13. Investments returns

Table 2.6 displays the results of each scenario. It can be seen that the Net Present Value (NPV) is positive for all scenarios. This indicates that the scenarios are economically feasible. The Scenario 1 with carbon credits (scenario 1.1) is the most attractive since the NPV and IRR are the highest values (203,821 euro and 8.1% respectively). Therefore, the concessionary company responsible for collecting, transporting and treating the waste can recover the investment costs and get benefits from implementing the biogas plant. Furthermore, the IRR results from all the scenarios are bigger than the assumed discount rate of 5 % supporting the results of the NPV method. Concerning the payback time, the four scenarios have similar results. Approximately 6 to 7 years are needed to recover 100 % of the investment costs of the project.

Table 2. 5: *LCOE values for different scenarios*

Scenarios	NPV (euros)	IRR (%)	Payback time (years)
Scenario 1.1	203,821	8.1	6.3
Scenario 1.2	199,322	7.9	6.4
Scenario 2.1	188,321	7.2	6.6
Scenario 2.2	183,832	7.0	6.7

2.3.1.14. Levelized Cost of Electricity (LCOE)

The Levelized Costs of Electricity (LCOE) for the various scenarios are presented in table 2.7. Based on these results, scenario 2 with carbon credit (scenario 2.2) will be the preferred option because the LCOE is lower. However, it has to be noted that this method evaluates only the costs of generating the electricity. For this reason, the method is used to compare the cost of electricity from the biogas plant to that of the other technologies and not for decision-making unlike in the case of the NPV and IRR methods where the whole project costs and revenues including the energy value are evaluated. However, it is worth noting that for the four (4) scenarios, the LCOE values obtained are significantly higher than the current LCOE in Sierra Leone, making it difficult to incentive for producing biogas in Sierra Leone. Therefore, it is necessary to search for an economic mechanism to reduce the LCOE for biogas.

Table 2. 6: *Levelized Cost of Electricity (LCOE) results*

Scenarios	LCOE (euro/kWh)
Scenario 1.1	0.473
Scenario 1.2	0.479
Scenario 2.1	0.280
Scenario 2.2	0.285

2.3.1.15. Sensitivity analysis of the biogas plant

The outcomes from the economic analysis of the scenarios are positive when considering investing in the biogas plant. However, some of the costs used in the analysis are average values for small-biogas technologies. Therefore, it is important to analyze how a change on the parameters influences the NPV. The NPV was selected due to its relevance for stakeholders when making decisions. The parameters evaluated were those related to the investment costs as well as the operating and maintenance costs (O&M costs). The investment costs and O&M costs were selected because several assumptions of the average values were based in literature for general small-scale biogas plants. As explained earlier, the sensitivity analysis was done for the most attractive scenario that in this case is Scenario II with carbon credits. The parameters were evaluated by increasing every 5 % and in a range from -25% to 25%. All these variations are illustrated in Figure 2.7.

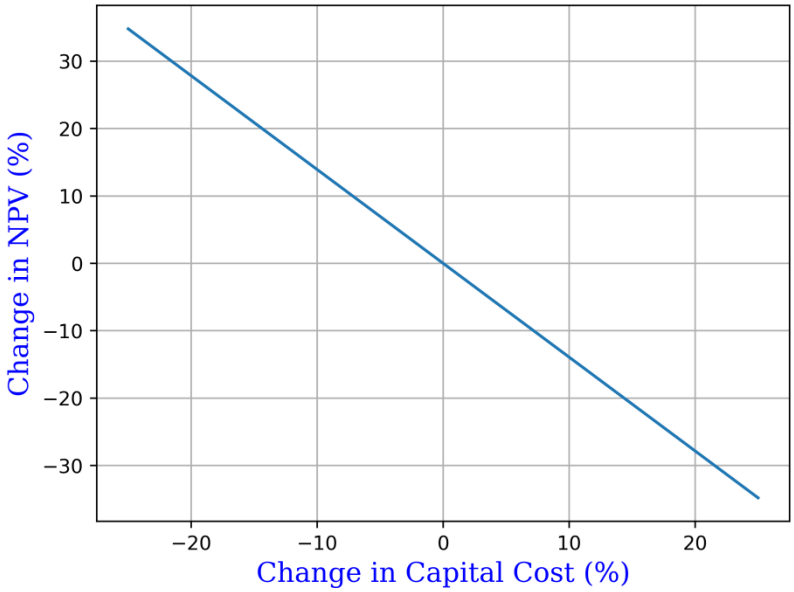


Figure 2. 7: *Sensitivity analysis of biogas plant*

Furthermore, Figure 2.7 shows that the variation of -25% on the investment costs generates an increase of about 35% in the NPV value while a decrease of 25% of investments generate an increment of about -35% in the net present value. This depicts the significant importance of change of investment costs on the outcomes of the project. Hence, since the capital cost of the biodigester is expected to decrease (TWT is working to reduce the price of the biodigester cost), the bioenergy technology can be considered as one of the more promising renewable energy technologies in Sierra Leone in future, thereby resulting the techno economic feasibility of the project.

2.3.1.16. Social impact of the local value chains (Partner: HUD)

In this section, a preliminary and qualitative analysis of the social value chain and circular economy of the Integrated Community Energy Systems implemented in the three contexts is presented, as the implementation of these structures has not been completed at the time of this deliverable.

For the analysis, inspiration has been taken from the Guidelines for Value Chain Selection developed by GIZ in cooperation with the International Labour Office in 2015[3], and it is done through the analysis of 8 principles: job creation, market growth, local resources, added value, inclusiveness of disadvantaged or marginalised social groups, decent working conditions that improve workers' life, social impact of the value chain on the surrounding communities and society at large, participation of the community.

The technological solution implemented in Sierra Leone context allows to convert waste into new products such as energy, water, and fertilizers. In peri-urban and urban contexts, access to energy and fertilizer for efficient local food production is one of the key global sustainability challenges. Food security is intimately tied to access to fertiliser and the long-term sustainability of agricultural production relies on the replenishment of soil organic content to maintain fertility.

Below is a discussion of the eight principles of the circular economy and social value chain in Sierra Leone:

[3] https://www.ilo.org/media/549576/download

- **Job creation:** the operation of the biodigester requires waste to be transformed into energy and fertiliser. Therefore, people will be needed to collect this waste for the biodigester to function. This has a positive impact on local job creation.
- **Market growth:** Biodigesters are devices that produce energy and fertiliser autonomously. Therefore, it is easy to bring them to communities to supply them with energy. However, as in the case of solar panels, the installation of these devices requires a very high initial investment, which many communities cannot afford.
- **Local resources:** The use of local waste to transform it into energy and fertiliser promotes access to energy as well as waste recycling. Thus, local resources are used to supply the population with energy, which favours autonomy and circularity.
- **Added value:** The added value of these systems is the generation of energy and fertilizer locally, which favours and strengthens the economic and labour structures of the area, in addition to the creation of skills in the community. In addition, the production of energy while recycling waste has a greater impact on the community. Also, as said for the Madagascar case, the integration of the community in the system through the ICES favours the appropriation of the system by the community, as well as its participation in the production, management, distribution and consumption of this energy, and participation in the decision-making processes. This means that the needs of the communities are better analysed and covered and has very positive impacts on community strengthening (sense of community, community engagement, horizontal governance, distribution of resources...).
- **Inclusiveness of disadvantaged or marginalised social groups:** The need to hire people to collect the waste promotes job creation, which can target disadvantaged or marginalised social groups, improving their economic situation. Thus, the inclusion of these people in the ICESs promotes their participation in the management of the ICESs, having a great impact on the empowerment of these social groups.
- **Decent working conditions that improve workers' life:** The fact of needing waste on a continuous and regular basis enables these workers to have access to a stable job and income, improving their economic resources and their quality of life.
- **Social impact of the value chain on the surrounding communities and society at large:** While the energy will be used in the health centre, the creation of fertiliser can improve access to fertiliser for local communities in the area, and also promotes the possibility of selling this resource, which translates into an increase in economic resources. Also, the creation of employment through waste collection improves people's economic resources. Furthermore, the production of energy locally promotes the autonomy of the centre, improving its operating conditions, which has a very positive impact on the development of the health activities that are carried out there, having a great impact on the communities that make use of the centre.
- **Participation of the community:** The inclusion of the community in this system has two parts: firstly, staff working in the health centre can be included in the ICES; secondly, people working in waste collection can also be included in the ICES. This opens the door to community participation in various steps of the energy production chain as well as exchange and community empowerment between different structures.

2.3.1.17. Biogas production and water purification in Sierra Leone

The water purification with anaerobic digestion of wastewater treatment plants (water purification system) is also incorporated in the local value chain. The benefits of AD wastewater are among others the production of biogas for electricity and heat production, the production of biofertilizer through composting and the generation of clean water. As an important consumer and generator of energy, the water purification system could be a key player that can influence development towards energy sustainability, contributing to value chain creation. Electricity produced from the biogas plant could

be used for water purification thereby contributing to the electricity market. On the other hand wastewater from municipalities and industrial sectors could be also processed to generate clean water as well as biogas and biofertilizer using the following steps:

- The sewage sludge (wastewater pre-processed) is pumped in an anaerobic digester where digestion takes place. During the retention, the microorganisms break down part of organic matter in the sludge and produce biogas.
- The raw biogas produced is dried and hydrogen sulphide and other trace substances are removed. After cleaning, the biogas can be combusted in a combined heat and power (CHP) engine to produce electricity and heat.
- Then the remaining digested sludge (after AD) is composted to produce biofertilizer.
- Finally, the digester liquids obtained from the dewatering of digester sludge are processed to remove the nitrogen and undergo further treatment in a solar catalytic reactor.

The water purification aspect with photocatalytic solar reactor is taken into account in work package 5 in **D5.4: *Assessment of photocatalytic pilot plant for solar water treatment***

2.3.2. Implementation of the value chains and circular economy

Figure 2.8 shows the diagram summarizing the local value chain of biogas plant. Indeed, the waste is used to produce biogas for electricity and heat generation through a combined heat and power (CHP) system and biofertilizer. The electricity and heat are used for the energy market while the biofertilizer is sold in the agriculture market. The agricultural residues as well as the municipal solid waste (MSW) from the city are then used to sustain the biomass resources. From this techno economic feasibility study, it is found that about 0.182 t biogas/t biowaste can be produced resulting in high technical potential. In addition, it is also found that about 64,000 kg of biofertilizer can be produced yearly based on 350 kg of daily organic load.

