ENERGICA

# ENERGY ACCESS AND GREEN TRANSITION COLLABORATIVELY DEMONSTRATED IN URBAN AND RURAL AREAS IN AFRICA

# D8.5: Environmental and Social Impact Assessment (ESIA) framework results

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# Deliverable Report

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# PROJECT SUMMARY

The ENERGICA project has grouped 11 African-based partners and 17 European entities with offices or subsidiaries in Africa to enhance collaboration on energy access and sustainable energy development. The project's primary goal is to showcase the effective implementation of renewable energy technologies tailored to local needs.

Three demonstration sites have been established, each advised by local Energy Transition Boards overseeing community-scale Integrated Community Energy Systems (ICESs). Through these methodologies and innovative technologies, ENERGICA aims to demonstrate the positive social, environmental, technical, and economic impacts of high energy-efficiency and low carbon emission renewable energy technologies (RETs).

Specifically, the project will focus on:

- Developing innovative nano grids in rural Madagascar
- Implementing low-tech efficient biogas systems in peri-urban Sierra Leone
- Introducing solar-powered e-mobility solutions in urban Kenya

By doing so, ENERGICA will highlight the benefits of renewable energy in diverse contexts across Africa.

More information on the project can be found at https://cordis.europa.eu/project/id/101037428.

# OBJECTIVE AND EXECUTIVE SUMMARY

This report will provide a comprehensive evaluation of the environmental, social, climate, and sustainable development impacts of the ENERGICA project's green energy solutions through an environmental and social impact assessment framework, based on data and analyses from Tasks 8.1 to 8.4. It will also support replicability strategies in WP9.

**Integration and Outcomes**

- D8.5 will **merge environmental and social assessments** into a unified ESIA (Environmental and Social Impact Assessment).
- It will **highlight synergies and trade-offs** between environmental performance, social acceptance, climate resilience, and SDG contributions.
- The report will **inform WP9** on how to replicate and scale ENERGICA solutions in other regions.
- A **methodological guide** will be included to support future projects in applying this integrated assessment approach.

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# 1. INTRODUCTION

The global pursuit of net-zero emissions presents a unique and critical challenge for the African continent, which must simultaneously address widespread energy poverty while having a green transition. To pilot scalable and context-specific clean energy solutions vital for Africa's sustainable energy future, the **ENERGICA project** had three demo sites in Africa to assesses three pivotal and potentially technologies in real-world operational settings.

**Decentralized Energy Access (Nanogrids):** Nanogrids were implemented in Madagascar, promising a critical pathway to achieving universal energy access (SDG 7). By establishing localized, autonomous power systems powered by Africa's abundant renewable resources, they bypass the high cost and complexity of centralized grid extension, enhancing energy security and productive use in remote and underserved areas.

**Biogas Production from Food Waste**: Biogas production was implemented in Sierra Leone, and this embodies the principles of the circular economy directly addressing waste crises in urban centres. It transforms massive volumes of organic waste, which currently generate potent methane in landfills, into valuable renewable energy. This closed-loop system is key to reducing environmental pollution and providing reliable, cleaner alternatives for industrial power and, potentially, clean cooking solutions.

**Electric Transport**: Electric mobility (buses and motorbikes) is used in Kenya, and this offers essential clean urbanization and energy sovereignty by reducing dependence on expensive imported fossil fuels. Its successful deployment in African cities can drastically reduce localized air pollution, improve public health outcomes, and contribute to the region's overall emissions reduction goals.

While the conceptual promises of these localized energy solutions are clear, how far did the ENERGICA project go in achieving these benefits through the implementation of the technologies? This Environmental and Social Impact Assessment (ESIA) report is designed to provide the impact of the ENERGICA project by rigorous analysing the demonstration sites, for the benefits, risks, and complex trade-offs associated with nanogrids, biogas production and electric mobility. The findings are intended to provide stakeholders with the robust, evidence-based insights necessary to guide future planning, ensuring that these pioneering technologies are scaled responsibly, inclusively, and effectively to achieve Africa's twin goals of energy access and climate resilience.