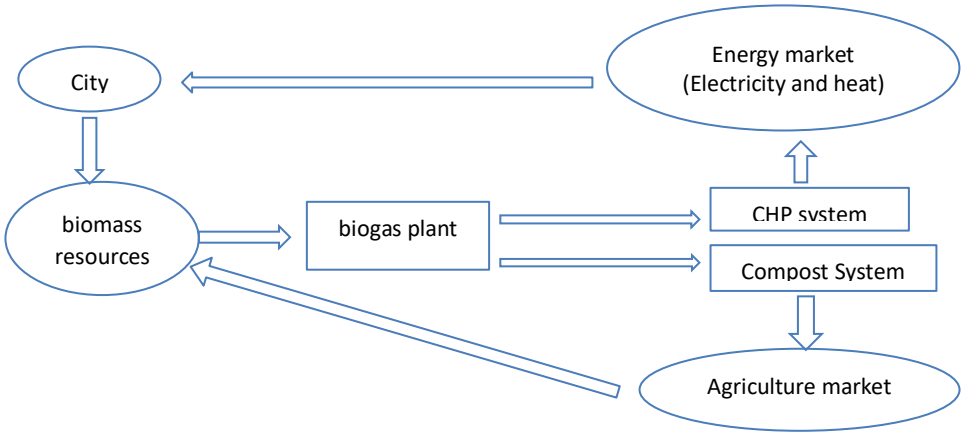


Figure 2. 8: *Local value chain creation and waste streams valorisation in Sierra Leone*

2.4. CONCLUSION AND RECOMMENDATIONS

As part of the objectives of the ENERGICA project, this study seeks to investigate the potential for local value chain and circular economy for the biogas production in Sierra Leone. Key techno-economic indicators have been considered for this purpose. The results are summarized as follows:

- The organic wastes represent approximately 80% of the total Municipal Solid Waste (MSW) generated in Sierra Leone indicating a high potential for resource availability and thereby biomass feedstock supply security;
- The technical potential for biogas production is estimated to be 182 kg/ton of biowaste showing the high technical potential for the biogas plant. Hence, using a daily organic load rate of 350 kg, the total biogas that can be produced annually is estimated to 20235 Nm^3/year. This will result to an annual net electricity and net heat production of 28835 kWh_e/year and 51465 kWh_{th} respectively;
- The economic analysis using the NPV and IRR revealed that the biogas plant is economically feasible. Indeed, positive values of NPV are obtained for the four scenarios considered for the business model, indicating the profitability of biogas plant implementation in Sierra Leone. However, it should be noted that the most attractive business model is the scenario 1 with carbon credit. In this scenario, it has been considered that the concessionary company responsible for collecting, transporting and treating the waste can recover the investment costs and get benefits from implementing the biogas plant.
- Furthermore, the results show that the payback period for all scenarios is estimated to be about 6 years. In other terms, it will require at least six years to recover the investments made. Nevertheless, this figure could change if the investment costs reduce;
- The amount of biofertilizer that can be sold in the market on a basis of 350 kg daily organic load is estimated to be 64780 kg/year. Besides the biofertilzer, other bioproducts can be also produced. Indeed, the amounts of nitrogen, phosphorus, and potassium that could be generated are estimated respectively to 1.6163875 kg/year; 0.25725 kg/year; 0.77175kg/year.
- The social benefits include job creation, access to clean and renewable energy, agricultural productivity as well as market growth. Indeed, the possibility of using organic fertilizer for soil recovery and agriculture can help to promote the production and consumption of local products. And finally, the improvement in the environmental conditions could provide a better living and sanitary conditions for the local inhabitants.
- The environmental benefits from the biogas plant are estimated based on the avoided carbon dioxide (CO_2) emissions. A total of about 14 tCO_2 /year could be avoided for electricity generation from biogas plants. This could lead to a potential contribution for the mitigation of climate change.

To sum up, a small-scale biogas plant could be a potential generator for green electricity and heat on one hand, and the generation of biofertilizer on the other hand for the agricultural market through the treatment of organic waste (MSW, market waste, agricultural residues, etc.). The biogas plant can achieve cost-recovery in the energy and agriculture market while at the same time contributing to waste management. For this reason, support from the government and municipalities in form of subsidies, awareness promotion and other economic incentives are necessary. The low-tech biogas plant can also provide to the country not only with economic profits but also environmental and social benefits.

The assessment of the local value chains and circular economy shows a great potential of biogas production and water purification in the Sierra Leone context. However, further improvement can be achieved on the following recommendations:

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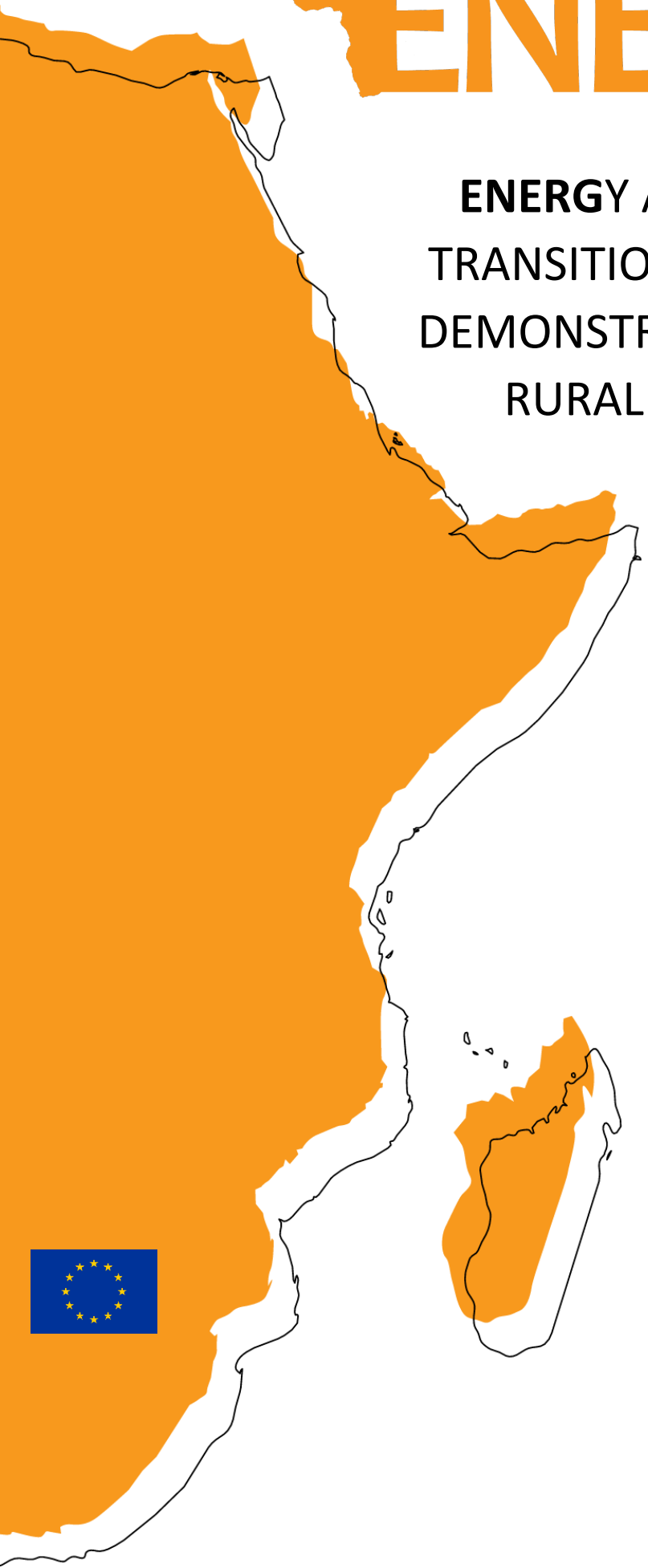
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ENERGICA

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ENERGY ACCESS AND GREEN TRANSITION COLLABORATIVELY DEMONSTRATED IN URBAN AND RURAL AREAS IN AFR**ICA**



PART C, Capacity for local value chains and Circular Economy - Kenya Context

3.1 KENYA CONTEXT

3.1.1 Demonstrator context – Kenya

Roam is an Original Design Manufacturer (ODM) of electric motorcycles based in Nairobi, Kenya. Roam designs and assembles the Roam Air, an electric motorcycle tailored for moto-taxi usage in Kenya and Sub-Saharan Africa. The Roam Air is sold with a lithium-ion battery with a capacity of 3.2 kWh, providing a range of about 70km. The Roam Air can carry up to two batteries.

According to the Boda-Boda Safety Association of Kenya (BAK) [1], there are an estimated 1.2 million of moto-taxi riders in Kenya, called boda-bodas. Switching from fuel to electric motorcycles enables boda-boda riders to save on energy and maintenance expenses, increasing their daily net income.

Roam enables moto-taxi riders to purchase the Roam Air including a battery and a portable charger. Roam has deployed networks of charging stations called the Roam Hubs, where riders can come to charge their battery and/or rent an extra battery. This flexibility of charging their battery anywhere using their own charger or by accessing battery charging or battery rental services at the Roam Hubs mitigates the challenge of range anxiety for boda-boda riders, enabling them to operate their motorcycle through the day.



Figure 3. 1: *The Roam Air motorcycle with two batteries*



Figure 3. 2: *The Roam Hub charging station*

In Work Package 6 (‘Urban grid flexibility through electric mobility – Kenya’), Roam is deploying 150 electric motorcycles in Nairobi together with a network of 15 Charging Hubs for boda-boda operators. Roam will then replicate a similar e-mobility demonstrator in Kisumu, a major Kenyan city located in Western Kenya, with an additional 12 Charging Hubs.

The present section aims at identifying the potential for local value chains and circular economy models for the electric motorcycles equipped with lithium-ion batteries deployed by Roam in Kenya, and describes how these concepts of value chain localization and circular economy are being implemented by Roam in the Kenyan e-mobility demonstrator.

3.1.2 Energy situation of the Kenyan demonstrator

Based on the official bi-annual statistics published by EPRA (Energy and Petroleum Regulation Authority), the national energy regulator, Kenya generated 85% of its electricity consumed from renewable energies (geothermal electricity, hydropower, wind turbines and solar photovoltaics) during the second half of 2023 [18]. Only 8.9% of the electricity consumed came from thermal power plants, which use the combustion of fossil fuels to generate electricity, generating CO2 emissions.