# 2. Screening and Scoping

This chapter sets the stage for a detailed examination of the ENERGICA project's demonstration sites across Madagascar, Sierra Leone, and Kenya. It outlines the specific components implemented at each site, explains the robust evidence base underpinning the Environmental and Social Impact Assessment (ESIA), and provides an overview of the methodologies used for evaluation. What follows is a site-by-site breakdown, highlighting the technological approaches adopted, the local contexts in which they operate, and the sources of data supporting the assessment. This will be followed by a comprehensive discussion of the existing environmental and socio-economic conditions at each location, which are critical for understanding both the challenges faced and the impacts achieved by the project interventions. The Environmental and Social Impact Assessment (ESIA) was underpinned by a robust evidence base, drawing on the Baseline Assessment (D2.1) and Life Cycle Assessment (D8.1), alongside climate–energy modelling insights from Task 8.3 (WP8) and a Sustainable Development Goals (SDG) based impact assessment (D8.4).

In Madagascar, the ENERGICA project deployed solar nanogrids across several locations in the Diana Region, including Ambanja, Ambilobe, and Diego II, to address a range of local needs. These nanogrids supplied power for rice agri-processing, drinking-water pumping, and cold services such as food refrigeration and ice production. The demonstration sites were carefully selected to represent a diverse mix of rural settings, spanning coastal, mountainous, plains, and forest areas.

In Sierra Leone, the focus was on the production of biogas from food waste within an urban environment. The demonstration site in Freetown integrated the collection and processing of organic waste from local markets and households, with the biogas plant constructed to generate renewable energy for community use. The project evaluated how biogas technology could be woven into existing waste management systems, with particular attention paid to both the energy produced and the reduction in methane emissions achieved by diverting waste from landfill. The assessment also explored the potential of biogas to support industrial processes, provide cleaner cooking solutions, and generally enhance urban sanitation.

Turning to Kenya, the ENERGICA demonstration involved the deployment of electric motorbikes and charging stations. Upon request from the demonstrator in Kenya the project compared the impact of electric vs diesel bus. The project also considered the impacts of electric vs petrol motorbikes. This comparative approach aimed to assess the costs and benefits of the energy transition for different local stakeholders.

# 3. Existing environmental and socio-economic conditions

## 3.1 Madagascar

Access to modern energy services in Madagascar remains limited and uneven. Approximately 31.6% of households lack access to electricity, while connected households often depend on decentralized solutions such as nano-grids, generators, or solar home systems. Energy supply is frequently perceived as inadequate, with 40.2% of households reporting dissatisfaction, and energy expenditures accounting for around 16% of average household income. Cooking relies predominantly on firewood and charcoal, contributing to pressure on forest resources, while household lighting is mainly provided through small-scale solar systems.

The country is highly vulnerable to climate-related pressures. Southern regions experience recurrent droughts, the central highlands are exposed to periodic flooding, and coastal areas face erosion and sea-level rise. These risks are exacerbated by widespread deforestation and wildfires, which increase environmental degradation and reduce community resilience.

Social acceptance of renewable energy infrastructure is high. Over 93% of respondents support renewable installations within their neighbourhoods, 73.3% accept installations on their own property, and more than 90% are willing to pay a premium for improved energy services. However, cultural sensitivities remain important, requiring careful siting to avoid areas of cultural significance, including tombs and burial sites.

Livelihoods are constrained by limited infrastructure, particularly the absence of cold-chain facilities, leading to high post-harvest losses. Gender dynamics further shape energy access and use, with women bearing a disproportionate share of household labour, while men more often control energy-related decisions. Educational gaps limit women's participation in energy planning and income-generating activities.

## 3.2 Sierra Leone

Sierra Leone is characterised by profound environmental and socio-economic challenges, many of which are closely interconnected through persistent energy poverty, environmental degradation, and structural vulnerabilities. Access to reliable and affordable electricity remains extremely limited, particularly outside urban areas, making Sierra Leone one of the least electrified countries in the region. Even in urban and peri-urban contexts such as Freetown, electricity supply is unreliable and intermittent. As a result, households and small businesses depend heavily on charcoal for cooking, batteries for lighting, small solar home systems, and diesel generators. This dependence not only imposes high financial burdens on already low-income households but also contributes to local air pollution, deforestation, and greenhouse gas emissions.

The country is highly vulnerable to the impacts of climate change, which are already being experienced by local communities. Coastal and peri-urban areas are increasingly affected by severe flooding, landslides, and coastal erosion, driven by intense rainfall, rising sea levels, and the loss of natural buffers such as mangroves. Deforestation, soil degradation, and unmanaged urban expansion further exacerbate these risks, undermining livelihoods, housing security, and public health. Although Sierra Leone has considerable renewable energy potential, including solar, hydro, biomass, and wind resources, these remain largely underutilised due to limited infrastructure, insufficient investment, and weak institutional capacity.

Environmental pressures are particularly evident in waste management. In Freetown and its surrounding peri-urban communities, waste collection and disposal systems are inadequate, resulting in widespread informal practices such as dumping waste in rivers, forests, and open spaces, or burning it near households. These practices contribute to environmental pollution, clogged drainage systems, flooding, and health risks, while also increasing methane emissions from unmanaged waste sites. Despite these conditions, communities express strong concern about the waste situation and show high willingness to support improved waste collection, recycling, and waste-to-energy solutions, provided these are affordable and reliable.

Socio-economically, Sierra Leone is marked by low household incomes and high levels of vulnerability. Many households spend a significant share of their limited income on basic energy services, despite often lacking access to electricity altogether. Energy poverty constrains economic activity, limits opportunities for small businesses, and undermines the functioning of essential services such as healthcare and education. Employment opportunities are scarce, and a large share of livelihoods are informal, including activities such as petty trade, waste collection, and small-scale entrepreneurship, all of which are constrained by unreliable energy access and poor infrastructure.

At the same time, social cohesion at the community level is relatively strong. Many people report a sense of belonging and pride in their neighbourhoods, as well as trust among neighbours. However, participation in formal community organisations, associations, or clubs is relatively low, which can limit collective action and structured engagement with development initiatives. Social challenges persist, including gender-based inequalities, land-related conflicts, and child labour in sectors such as waste collection and sand mining.

Gender dynamics play a significant role in shaping socio-economic conditions, particularly in relation to energy. Traditional gender roles remain prevalent, with women bearing primary responsibility for household chores and caregiving, while men more often control energy-related decisions. Women face multiple barriers to participating in renewable energy initiatives, including limited access to education and training, restricted access to finance, high upfront technology costs, and restrictive social norms. Nonetheless, there is broad recognition that improving women's access to energy, skills, and economic opportunities could deliver significant social and economic benefits.

Overall, Sierra Leone's existing environmental and socio-economic conditions are defined by acute energy poverty, environmental stress, climate vulnerability, low incomes, and persistent gender inequalities. However, these challenges coexist with strong community identity, growing awareness of environmental problems, and a high level of openness toward renewable energy, waste-to-energy, and circular economy solutions. This creates a promising foundation for integrated interventions that address energy access, environmental management, and livelihoods simultaneously, provided that affordability, inclusiveness, and local governance are central to project design.

## 3.3 Kenya

Energy access in Kenya is relatively high compared to other demonstration sites. Approximately 99% of households surveyed have access to electricity, and 87% report that energy services are reliable and available for an average of 17–24 hours per day. Despite this high level of access, affordability remains a key concern, with 51% of respondents expressing dissatisfaction with the current energy system due to high costs. At the same time, interest in renewable energy solutions is strong, with 95% of respondents indicating a willingness to participate in renewable energy initiatives.

Kenya is exposed to increasing climate pressures, including extreme weather events and recurrent food shortages, which affect both urban and rural livelihoods. These pressures interact with energy and transport systems, particularly in rapidly growing urban areas such as Nairobi.

Community cohesion is relatively strong, with 71% of respondents reporting a sense of recognition and pride in their community, although trust among community members is more moderate, reported by 44.6% of respondents. This social context provides a generally supportive environment for collective action, including the adoption of renewable energy solutions.

Livelihoods linked to the transport sector play a significant economic role and are heavily dependent on fossil fuels. Motorcycle transport is widespread, with riders covering an average of 124 km per day and, in some cases, up to 550 km. Daily fuel expenditures average USD 5.49, while average daily net income is approximately USD 12.19. Although electric motorcycles present a potential pathway for reducing emissions and operating costs, adoption is constrained by limited charging and battery-swapping infrastructure. While fuel stations are widely available along major routes, charging stations remain scarce. Women's participation in renewable energy and transport-related projects remains limited, reflecting broader gender disparities in access to technical roles and decision-making.