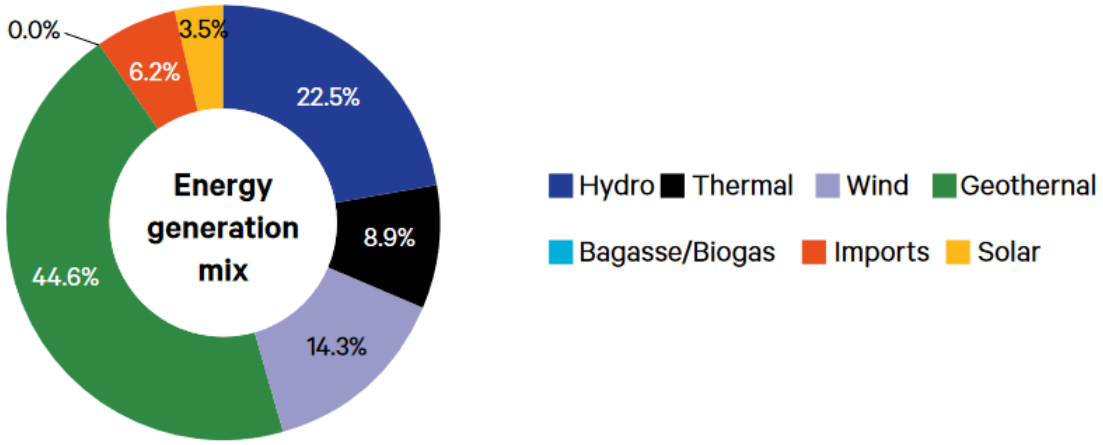


Figure 3. 3: *Share of electricity generation by energy source from June to December 2023 - EPRA*

This large share of electricity generated from renewable energy sources provides a clear benefit for the country to benefit from deploying electric vehicles in terms of savings on fuel imports, reduction in urban air pollution and CO2 emissions [18]. In the same report published for financial year 2023/2024 [18], EPRA estimates that the electricity consumption for charging of electric vehicles in the country has more than doubled from about 30,000 kWh in July 2023 to 75,000 kWh in December 2023, due to the growth of the number of electric vehicles registered in the country. The report also mentions that the adoption of EVs in the country has the potential to increase electricity demand during off-peak periods (mainly at night), where consumption is significantly lower than during peak hours.

The draft national e-mobility policy report published in March 2024 by the national E-mobility Task Force appointed by the Kenyan government indicates that in 2015, the transportation sector utilized 72% of petroleum products imported in the country, and accounted for 13% of green-house gas emissions in the country [19].

3.1.3 Literature review – Kenya

3.1.3.1 Growth and potential of electric motorcycles in Kenya

As shown on the chart below, the number of new motorcycles registered in Kenya has rapidly increased over the past few years, from about 120,000 units sold in 2016 to 290,000 units in 2021 [2].

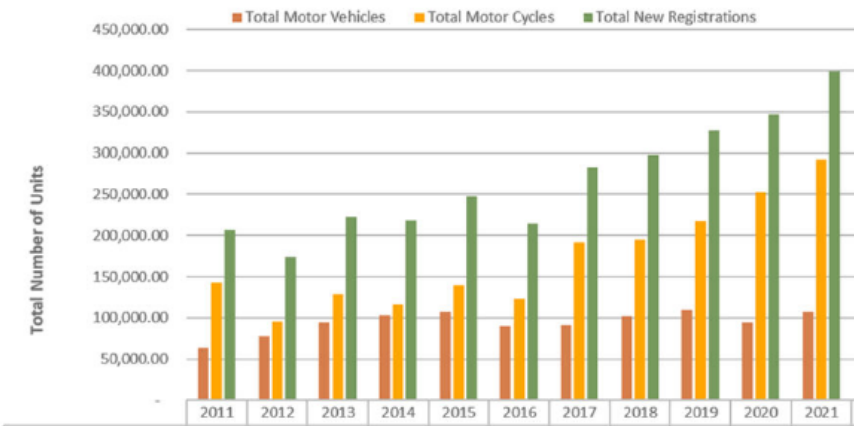


Figure 3. 4: *Number of new vehicles registered in Kenya per year per vehicle type, GIZ*

According to EPRA (Kenyan Energy and Petroleum Regulatory Authority), there were a record 2,694 electric vehicles registered in the country between July and December 2023, most of them being electric motorcycles. These new registrations raise the total number of EVs registered in the country to 3,753 at the end of 2023. This rapid increase in electric motorcycles in Kenya is driven by a dynamic private sector, with more than 10 start-ups deploying electric motorcycles with battery charging or battery swapping services in Nairobi. This trend is also driven by favourable policy implemented by the government in favour of electric vehicles. [3]

According to a study conducted by Manufacturing Africa in 2021 [4], electric motorcycles could represent between 18 and 40% of total sales of motorcycles in the country by 2030. The rapid uptake of electric motorcycles in the country will mainly be enabled by the economic benefit of electric motorcycles relative to fuel motorcycles. The switch from fuel to electric motorcycles is driven by the lower operating expenses of electric motorcycles, resulting in a significantly lower TCO (Total Cost of Ownership) already today for commercial boda-boda riders.

3.1.3.2 Local assembly and manufacturing of electric motorcycles

The Manufacturing Africa study emphasizes on the importance of assembling electric motorcycles locally in Kenya combined with favorable tax incentives to make the purchase cost of an electric motorcycle cost-competitive with a fuel motorcycle, which will further accelerate the transition.

Furthermore, the study estimates that the electric motorcycle industry has the potential to create between 900 and 2,000 direct jobs by 2030, and between 5,000 and 6,700 by 2040. These direct jobs would be created in the sectors of e-motorcycle assembly, e-motorcycle repair, e-motorcycle sale and operation of battery charging infrastructure.

In line with the East African Community (EAC) policy, the Kenyan regulation has been highly supportive of local assembly and manufacturing of motorcycles. In 2017, the government of President Kenyatta had set local manufacturing as one of the Big 4 Economic Pillars (together with food security, affordable housing and universal health care) for developing the country and realizing the national vision for 2030 [5]. The motorcycle assembly industry in Kenya is governed by Legal notice 112 date of June 2020. This regulation has set tax incentives for assembling motorcycles from CKD kits (completely knocked down) as opposed to importing motorcycles fully built from Asia (India, China or Japan). In addition, this Legal Notice has set some obligation for CKD motorcycle importers and assemblers to locally source 14 motorcycle parts from local part manufacturers. This regulation aims at supporting local industrialization and job creation by favoring the assembly of motorcycles from CKD kits and local manufacturing of motorcycle parts.

In 2023, the Kenyan government started implementing policy incentives in favor of electric motorcycles. The Finance Act of 2023 implemented in the regulation three tax incentives supporting e-motorcycles [6]:

- Zero rating of VAT for electric motorcycles
- Exemption of electric motorcycles from excise duty (previously about 100 USD, as for fuel motorcycles)
- Reduction of corporate tax from 30% to 15% for the initial 5 years of operations for EV companies setting up plants for local assembly of electric motorcycles from CKD kits. Companies can extend these benefits for an additional 5 years by increasing their local value addition to 50%, through sourcing of locally manufactured parts.

In Kenya, Roam, as well as other e-mobility start-ups such as Arc Ride, PowerHive, Ampersand or Spiro have set-up local assembly facilities to assemble electric motorcycles from CKD kits. In its 2023 study 'Charging Ahead: accelerating e-mobility in Africa', PREO (Powering Renewable Energy Opportunities), a program providing funding for sustainable energy start-ups in Africa, confirms that [7]:
'Several manufacturers already import parts, assemble electric motorcycles and offer maintenance services for electric motorcycle owners, thereby capturing some supply chain value in-country. Opportunities for local manufacturing of parts could significantly boost the impact of the electric motorcycle sector on local economic development and create more jobs.'
So far, most of the e-motorcycle start-ups in Kenya have focused on setting up assembly lines for motorcycles, but have not started assembling lithium-ion battery packs used in electric motorcycles. This might come in a second phase, especially if the policy implements tax incentives for importing lithium battery cells rather than EV battery packs. In the neighboring countries of East Africa, Ampersand and Gogo have started importing battery cells to assemble battery packs locally in Rwanda and Uganda respectively.

3.1.3.3 Filling the skills gaps to enhance localization of the e-motorcycle and battery value chain

As previously mentioned, the development of electric motorcycles in Kenya provides a clear opportunity for the creation of direct jobs, which could reach between 900 and 2,000 by 2030 according to Manufacturing Africa [4].

In the report on e-mobility published by PREO in 2023 [7], Roam describes that there is a clear gap in terms of skills and qualified workforce in the Kenyan e-mobility sector, which needs to be filled to

meet the future growth of the sector and enhance the localization of the e-mobility value chain in the country.

In a 'Policy Paper' published in 2023 and entitled 'EV Importation and Industrialization', the AfEMA (Association for Electric Mobility in Africa) confirms that there is a clear 'mismatch between the skills present in the market and those essential for local EV assembly and manufacturing'. In particular, there is a clear lack of adapted training and courses in training and education institutions relative to the emerging e-mobility sector. This gap has also been identified by the Task Force appointed by President Ruto in 2023 in charge of drafting a National Policy on E-mobility, which identifies as key priority for the development of a national e-mobility roadmap to: 'enhance local technical capacity and skills across the e-mobility value chain', including the implementation of dedicated courses and modules in Universities, promoting R&D initiatives, as well as encouraging OEM or distributors of electric vehicles to integrate user training and manuals of their products [19].

3.1.3.4 Circular economy for EV lithium-ion batteries

According to the definition of the European Commission, the concept of circular economy can be formulated as follows [8]:

'The concept of a circular economy aims at maintaining the value of products and materials for as long as possible, minimizing the use of resources and generation of waste, and to keep resources within the economy after products have reached the end of their life cycle […] In contrast to traditional waste management concepts that focus on the management of generated waste (recycling, energy recovery, disposal), circular economy starts with system and product design to anticipate and support a long and efficient use of products, to support repair and reuse and facilitate recycling in the end-of-life phase.'

TUMI (Transformative Urban Mobility Initiative), a global implementation initiative on sustainable mobility supported by the German Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by GIZ, published in 2023 a report entitled 'Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses'. In this report [8] is shown the following illustration of the ideal pathway for management of e-bus batteries (extracted from a study of the Oeko Institut):

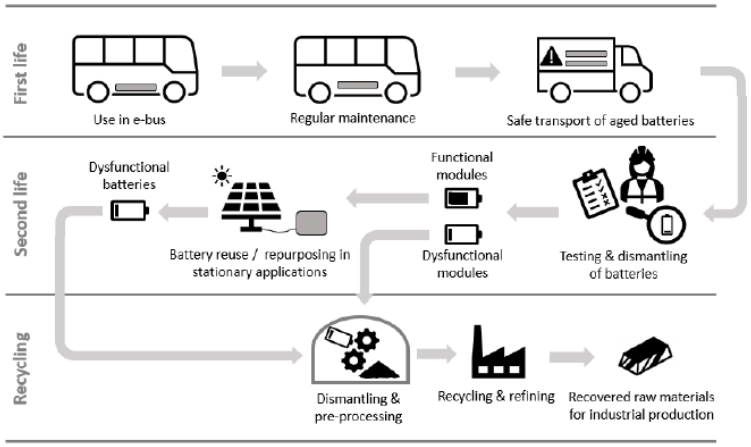


Figure 3. 5: *Ideal management pathways of e-bus batteries*

As reminded by TUMI [8], lithium-ion batteries used in electric buses as well as electric motorcycles contain various raw materials that are considered as 'critical for economic development and expansion of green energy technologies' such as lithium, graphite, nickel, cobalt and copper. Lithium-ion batteries also contain 'various constituents that can have considerable negative impacts on human health and the environment if not managed properly'. As a result, it is essential to apply the concept of circular economy to the deployment of lithium batteries, included the ones used to power electric motorcycles used by motorcycle taxi riders in Kenya.

The report describes that the energy capacity of lithium batteries typically decreases during the use of the electric vehicle (such as an electric bus or motorcycle) until it is no longer suitable for operating the vehicle. However, even after losing for example 20 or 30% of their initial energy storage capacity, these batteries still have enough capacity or enough 'life' to be used in other applications, such as stationary energy storage systems used for low-power applications. Using the batteries in a second life application after being used in the electric motorcycles provide a clear opportunity for maximizing the duration of battery resources, minimizing waste, contributing to 'resource efficiency and circularity' [8].

3.2 METHODOLOGY

This section describes the three main steps followed to study and assess the potential for localization of value chain and circular economy models for electric motorcycles equipped with lithium-ion batteries in the Kenyan E-mobility demonstrator.

The first step consisted in carrying out a literature review and market study on localization and circular economies associated with the sector of electric motorcycles and battery swapping (or charging) in Kenya.

The second step consisted in doing an analysis of the local value chains and innovative circular economy models applied to the Kenyan e-mobility demonstrator implemented by Roam in Nairobi. The analysis starts with a definition of terms, scope and objective of the analysis. After assessing the current and future potential for local value chains and circular economy models, we carried out a simplified techno-economic analysis of selected actions targeting value chain localization and circular economy.

The first phase of the study consisted in describing the implementation of local value chains and circular economy models by Roam and its partners in Kenya.

3.3 RESULTS

3.3.1 Definition of local value chains and innovative circular economy models

3.3.1.1 . Definition of local value chains

Local value chains refer to the activities that occur within a certain geography to enable the production, delivery, utilization, servicing of goods and services.

In our context, we could consider several dimensions of the term 'localization', for example:

- At the scale the city or county of the demonstrator (Nairobi)
- National scale: Kenya
- Regional scale: East African Community
- Continental scale: Africa

In this study, we choose to define local value chains as activities occurring within Kenya, in line with the national e-mobility strategy targeting the development of industrialization, job creation and sustainable development in the country.

We consider value chains in a holistic approach, based on the entire life-cycle of electric motorcycles with lithium-ion batteries, including the phases of design, assembly, distribution, utilization, charging, repair and end-of-life management. Our definition also extends beyond the direct jobs created by Roam to include the broader economic activities generated within the local economy through partnerships and stakeholders involved in the e-mobility value chain. This comprehensive perspective ensures that we capture the full spectrum of economic and industrial impact in Kenya's pursuit of sustainable e-mobility.

3.3.1.2 Analysis and potential of local value chains

The chart below provides an overview of the electric motorcycle value chain in Kenya. Each component of the value chain is attributed one (or several) colour representing the degree and potential for localization:

- Green: value chain components that are already localized by Roam or by other local stakeholders
- Orange: value chain components for which localization is feasible in the medium term, either fully or to some extent
- Red: value chain components that are more difficult to localize in medium and long-term due to techno-economic constraints

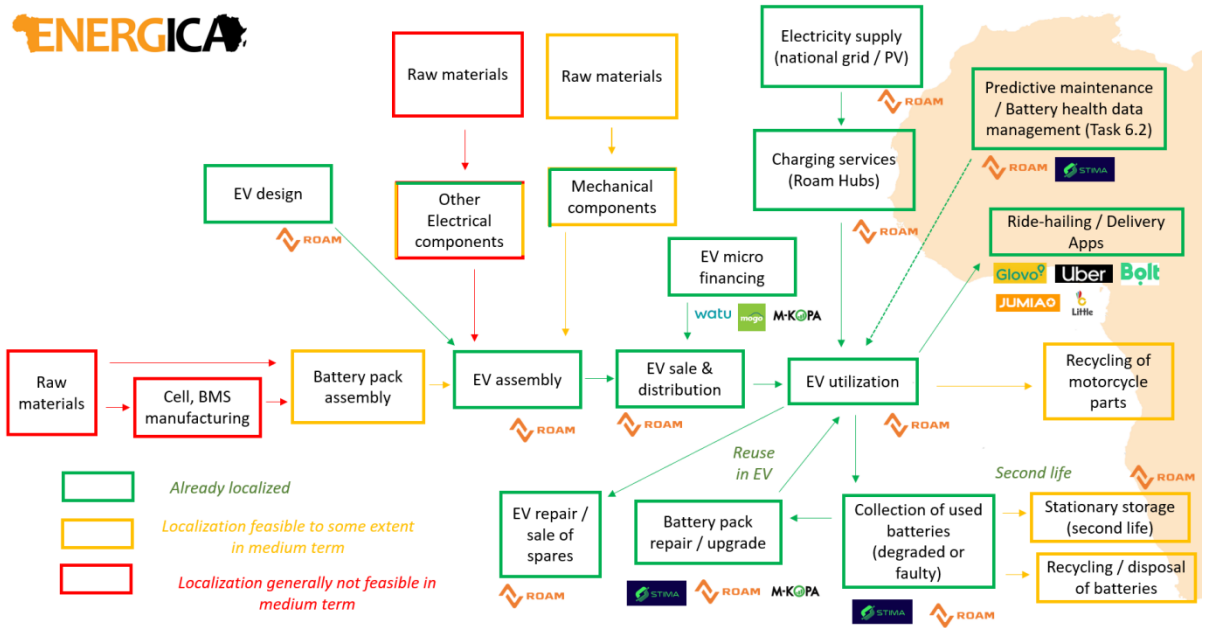


Figure 3. 6: *Value chain analysis of e-motorcycles in Kenya and potential for localization*

We can define as the starting point of the e-motorcycle value chain the phase of designing the vehicle. As an UEMI, Roam has designed in-house the Roam Air, an electric motorcycle tailored for the Kenyan and African moto-taxi market. Roam also assembles the Roam Air in the Roam Park, its assembly facility located in the industrial district of Nairobi.

Roam assembles the Roam Air from CKD (completely knocked down) kits, using a mix of parts imported from Asia (China or India) and parts produced locally and supplied by local part manufacturers. Battery packs are currently imported from China, a global leader for the manufacturing of lithium battery cells and battery packs for consumer electronics, stationary energy storage and electric vehicles. The PREO study indicates that Roam is currently working with 10 local part manufacturers to source an increasing number of motorcycle parts locally in Kenya. The report also mentions that 'some components such as battery cells and base components (resistors and converters) require high production standards and capital expenditures to set up locally' and as a result 'will still have to be procured internationally' [7].

Roam then organizes the sale and distribution of the Roam Air, in motorcycle dealerships operated by Roam or by its motorcycle micro-financing partners. Roam partners with M-Kopa and other motorcycle financing companies to enable boda-boda riders to purchase the Roam Air on credit via instalments.

Once electric motorcycles are sold to individual boda-boda riders comes the phase of utilization.

Roam sells its motorcycles with individual chargers, enabling boda-boda riders to charge their battery by themselves at home or on any standard electrical socket. Roam also provides services of battery charging, battery rentals or battery swapping at the Roam Hubs deployed in Nairobi. Riders can also go to the Roam Hubs to purchase spare parts for their motorcycle or access repair services from trained technicians.

Boda-boda riders are typically organized in stages, which are spaces on the roadsides of the city where boda-boda riders typically park their motorcycle, wait for customers and come back to when they finish their rides. Boda-boda riders also operate using various ride-hailing and delivery mobile Apps such as Glovo, Jumia, Uber, Bolt or Little.

Roam has developed a battery lab at the Roam Park to be able to maintain and repair its lithium batteries. With its engineering team and in collaboration with STIMA, Roam started analysing real time battery data collected via IoT systems (Internet of Things) to carry out predictive maintenance and monitor the cycle life of battery packs. Roam also plans to leverage this battery operating data to improve the battery packs in the next iterations and improve battery warranty provided by its battery supplier.

3.3.1.3 Innovative circular economy models

As previously described, we consider here circular economy as the concept that aims at:

- 'maintaining the value of products and materials for as long as possible'
- 'minimizing the use of resources and generation of waste'
- 'keep[ing] resources within the economy after products have reached the end of their life cycle'

Our definition also emphasized that the concept of circular economy starts with the phase of 'product design'. Indeed, 'product design' is an absolutely critical phase when it comes to studying the potential of innovative circular economy models for the sector of electric motorcycles in Kenya.

3.3.1.3.1 The importance of designing a robust electric motorcycle with spare parts compatible with the existing fuel motorcycles

The study entitled 'Charging ahead: accelerating e-mobility in Africa' published by PREO in 2023 insists on the importance of building a robust electric motorcycle tailored to the African market, built with parts compatible with local spare parts already available for fuel motorcycles.

The robustness of the electric motorcycle is critical to ensure that the motorcycle can last under the intensive usage (about 100 km/day) of boda-boda riders under challenging conditions (heavy loads, difficult road terrains, heavy traffics, etc.). It is clear that off-the-shelf electric motorcycles built in China for the Chinese domestic market (targeting mainly personal commuting) would not be adapted to the African moto-taxi market.

Secondly, ensuring a maximum compatibility of spare parts between the electric motorcycle and the existing fuel motorcycles is critical to ensure the repairability of the electric motorcycle. In Kenya, the market of fuel motorcycles for boda-boda riders is dominated by two Indian OEMs (Bajaj and TVS) and one Japanese OEM (Honda). Designing a motorcycle with a maximum of spare parts compatible with these brands would enable boda-boda riders to benefit from the wide existing network of sale and distribution of spare parts in the country. This would also enable to leverage the existing knowledge of local repair technicians, that are used to repairing the Indian and Japanese fuel motorcycles. This is

even more critical in the long-term when e-mobility companies will expand beyond Nairobi and sell motorcycles to secondary cities of Kenya, as well as rural areas.