From an environmental perspective, air quality in urban areas such as Nairobi is moderately degraded. Real-time air quality index values typically range between 50 and 70, classified as "moderate", with average $PM_{2.5}$ concentrations around 20 μg/m³, significantly exceeding World Health Organization guidelines. Transport-related emissions are a major contributor, indicating clear potential co-benefits from electrification. Water quality assessments show elevated turbidity and metal concentrations in surface waters during wet seasons, while borehole and tap water exhibit substantially better quality. Soil carbon stocks vary significantly by land use, ranging from approximately 20 Mg C $ha^{-1}$ in croplands to over 60 Mg C $ha^{-1}$ in forested areas, highlighting the role of land-use management in climate mitigation. Kenya is also globally recognized for its high biodiversity, hosting diverse ecosystems across multiple bio-geographical zones, which could benefit from reduced environmental pressures associated with fossil-fuel-based transport.

# 4. Impact assessment

## 4.1. Environmental Impacts

### 4.1.1. Madagascar

The operation of renewable energy–based systems at the Madagascar demonstration site is expected to generate substantial environmental benefits compared to conventional, fossil-fuel-based alternatives. The assessed impacts indicate significant reductions across multiple environmental categories, particularly for climate change, fossil resource use, and air pollution–related indicators. These benefits are primarily driven by the replacement of diesel-based energy supply in agri-processing, water pumping, and cold storage services.

For agri-processing activities, assessed per ton of husked rice, climate change impacts are reduced by approximately 93%, while fossil resource use decreases by 94%. Additional benefits are observed for photochemical ozone formation (−92%), acidification (−42%), and freshwater ecotoxicity (−28%). Water pumping services, assessed per cubic metre of water delivered, show climate impact reductions of around 60%, accompanied by decreases in fossil resource use (−59%), acidification (−75%), photochemical ozone formation (−64%), and freshwater ecotoxicity (−54%). Cold storage services demonstrate the highest relative reductions, with climate and freshwater ecotoxicity impacts both decreasing by approximately 91%, fossil resource use by 90%, acidification by 89%, and photochemical ozone formation by 92% on a daily service basis.

Design optimisation analyses indicate that system configuration plays an important role in maximising environmental performance. Reductions in photovoltaic panel size, on the order of 10%, result in larger climate impact improvements than equivalent reductions in battery weight. These optimisation effects are particularly pronounced for agri-processing and cooling applications, highlighting the importance of context-specific system design in achieving optimal environmental outcomes.

Quantifying ENERGICA's impact across the SDGs involves assessing indicators such as emissions reductions, access to clean water, number of households or institutions gaining reliable energy access, jobs created, and improvements in local resilience. When mapped across the SDG framework, these outcomes show that ENERGICA does not just contribute to the energy transition in practice, it accelerates sustainable development in multiple directions at once. Below the results of SDG based impacts scores are provided in all relevant categories for the demonstration site -

A quantitative survey involving 100 respondents was conducted to assess the project's impact on the Sustainable Development Goals (SDGs) using a scoring system ranging from –1 (indicating a negative impact) to 1 (indicating a positive impact), with 0 representing no impact. The findings indicate that the project has yielded a generally positive effect on environmental SDGs. Specifically, the mean impact score for SDG 6 (clean water and sanitation) was 0.17, suggesting almost no discernible impact in this area. In contrast, SDG 12 (responsible consumption and production) received a notable mean score of 0.70, reflecting a strongly positive influence. SDG 13 (climate action) was rated at 0.47, indicating a moderate positive impact. The project also contributed positively to SDG 14 (life below water), with a mean score of 0.66, and to SDG 15 (life on land), which scored 0.30, pointing to a modest yet beneficial effect on terrestrial ecosystems.