We can see here how the concepts of circular economy and localization of value chains are directly linked with each other in the context of the Kenyan e-mobility demonstrator. Indeed:

- Designing a motorcycle based on the local specificities of the market is critical to ensure the durability of the motorcycle under intensive and challenging usage conditions
- Leveraging the existing local networks of spare parts distributions and the knowledge of technicians and mechanics used to repair specific brands of fuel motorcycles is essential to guarantee the repairability of the electric motorcycle

3.3.1.3.2 Key measures for improving the circularity of e-motorcycle lithium batteries in Kenya

In this paragraph, we introduce five key measures that would enable us to improve the circularity of lithium batteries used in electric motorcycles in the Kenyan demonstrator. These five measures were selected from the 'Measures Catalogue for Improving the Circularity of Batteries Used in E-Buses' published by UEMI in April 2023 [8]. We then adapted the description of these measures applied to the context of the Kenyan e-motorcycle demonstrator.

3.3.1.3.3 Battery sourcing and design phase

Measure 1: Reduced concentration of harmful substances

- Favouring lithium batteries over lead acid batteries enable to eliminate the usage of lead, a heavy metal posing environmental and health risks
- Selecting lithium-ion chemistries that minimize the usage of harmful substances, such as lithium-iron phosphate (LFP)

Measure 2: Appropriate sizing of the battery

- An under-sized battery would not meet the needs of boda-boda riders in terms of minimum range. It could also degrade faster if the battery capacity is not sufficient to regularly absorb the high currents from the electric motorcycle.
- An over-sized battery would increase the cost and amount of material used to deliver its function

Measure 3: Battery durability and warranties

- Select batteries that are cost-effective but also with sufficient quality and durability, to enable less frequent replacement and longer lifespan
- Ensure adequate and actionable warranty terms with battery suppliers (usually defined with a minimum battery lifespan in number of years or number of charge/discharge cycles)

3.3.1.3.4 Battery utilization phase

Measure 4: collection and analysis of battery operational data collected via IoT (Internet of Things)

- Battery operational data is critical to enable monitoring of battery state of health and for various measures around maintenance and extension of battery cycle life
- Certain battery operational data can be shared by operating companies with motorcycle and battery suppliers, as well as battery financiers, to enhance transparency and collaboration in the EV value chain

3.3.1.3.5 Battery end-of-life phase

Measure 5: Encouraging battery second life utilization

- Encourage battery designs and business models that anticipate and intend to re-use / repurpose the batteries after the first life in electric motorcycles, in particular stationary energy storage

3.3.1.4 Techno-economic feasibilities study for the Kenyan context

3.3.1.4.1 Local assembly of electric motorcycles from CKD kits relative to importation of fully built units

The following chart provides a comparison of the breakdown of the landed cost of electric motorcycles in Kenya (excluding the cost of batteries) in 4 different scenarios:

- Scenario 1: E-motorcycle imported in CKD (completely knocked down kits) and assembled in Kenya, before implementation of the Finance Act 2023
- Scenario 2: E-motorcycle imported in CKD (completely knocked down kits) and assembled in Kenya, after implementation of the Finance Act 2023
- Scenario 3: E-motorcycle imported in CBU (fully built units), before implementation of the Finance Act 2023
- Scenario 4: E-motorcycle imported in CBU (fully built units), after implementation of the Finance Act 2023

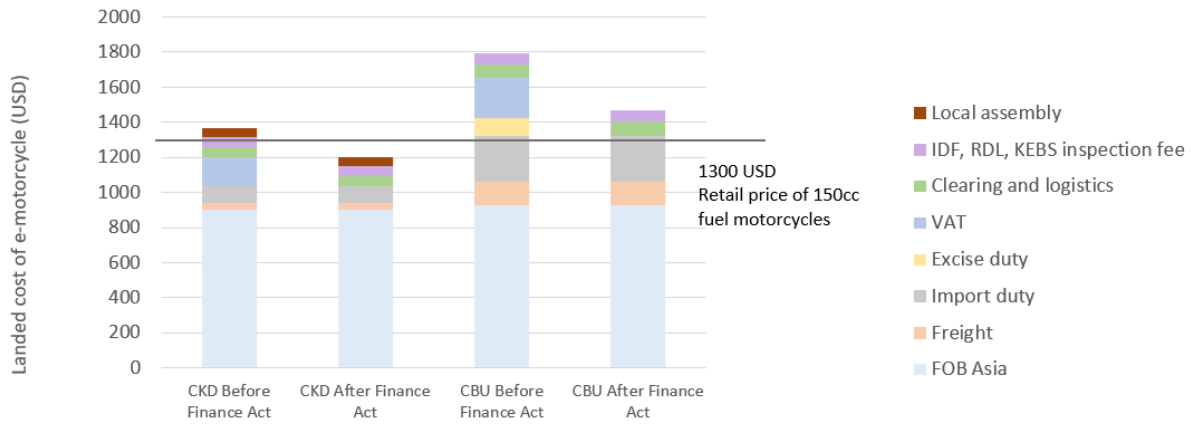


Figure 3. 7: *Breakdown of landed cost of e-motorcycles in Kenya*

The table below summarizes the assumptions used to build the cost breakdown comparison between the 4 scenarios:

Table 3. 1: *cost breakdown comparison between the 4 scenarios*

	CKD		**CBU**	
	Before Finance Act 2023	After Finance Act 2023	Before Finance Act 2023	After Finance Act 2023
Motorcycle FOB Price (India/China)	900	900	925	925
Freight	4,000 USD for 100 units	4,000 USD for 100 units	4,000 USD for 30 units	4,000 USD for 30 units
Import duty	10%	10%	25%	25%
Excise duty	0	0	100 USD	0
VAT	16%	0	16%	0
Fixed charges for clearing & logistics	60 USD per unit	60 USD per unit	80 USD per unit	80 USD per unit
Other taxes (IDF, RDL) + KEBS inspection fee	6% (3.5+2.0+0.5)	6% (3.5+2.0+0.5)	6% (3.5+2.0+0.5)	6% (3.5+2.0+0.5)
Local assembly	50 USD per unit	50 USD per unit	0	0

The Finance Act was passed in July of 2023. As mentioned in the literature review section, the act enabled the zero-rating of VAT of electric motorcycles and made them exempt from excise duty. According to the national regulation on importation and assembly of motorcycles, motorcycles (fuel and electric) that are assembled from CKD kits benefit from a reduction of import duty from 25% to 10% as well as an exemption of excise duty.

The result of the cost breakdown analysis show that the landed cost of electric motorcycles (excluding the cost of battery) is:

- 1,366 USD in Scenario 1 (CKD Before Finance Act)
- 1,200 USD in Scenario 2 (CKD After Finance Act)
- 1,794 USD in Scenario 3 (CBU Before Finance Act)
- 1,466 USD in Scenario 4 (CBU After Finance Act)

This comparison demonstrates the importance of the tax incentives implemented with the Finance Act of 2023, which enables a reduction of the landed cost of electric motorcycles by 12% and 18% in the case of motorcycles imported in CKD or CBU respectively.

The calculation also shows the cost benefit of assembling electric motorcycles in Kenya from CKD kits rather than importing fully built units, thanks to a reduction in freight and logistic costs and thanks to reduction in import taxes. Indeed, the analysis shows that assembling motorcycles from CKD kits in Kenya enables to reduce the final cost of electric motorcycles by 24% and 18% respectively before and after implementation of the Finance Act 2023.

3.3.1.4.2 Optimization of local electricity consumption via solar photovoltaics and time of use rates of electricity

According to statistics published by the Energy and Petroleum Regulatory Authority (EPRA), 85% of the electricity consumed in Kenya in 2023 was generated from national renewable energy sources

including geothermal energy (covering 45% of national consumption), hydropower (19%), wind power (17%) and solar photovoltaics (3%) [9]. Electricity produced from thermal generation covered 10% of the consumption, while importation of electricity represented 5% of the annual consumption.

In April of 2023, EPRA implemented for the first time a new tariff specifically dedicated to charging of electric vehicles, including electric motorcycles. This new tariff includes time of use rates of electricity with a higher electricity price during peak hours and a lower electricity price during off-peak hours as follow:

Table 3. 2: Electricity tariffs during peak and off-peak periods

Electricity tariff	**Peak and off-peak schedules**		
	Weekdays	Saturday and public holidays	Sundays
Peak times = 32 KSH/kWh = 0.23 €/kWh (incl. Tax)	6am to 10pm	8am to 2pm	-
Off-peak times = 22 KSH/kWh = 0.16 €/kWh (incl. Tax)	10pm to 6am	2pm to 8am	All day

This new e-mobility tariff provides an incentive to e-mobility companies to charge EV batteries from the national grid in priority during off-peak periods, when the electricity demand on the grid is limited and when there is an excess of renewable energy capacity (in particular geothermal energy) able to produce electricity at a low marginal cost.

According to the African Energy Outlook published by the International Energy Agency (IEA) in 2022, the average levelized cost of electricity (LCOE) for solar photovoltaic energy in Africa ranges between 0.028 €/kWh and 0.084 €/kWh in 2020, and is expected to achieve between 0.016 €/kWh and 0.045 €/kWh in 2030 based on the Sustainable Africa Scenario of the IEA.

Roam has been deploying several Roam Hubs in Nairobi, where riders can access services of battery charging or battery rentals. The Roam Hubs are connected to the national grid, and some of them include solar PV panels to generate part of the electricity consumed by the station.

According to Roam, a typical Roam Hub containing 24 charging slots for charging batteries can deliver 269 kWh of charge energy per day. Assuming a charge efficiency of 90%, we can estimate that the station consumes 299 kWh of electricity per day from a mix of the grid and its solar panels. We assume that a Roam Hub is equipped with a solar PV system of 10 kW, which typically produces 43 kWh of solar electricity per day, considering a capacity factor of 18% (medium value used in [11]). We can therefore estimate that the 10kW solar PV system can cover about 14% (=43/299) of the total electricity consumed by the station.

For this study, we will assume a LCOE of electricity produced by the PV system installed on the Roam Hub 0.08 €/kWh (including taxes). We decided to use the higher range of the estimation of LCOE from PV systems in Africa provided by the IEA, taking into account that a rooftop 10 kW PV system tend to have a higher LCOE than PV systems of higher capacities used for larger C&I or utility-scale applications, as confirmed in the report entitled 'A Study on the regulatory impact of net metering in Kenya' published by EPRA in 2022 [11].

We will assume that on average, 20% of the electricity consumed to charge the batteries in the Roam Hubs can be consumed during off-peak periods, and benefit from the reduced off-peak electricity tariff of 0.16 €/kWh.

Assuming that on average, 14% of electricity consumed by the Roam Hub is generated by on-site PV panels and 20% of the electricity is consumed from the grid at the lower off-peak tariff, we can estimate that the average cost of electricity consumed to charge the batteries is equal to:

$$14\% \times 0.08 + 20\% \times 0.16 + 66\% \times 0.23 = 0.195\ €/kWh$$

We can conclude that it is possible to reduce the cost of electricity to charge batteries in the Roam Hub by about 15% by generating solar PV electricity on-site and favouring consumption of electricity during off-peak hours, relative to the standard grid electricity tariff of 0.23 €/kWh applicable during peak hours.

Assuming as indicated by Roam that a boda-boda rider drives on average 100 km per day and that one full Roam battery of 3.2 kWh provides a range of about 70 km, we can calculate that one boda-boda rider consumes about 4.6 kWh of battery charge per day. Taking into account the charge efficiency factor of 90% in the Roam Hubs, one boda-boda rider requires 5.1 kWh per day of electricity as input energy for the battery chargers. The reduction of electricity cost from 0.23 €/kWh to 0.195 €/kWh therefore represents a saving in electricity expenses of 0.18 € (or 25 Kenyan shillings) per rider and per day.

We can therefore conclude that there is a clear economic benefit associated with maximizing the consumption of electricity from excess national renewable energy capacity during off-peak demand periods as well as generating electricity from PV systems installed on-site on the Roam Hubs.

3.3.1.4.3 Maximization of battery lifespan for battery-as-a-service business models

Lithium batteries are a relatively expensive asset, which typically represent 30 to 40% of the total cost of an electric motorcycle designed for the Kenyan market. Boda-boda riders, having a limited purchasing power, are in most cases not able to afford an electric motorcycle including the battery in direct cash purchase. According to an analysis published in 2022 by Persistent Energy (an investment fund financing early-stage start-ups in Africa), electric motorcycles in Kenya can cost up to twice as much as a fuel motorcycle when including the cost of the battery. The same report emphasizes on the importance of battery leasing or battery swapping business models where riders can repay for the cost of batteries over time through daily or weekly payments, through the following period:

- 12 to 24 months in the case of battery leasing, where the battery would be leased together with the motorcycle
- The lifespan of batteries in the case of battery swapping, which can typically be around 1,000 to 2,000 charging/discharging cycles

As developed during the task 6.2 of the Kenyan Demonstrator, Roam and STIMA were able to describe how analysing real-time battery data collected via IoT (internet of things) can enable to monitor and minimize the loss of capacity of lithium batteries over the cycle lifespan.

The following simple calculation shows that extending the lifespan of a certain e-motorcycle battery (with a fixed cost) by 50% would enable to reduce the daily amortization cost of batteries by 33%:

$$Cycles_{extended} = 1.5 \times Cycles_{standard}$$

$$Daily\ cost\ _{standard} = \frac{Battery\ cost}{Cycles_{standard}}$$

$$Daily\ cost\ _{extended} = \frac{Battery\ cost}{Cycles_{extended}}$$

$$\frac{Daily\ cost\ _{extended}}{Daily\ cost_{standard}} = \frac{Cycles_{standard}}{Cycles_{extended}} = \frac{1}{1.5} = 66.7\%$$

We can then calculate the savings per cycle and per day for boda-boda riders that could be obtained by extending the battery lifespan of Roam batteries by 50%, using the following assumptions:

- Battery price (in Kenya): 800 €
- Battery range per full charge: 70 km
- Daily distance covered per rider and per working day: 100 km/working day
- Number of working days per year: 310 working day / year
- Standard battery cycle life = 800 cycles
- Extended battery cycle life = 1,200 cycles (+50%)

The amortization cost of batteries per cycle can be obtained as previously defined:

$$Daily\ cost\ _{standard} = \frac{Battery\ cost}{Cycles_{standard}} = \frac{800}{800} = 1\ €/cycle$$

$$Daily\ cost\ _{extended} = \frac{Battery\ cost}{Cycles_{extended}} = \frac{800}{1.200} = 0.67\ €/cycle$$

The average number of equivalent full charging/discharging cycles per battery and per working day can be calculated as follow:

$$Daily\ Cycles = \frac{Distance_{per\ working\ day}}{Battery\ range} = \frac{100\ km/workingday}{70\ km/cycle} = 1.43\ cycles/workingday$$

The daily cost of amortization of batteries can then be calculated in €/working day as follows:

$$Daily\ cost\ _{standard} = 1\ €/cycle \times 1.43\ cycles/workingday = 1.43\ €/workingday$$

$$Daily\ cost\ _{extended} = 0.67\ €/cycle \times 1.43\ cycles/workingday = 0.95\ €/workingday$$

Based on the assumptions introduced above, we can estimate that extending the lifespan of Roam batteries by 50% thanks to advanced battery data analytics could enable to reduce the amortization cost of batteries for boda-boda riders by 0.48 €/working day (equal to 68 Kenyan shillings using an exchange rate of 142 KSH/€ as of August 2024).

Multiplying by 310 working days/year, this would represent potential annual savings of 148 €/year for boda-boda riders (equal to 21,000 KSH).

3.3.1.5 Social impact of the local value chains (Partner: HUD)

In this section, a preliminary and qualitative analysis of the social value chain and circular economy of the Integrated Community Energy Systems implemented in the Kenya context is presented, as the implementation of these structures has not been completed at the time of this deliverable.

For the analysis, inspiration has been taken from the Guidelines for Value Chain Selection developed by GIZ in cooperation with the International Labour Office in 2015[4], and it is done through the analysis of 8 principles: job creation, market growth, local resources, added value, inclusiveness of disadvantaged or marginalised societal groups, decent working conditions that improve workers' life, social impact of the value chain on the surrounding communities and society at large, participation of the community.

Kenya is currently at the forefront of the transition to a low-carbon economy through the Climate Change Act of 2016 and the Energy Act of 2019. About 85 % of Kenya's energy is derived from renewable sources i.e., Hydro Power (826.23 MW), Wind (336.05 MW), Solar (52 MW), Biomass (2 MW), and Geothermal (828.04 MW), and excess production of about 800MW, the country still faces challenges with energy access, transport, pollution and congestion because of an inefficient transportation system and old vehicle fleets[5]. The latter is especially responsible for the most hazardous particle emissions affecting the environment and public health.

Below is a discussion of the eight principles of the circular economy and social value chain in Kenya:

- **Job creation:** Changing batteries on motorbikes may require operators to change and charge the batteries. Therefore, this model favours the creation of jobs at the collection and charging points.
- **Market growth:** This model has a place in growth, since the fleet of electric motorcycles and the number of charging points can be increased, and there is great movement in the city of Nairobi in terms of transportation. However, according to the information collected in the baseline report (D2.1) on the acceptability of electric vehicles, the acceptability of the use of this type of vehicles should be encouraged.
- **Local resources:** The use of electric batteries charged locally with renewable sources favours energy autonomy, since fossil fuels such as diesel will not be used for transportation, reducing dependence on the international market or external factors.
- **Added value:** The use of electric batteries for transportation reduces the consumption of fossil fuels, increasing energy autonomy while reducing the emission of greenhouse gases. Therefore, this approach has a great impact in several areas, although the business model does not promote community inclusion at the same level as in the other two contexts.
- **Inclusiveness of disadvantaged or marginalised societal groups:** People from marginalized groups can be trained and hired at charging points to be in charge of installing and charging the batteries. This fosters their inclusion in the labour market. However,

[4] https://www.ilo.org/media/549576/download

[5] https://www.energy.go.ke/

the inclusion of the community in the ICESs promotes its integration in the control of the productive uses of energy, which can favour the economy of the people who depend on these productive groups, increasing their stability and their economic resources.

- **Decent working conditions that improve workers' life:** The constant need for staff to change batteries means that they can have access to a permanent and stable job, which can improve the economic stability and quality of life of these workers.
- **Social impact of the value chain on the surrounding communities and society at large:** The use of electric motorcycles contributes to reducing the emission of greenhouse gases associated with transportation, improving the health and quality of life of the entire city. Likewise, the option to stop transportation at a low cost improves the economic situation of the users of these motorcycles. Finally, the workers involved in this business improve their income and stability, contributing to an improvement in the quality of life of their families and their community.
- **Participation of the community:** As stated previously, this model is not designed to fully include the community with a participatory approach, despite having a very positive impact on it. Therefore, the level of community participation is lower than in the cases of Madagascar and Sierra Leone.

To sum upwe can conclude that the Kenyan model, although it has very positive benefits for the community, does not facilitate the inclusion of the community in the production or management of the system to the same level.
the Madagascar model can have a great social impact and in the circular management of the communities' economy. Besides, the systems allow these communities to be included in the established ICESs.

3.3.2 Implementation of the value chains and circular economy

3.3.2.1 . Implementation of local value chains

3.3.2.1.1 CKD assembly of the Roam Air at the Roam Park

In 2023, Roam opened the Roam Park, a new 10,000 square meter facility which is the largest electric motorcycle assembly plant in East Africa, with a capacity of producing up to 50,000 units per year [13].



Figure 3. 8: *Photos of the Roam Park motorcycle assembly plant in Nairobi*

Roam currently employs 200 staff in this facility located in the Industrial area of Nairobi. The assembly line is currently composed of 8 stations that require 11 people. Roam currently runs a continuous production line that has a general expected output of 25 bikes a day on one shift and one line. The assembly process includes several steps of quality inspection (inbound quality, process quality,

outbound quality and pre-delivery) that enable Roam to detect and report workmanship issues as well as material defects.

3.3.2.1.2 *Localization of motorcycle parts*

Roam has designed a robust electric motorcycle tailored for Africa, with parts compatible with the local market of fuel motorcycles. Roam has been working on sourcing an increasing number of motorcycle parts from local part manufacturers. Localizing motorcycle parts will enable Roam in the medium and long term to reduce cost and time of manufacturing, increase flexibility, control and reliability. Today, Roam has managed to source 14 parts from Kenyan part manufacturers and has an objective to manufacture 70% of its electric motorcycle locally in the next 3 to 5 years, as indicated in the PREO report [7]. The same report also explains that Roam first decided to prioritize the local sourcing of 'components where local manufacturing capacity already exists, e.g. injection moulding, welding, metal bending and sub-assemblies'.