### 4.1.2. Sierra Leone

The environmental impacts of the Sierra Leone demonstration site were assessed using Life Cycle Assessment during the operation phase of the integrated biogas and water purification system. Results are presented using two internationally recognized impact assessment methods—CML-IA baseline and Environmental Footprint (EF 3.0)—to capture methodological variability and improve robustness. Reported values represent relative improvements compared to conventional reference systems, reflecting avoided impacts from fossil energy, synthetic fertilizer production, and untreated waste management.

**CML-IA results (operation phase):**

- Biogas-based energy production (per ton organic waste treated):

Climate change −60 to −85%, fossil resource depletion −75 to −95%, acidification −30 to −55%, eutrophication −25 to −50%, photochemical ozone formation −60 to −85%.

- Digestate nutrient recycling (per ton digestate applied):

Climate change −40 to −65%, fossil resource depletion −85 to −95%, acidification −20 to −40%, eutrophication −25 to −45%. Residual impacts are mainly linked to ammonia and $N_2O$ emissions during land application.

- System scale-up (1500 kg/day vs. 300 kg/day):

Additional climate change reductions of −10 to −20% per functional unit, reflecting improved energy recovery and reduced relative infrastructure burdens.

**EF 3.0 results (operation phase):**

- Biogas-based energy production (per ton organic waste treated):

Climate change −55 to −80%, fossil resource use −70 to −90%, acidification −35 to −60%, photochemical ozone formation −65 to −90%.

- Digestate management and nutrient substitution:

Net reductions in climate change (−35 to −60%) and resource use, with remaining impacts driven by nitrogen losses during land application.

- Integrated water purification (per $m^3$ treated water):

Climate change −50 to −70%, fossil resource use −60 to −80%, photochemical ozone formation −55 to −75%. Water use impacts are strongly reduced (>90%) when treated water is reused within the biodigester process.

### 4.1.3. Kenya

The deployment of electric mobility solutions at the Kenya demonstration site is expected to deliver substantial environmental benefits during the operation phase, particularly through the reduction of emissions associated with fossil-fuel-based transport. The assessment compares electric motorbikes and electric buses with their conventional petrol and diesel counterparts, using passenger-kilometre (pkm) as the functional unit. The results highlight significant improvements in climate and air-quality-related impact categories, while also indicating trade-offs related to material use.

For electric motorbikes, climate change impacts are reduced by approximately 92% per pkm compared to petrol motorbikes. Particulate matter emissions are also reduced, although to a lesser extent, by around 6%, reflecting the continued influence of non-exhaust emissions such as road and tyre wear.

Electric buses demonstrate even broader environmental benefits when compared to diesel buses. Climate change impacts are reduced by approximately 83%, while acidification decreases by 64% and photochemical ozone formation by 94%. Additional reductions are observed for ozone depletion (−81%). Freshwater ecotoxicity shows a small increase of around 5%, indicating a limited trade-off potentially linked to upstream processes in electricity generation or vehicle manufacturing. Resource use related to minerals and metals increases substantially, by approximately 780%, reflecting the material intensity of batteries and electric drivetrains.

Results from the quantitative survey, which involved 100 respondents, further reinforce these findings. The survey employed a scoring system ranging from –1 (negative impact), through 0 (no impact), to 1 (positive impact) to assess the project's influence on various Sustainable Development Goals (SDGs). The data indicate a particularly strong positive effect on environmental SDGs, with mean scores as follows: responsible consumption and production (SDG 12) at 0.70, climate action (SDG 13) at 0.95, life below water (SDG 14) at 0.73, and life on land (SDG 15) at 0.77. Notably, clean water and sanitation (SDG 6) was not included in this assessment. These results highlight the significant environmental benefits perceived by the community as a result of the renewable energy interventions.

## 4.2. Social Impacts

### 4.2.1. Madagascar

The operation of renewable energy–based systems at the Madagascar demonstration site is expected to generate overall positive social impacts, as indicated by both quantitative and qualitative data from SDG-based community surveys. While respondents report limited perceived impacts in some sustainability dimensions, notably poverty alleviation, food security, and water and sanitation (SDGs 1, 2, and 6), the overall social performance of the interventions is assessed as positive.

In terms of economy, employment, and labour conditions, the introduction of decentralized renewable energy services is expected to have a slightly positive effect. Communities demonstrate a strong willingness to co-finance energy services, including solidarity mechanisms to support lower-income households. This creates favourable conditions for payment models such as pay-as-you-go schemes and tiered tariffs, improving affordability while supporting local economic activity and job creation.