Roam's strategy to increase local manufacturing content of its electric motorcycle directly aligns with the Kenyan policy on importation and assembly of motorcycle, directed by the Legal Notice N° 112 of the 'Tax Procedures (Unassembled motorcycles) regulation, 2020'. As mentions in the literature review section, this law enables companies that assemble motorcycles from CKD kits while sourcing 14 motorcycle parts locally to benefit from import tax incentives.

3.3.2.1.3 *Distributed and flexible battery charging/rentals services at Roam Hubs powered with local PV electricity*

In 2023, Roam started deploying Roam Hubs in Nairobi, which are stations dedicated to charging and delivering batteries to boda-boda riders. The Roam Hubs serve individual boda-boda riders as well as riders working for corporate EV fleets.



Figure 3. 9: *A Roam Hub equipped with solar PV panels installed on Waiyaki Way, Nairobi*

The Roam Hubs are built from 20-foot marine containers retrofitted by Roam into charging stations. A Roam Hub typically includes about 24 charging slots to charge Roam batteries. The Hub is connected to the main electricity grid of KPLC ('Kenya Power and Lighting Company'), the national electricity transportation and distribution company. Some of the Hubs are also equipped with solar PV panels providing solar electricity to charge the batteries. As shown in the techno-economic feasibility section, solar PV panels enable to reduce the average cost of electricity needed to charge the batteries in the Roam Hub.

One Roam Hub typically employs 4 swappers who are the attendants in charge of delivering batteries to the boda-boda riders. Boda-boda riders can go to the Roam Hubs to charge their own batteries or access an extra battery that they can rent. Some corporate clients such as Greenwheels, an EV fleet management operating in Nairobi, use the Roam Hubs to swap batteries, meaning exchanging an empty battery for a full battery.

As of the end of August 2024, Roam has deployed 4 Roam Hubs in Nairobi (Waiyaki Way, Lusaka, Kayole and Roysambu), and in planning to open more Hubs in the coming months.

3.3.2.1.4 Contribution to E-mobility skills development

As previously mentioned in the literature review section, there is currently a gap in terms of skilled technical workforce (technicians and engineers) in the e-mobility sector. As indicated in the PREO study previously cited [7], Roam has developed internal training programs for its employees and leverage its network of experienced specialists to bridge the skills gap.

Roam is also actively contributing to training programs organized by associations of the local EV industry. For example, Roam has been a leading partner of a Technical e-mobility training program organized by Advanced Mobility Center and AfricanEV, two local associations promoting the development of the e-mobility sector. The first edition of this training program was held in May 2023 and enabled 35 participants to receive a technical training on electric vehicles [14]. Roam hosted the second edition, which included 60 participants. In this second edition, the participants had the opportunity to completely dismantle a Nissan Leaf electric car at the Roam Park.



***Figure 3. 10:**: Photos of AfricanEV technical training program held at Roam Park in January 2024*

3.3.2.1.5 Partnership with M-Kopa, local micro-financing company

In Kenya, most boda-boda riders are unable to purchase a motorcycle (fuel or electric) cash. Most of the motorcycles are currently sold to boda-boda riders on instalments by specialized micro-finance companies. Two main companies based in Kenya (Watu Credit and Mogo) have been dominating the market for the sale of fuel motorcycles on credit to boda-boda riders. They typically sell motorcycles with a down-payment of at least 25,000 Kenyan Shillings (about 180 €) and weekly instalments usually ranging between 300 and 500 Kenyan Shillings, depending on the duration of the loan (typically 12 to 24 months). At the end of the loan period, the motorcycle driver becomes the owner of his motorcycle. Due to high the lack of credit history and high default rates of boda-boda riders, annual interest rates charged on boda-boda loans are very high, typically around 50% per year.

Watu Credit and Mogo started financing electric motorcycles, as well as M-Kopa, a company specialized in selling products such as solar home systems and smartphones in PAY-AS-YOU-GO, via a similar lease-to-own scheme of regular instalments.

In July of 2023, Roam launched a partnership with M-Kopa to enable boda-boda riders to purchase the Roam Air motorcycle in instalments through M-Kopa [15]. In April of 2024, Roam and M-Kopa strengthened this partnership by launching a new collaboration with Bolt, a leading ride-hailing platform for boda-boda rides in Nairobi. The new partnership with Bolt enables new and existing boda-boda riders operating on the Bolt mobile ride-hailing App to purchase a Roam Air via a lease-to-own scheme proposed by M-Kopa at a discounted rate compared with market prices [16].



Figure 3. 11: *Launch of the Roam-MKopa partnership for micro-financing of the Roam Air motorcycle in Nairobi in July 2023 (left), Launch of the Roam-MKopa-Bolt partnership in May 2024 (right)*

3.3.2.2. Implementation of innovative circular economy models

3.3.2.2.1. Designing a robust motorcycle with spare parts compatible with the local market

As explained by PREO [7], Africa needs access to durable motorcycles. Most e-mobility start-ups in East and West Africa have been importing electric motorcycles from fully built units or CKD kits from Chinese OEMs. However, the report mentions that 'The often rough terrain navigated by drivers across SSA results in significant wear and tear of the electric motorcycle caused by unpaved roads, long journeys and intense commercial use'. Therefore, most electric motorcycles designed in China or other Asian countries (India, South-East Asia) are not adapted for the African moto-taxi market.

Roam is the first e-mobility company in Africa that decided to design a new electric motorcycle tailored for the African market, rather than directly importing models designed and produced by Asian OEMs. Designing an electric motorcycle tailored for the African moto-taxi market enables to ensure that the motorcycle fits with the needs of boda-boda riders in terms of robustness, performance and range. Building a robust motorcycle is essential to ensure that the motorcycle will last at least as long as the current fuel motorcycles used by boda-boda riders. Roam built a proprietary frame engineered to tackle all terrains and accommodate 220kg of carrying capacity [17].

In addition, it enabled Roam to design a motorcycle where a maximum number of parts are compatible with the existing models of fuel motorcycles, which is critical for the successful deployment of electric motorcycles in the long-term. As other electric motorcycles, the Roam Air does not use any oil, spark plugs, air filters, timing belts, gearbox, clutch that are found in fuel motorcycles [17]. As a result, the need and cost for maintenance is significantly reduced relative to fuel motorcycles. Nevertheless, the availability of basic spare parts (tyres, brakes, suspensions, side mirrors) is a critical element that boda-boda riders consider when they make the decision to purchase a specific brand and model of motorcycle. Moreover, the motorcycle has been designed to ensure that as many components as possible can be easily repaired by local technicians at local repair shops, in the same way as fuel motorcycles. This ensures that the motorcycle can be repaired even as Roam scales-up in secondary cities of Kenya and rural areas.

3.3.2.2.2. Maximizing battery utilization and lifespan through careful battery sourcing and data monitoring

According to the PREO study [7], the challenge for e-mobility start-ups in Africa to access high-quality lithium batteries has been one of the major barriers for scaling-up the e-mobility sector in Sub-Saharan Africa over the past years. The study explains that:

'high-quality batteries from overseas suppliers are largely only available to large global buyers, who prioritise volume buyers, creating an obvious barrier among startups in sub-Saharan Africa. As a result, lower-quality batteries are often used, which fail to deliver on their stated performance, preventing electric mobility companies from making profits since batteries require extensive investment.' [7]

The report mentions that both Roam and Zembo (another e-mobility start-up deploying electric motorcycles with battery swapping systems in Uganda) experienced issues of battery quality. Roam received a batch of batteries that were depleted on arrival because of defects on the internal wiring. Zembo purchased batteries that experienced a degradation (loss of energy capacity) that was much faster than expected in the battery specifications.

Such issues of battery quality can significantly reduce the utilization rate of the batteries through their lifespan, which opposes the concept of circular economy that aims to 'support a long and efficient use of products', as previously defined.

In the PREO report, Roam emphasizes on the importance of setting up an 'in-depth quality control framework' to tackle these issues related to battery quality.

In addition, Roam and other e-mobility players need to give a particular attention to designing and sourcing a high-quality and durable battery, by selecting:

- The right battery cells, in particular choosing between the two dominant chemistries used for e-motorcycle battery packs that are NMC (Nickel Manganese Cobalt) and LFP (Lithium Iron Phosphate), based on the trade-off between energy density (higher for NMC) and lifespan (higher for LFP). E-mobility companies also need to study closely the specifications and test reports of the cells and battery packs they plan to use to assess if they can meet the performance criteria (range, cycle life, etc.) under the expected operating conditions (discharge current, temperature, etc.).
- The right battery management system (BMS), able to efficiently balance and maintain the battery cells within safe operating conditions
- The right thermal management system inside the battery pack (enabling adequate thermal dissipation and avoid overheating inside the battery pack, responsible for faster capacity degradation over time)
- The right grade of cells (defined by the cell quality as measured at the end of production lines)
- The right battery pack and cell manufacturers, able to demonstrate the application of adequate quality control procedures during production

In collaboration with STIMA, Roam started collecting battery operating data via IoT (Internet of Things) systems connected to 270 battery packs during charge and discharge of the batteries. The IoT systems enable to collect data measured by the BMS of the battery, such as current, voltage, temperature, state of charge, as well as various BMS alerts.

STIMA and Roam have been working on analyzing this data to assess the rate of degradation of this fleet of 270 battery packs and anticipate the remaining cycle life of the packs during operation. As part of task 6.2 of the Energica Project, STIMA developed an algorithm to estimate the residual energy capacity of Roam battery packs from the analysis of battery IoT data. Roam and STIMA were able to compare the results of this algorithm with physical tests of battery capacity carried out regularly by Roam and STIMA with battery pack testers in their respective battery labs.

The analysis also enabled Roam to identify certain batteries that have experienced a faster degradation relative to the average of the battery fleet. These batteries were temporarily taken out of the battery network to be tested by Roam and its partner M-Kopa, with the objective of identifying potential causes or defects explaining the accelerated loss of energy capacity.

Collecting and analyzing battery data has been a key strategy for Roam to monitor the degradation of batteries and carry out predictive maintenance. In the medium and long-term, this work on battery data analytics will enable Roam to minimize battery downtime and maximize battery lifespan. This will enable Roam to optimize the economics of its battery renting, lease-to-own or battery swapping business model, while contributing to the objectives of the circular economy.

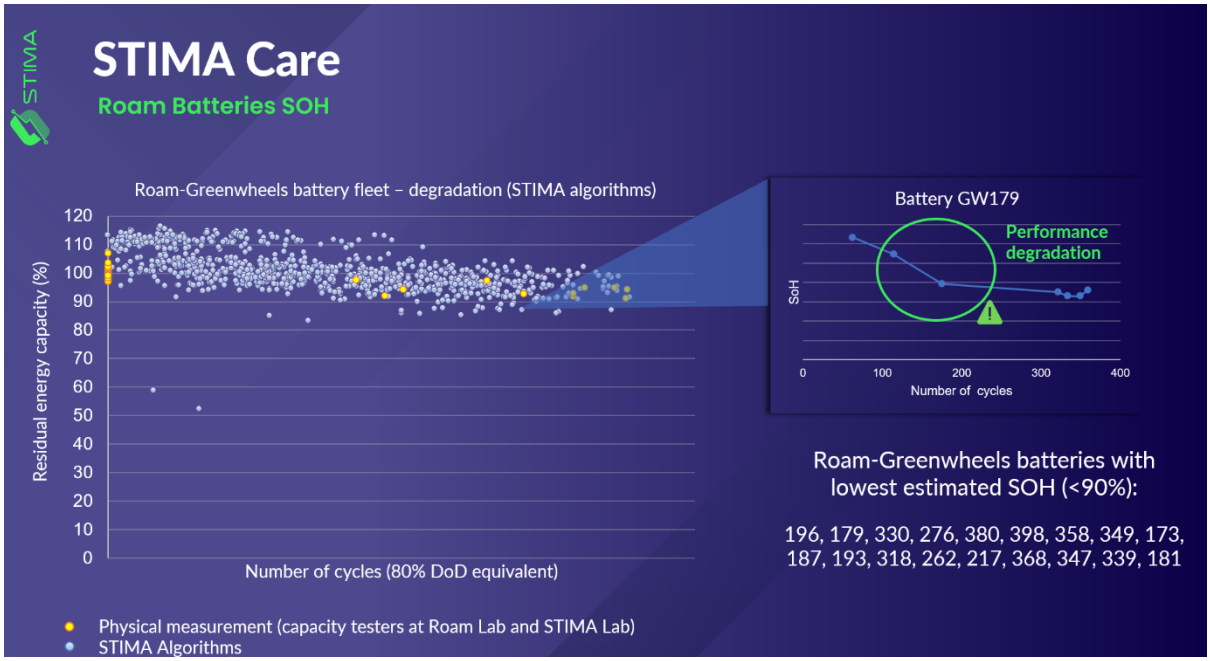


Figure 3. 12: *Illustration of SOH (state of health) degradation for a fleet of 270 batteries as estimatedusing algorithms developed by STIMA under Task 6.2 of the Energica Project*

3.3.2.2.3. Planning for second-life applications of lithium batteries

When the lithium batteries reach their end-of-life for the e-motorcycle application, Roam plans to leverage its existing business of sale and installation of solar PV systems in Kenya to be able to re-use the batteries for stationary energy storage applications, such as energy storage for grid back-up or off-grid storage combined with PV systems.

Indeed, Roam will most likely decide to retire the batteries from its e-mobility network when the batteries have degraded up to reaching 70% or 80% of their initial energy and/or power capacity. At this point, the batteries would not provide enough range or enough power to support the needs of boda-boda riders. Nevertheless, these battery packs can still be used for stationary applications that would require less energy or less power density relative to the usage in the electric motorcycle.

This approach enables to enhance the circular economy while optimizing the residual value of battery packs for its e-mobility business model.

At the end of the second life of these batteries, Roam can work with local companies specialized in recycling or repurposing or electronic equipment and lithium batteries such as the WEEE Center, Enviroserve Kenya or Qtron electronics.

3.4. CONCLUSION AND RECOMMENDATIONS

Our study showed the high potential of the Kenyan e-mobility demonstrator for contribution to local value chains and circular economy.

Unlike most e-mobility start-ups in Sub-Saharan Africa, Roam ventured into designing locally an electric motorcycle tailored for the African market, considering the need to build a motorcycle with spare parts compatible with the existing motorcycle market.

Roam was also one of the first e-mobility start-ups in East Africa to set-up a local assembly plant, enabling the assembly of its motorcycle in its Nairobi facility from completely knocked down (CKD) kits. Furthermore, Roam deployed a network of charging stations in Nairobi (called the Roam Hubs), enabling riders to access flexible services of battery charging, battery rentals or battery swapping.

This use case of the Kenyan e-mobility demonstrator implemented by Roam demonstrates the importance of the design phase in building a product that contributes to the circular economy. Rather than importing off-the-shelf motorcycles from Asia, Roam designed the Roam Air as a motorcycle able to last under the intensive and challenging usage of boda-bodas riders in Kenya, equipped with a durable lithium battery equipped with an IoT system for constant data monitoring, and able to be repaired for the most part with local technicians and local spare parts.

Roam also managed to set-up strong partnerships on the local e-mobility value chain. We can cite for example Roam's partnership with leading micro finance company M-Kopa for the financing and distribution of its Roam Air motorcycle. We can also mention Roam's partnership with STIMA on battery data monitoring aiming at maximizing battery utilization and lifespan, in line with the concept of circular economy.

In its 2022 study previously cited, early stage investment fund Persistent Energy emphasizes on the importance of specialization in the local e-mobility value chain for the sustainable development of the African e-mobility sector: 'in the long run, value chain specialization by surviving market players (e.g. finance,manufacturing, distribution, charging, etc.) will be essential for the e-mobility sector's success.For each market player, some degree of specialization will likely be a key source of sustainablecompetitive advantage.'

Finally, our study also emphasized on the potential of using lithium batteries at the end of their first life in the e-motorcycle application to be reused in a second life as energy storage for grid back-up or for storing solar PV electricity. Considering the potential second life of batteries enables to improve the battery-as-a-service business model for the e-mobility application while contributing to the circular economy.

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GENERAL CONCLUSION

This report of the deliverable D3.5 aims at providing the results on local value chains and circular economy models' capacity at different scales up to ensure an enhanced uptake of environmentally compliant energy technologies in the three contexts of the ENERGICA project. The summary of the key findings is as followed:

1. **For the Madagascar context**: The evaluation of local value chains and circular economy capacity in Madagascar shows progress in various sectors such as solar nanogrids, agri-specific solutions, water-specific solutions, and cooling-specific solutions. Recommendations include expanding solar nanogrid coverage, enhancing economic viability through financing options, supporting agri-specific technology development, strengthening water infrastructure, advocating for supportive policies and incentives, and promoting a circular economy integration. By implementing these recommendations, Madagascar can improve local value chains, sustainability, and economic growth while aligning with environmental conservation goals.

   For all three studied solutions, the agri-processing as well as the water- and cooling equipment the annual utilization as well as the interest rate on the investment cost has great influence on the economic evaluation. During peak months of husking (May-July) the higher daily husking capacity tested is required to match the average need according to the survey done in the project. Increasing the battery capacity would make possible increased daily utilization as well as adding additional equipment such as milling. For the agrispecific solution both the income from the husking as well as from selling the husking residues is important. With a pure private investment (15% interest rate) the higher utilization rate of the two tested was required to reach a positive revenue. There are several alternatives for utilizing the residues from the rice value chain that would imply For the NanoWater solution both alternatives with higher and lower interest rate (pure private and eager) expected costs are higher than the income. Some kind of investment support or subsidy could be one solution to reach profitability. For the NanoCold solution the expected income is higher than the costs.

2. **For the Sierra Leone context**: the study conducted as part of the ENERGICA project focuses on examining the potential for a local value chain and circular economy in biogas production in Sierra Leone. It was found that organic waste accounts for about 80% of the total Municipal Solid Waste in the country, indicating a significant resource availability for biomass feedstock. The technical potential for biogas production is estimated to be 176 Nm^3/ton of biowaste, with an annual production of 23131 Nm^3/year. Economic analysis using NPV and IRR shows that implementing a biogas plant in Sierra Leone is economically feasible, particularly in Scenario 1 with carbon credits. The payback period for all scenarios is approximately 6 years. However, a relatively higher value of LCOE (ranging from 0.285 to 0.475 euro/kWh) is obtained making the electricity produced by the biogas plant less competitive compared to other electricity sources. Nevertheless, the biogas plant can also produce biofertilizer and other valuable byproducts, creating social benefits such as job creation, access to clean energy, and improved environmental conditions. Moreover, the plant can contribute to reducing carbon dioxide emissions, potentially aiding in climate change mitigation. Overall, a small-scale biogas plant in Sierra Leone has the potential to generate green electricity, biofertilizer, and other valuable products while addressing waste management issues. Government support and incentives are crucial for the success of such initiatives.

3. **For the Kenya Context:** the study highlighted the potential of the Kenyan e-mobility demonstrator, created by Roam, to contribute to local value chains and the circular economy. Roam stands out among e-mobility start-ups in Sub-Saharan Africa by designing an electric

motorcycle tailored to the African market with spare parts compatible with existing motorcycles. They operate a local assembly plant in Nairobi and offer charging stations for flexible services. Roam's partnership with M-Kopa and STIMA demonstrates their commitment to the local e-mobility value chain. The importance of specialization within the e-mobility value chain for sustainable development is also noted. Additionally, the study suggests using lithium batteries from e-motorcycles for a second life as grid back-up or energy storage, improving the battery-as-a-service model. This approach aligns with the concept of circular economy and can enhance the success of the e-mobility sector in Africa.

The study of the Kenyan demonstrator of electric motorcycles with battery charging stations showed how the considerations around circular economy and localization of value chains are directly related to the objective of enhancing its economic viability. Firstly, the techno-economic feasibility study carried out for this demonstrator showed that assembling electric motorcycles in Kenya from completely knocked down (CKD) kits rather than importing fully built units can reduce the cost of electric motorcycles by 18 to 24%, thanks to reductions in logistic costs and import tax incentives. The study then estimated that integrating on-site solar photovoltaic panels can enable Roam to reduce electricity expenses needed to charge batteries by 15% relative to the standard electricity tariff of the national grid. Such cost saving enabled by integrating PV panels on Roam charging stations can translate into a saving of 25 Kenyan shilling (0.18 €) per moto-taxi rider and per day. We then demonstrated how enhancing battery lifespan through advanced battery health and performance monitoring can significantly reduce the cost of leasing batteries for boda-boda riders. The study concluded that extending battery lifespan by 50% would enable to generate 68 Kenyan shillings (0.48 €) of savings on battery amortization per moto-taxi rider and per day.

4. **For the social impact of the value chain in the three contexts**: The Madagascar context can have a significant social impact and contribute to the circular management of the local economy. Additionally, these communities can be incorporated into the existing ICESs thanks to the systems. The economic and social benefits are also quite high in the Sierra Leone context since recycling is encouraged and local resources are used to produce fertilizer and electricity in addition to water. Lastly, despite its many good effects on the community, the Kenyan context does not allow for the same degree of community participation for instance in production or system management.