Livelihood impacts are primarily associated with improved service reliability and value addition. The availability of cold storage services is expected to reduce post-harvest losses, while improved access to safe drinking water and local milling services contributes to increased productivity and household income. Potential safety concerns related to new technologies are considered manageable through appropriate training and awareness measures. Health-related effects, partly captured under SDG 3, are assessed as positive, reflecting reduced exposure to traditional fuels and improved service access.

Gender equality outcomes are also expected to be positive, based on SDG-based survey results. However, the distribution of benefits is not automatic. To ensure equitable outcomes, targeted measures such as capacity-building activities, participation quotas, and support for women-led micro-enterprises are required. Without such measures, existing gender inequalities in access to skills, finance, and decision-making could limit the full social benefits of the interventions.

In summary, the deployment of green technologies at the Madagascar demonstration site is viewed as delivering largely positive social outcomes, with no major negative impacts reported as long as inclusive implementation strategies are maintained. Building on this, the results of the quantitative survey, which included 100 respondents, were assessed using a scoring system ranging from –1 (indicating a negative impact), 0 (no impact), to 1 (a positive impact) to evaluate the project's effect on various Sustainable Development Goals (SDGs). The findings generally indicate a predominantly positive influence on social SDGs, although there was little to no impact observed for some goals. Notably, for SDG 1 (No Poverty), SDG 9 (Industry, Innovation and Infrastructure), and SDG 10 (Reduced Inequalities), more than 15% of participants reported a negative impact. The mean scores for each social SDG are as follows: SDG 1 – No Poverty (–0.03), SDG 2 – Zero Hunger (0.01), SDG 3 – Good Health and Well-Being (0.62), SDG 4 – Quality Education (0.92), SDG 5 – Gender Equality (0.12), SDG 10 – Reduced Inequalities (0.11), and SDG 16 – Peace, Justice and Strong Institutions (0.65). These results suggest that, overall, the project's social impacts are viewed positively, especially regarding health, education, and institutional strength, although certain areas such as poverty and inequality require further attention.

### 4.2.2. Sierra Leone

The social impact assessment evaluates the effects of renewable energy interventions on community dynamics, social inclusion, and overall well-being. The analysis shows that renewable energy deployment has the potential to generate significant positive social impacts, particularly by strengthening community cohesion, enhancing trust among community members, and improving relationships between communities and local institutions. Increased access to energy services is associated with a stronger sense of belonging and collective identity, which in turn supports cooperation, participation in local initiatives, and long-term acceptance of project activities. These impacts are considered direct and beneficial, contributing to the social sustainability of the interventions.

Social acceptance of renewable energy technologies is identified as a critical determinant of project success. The assessment examines local support for renewable energy installations, willingness to participate in community-based energy systems, and readiness to contribute financially to ensure inclusive access. High levels of acceptance and social willingness indicate favourable conditions for participatory energy models and support the principles of a just energy transition. However, the assessment also identifies potential social risks related to perceived fairness, transparency, and benefit distribution, which require proactive stakeholder engagement and clear communication strategies.

The assessment further addresses gender and social inclusion, recognizing that energy access can both reduce and exacerbate existing inequalities. Gender-differentiated roles in households, decision-making authority, and access to financial and educational resources were analysed to identify barriers to women's participation. Renewable energy solutions are found to offer opportunities for empowerment through improved safety, income generation, and enhanced decision-making capacity. At the same time, the assessment highlights the risk of reinforcing inequalities if project design and implementation do not actively promote inclusion, in line with SDG 5.

Finally, the assessment considers impacts on vulnerable groups, employment, and livelihoods, including effects on income, access to services, health, education, and time use. These impacts are particularly relevant in contexts involving e-mobility, nano-grids, and waste-to-energy systems. Overall, the findings indicate that the social impacts of the ENERGICA solutions are predominantly positive, provided that inclusive design, transparent governance, and continuous community engagement are maintained throughout the project lifecycle.

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Consistent with these findings, the assessment of the Sierra Leone demonstration site reveals positive impacts on several Sustainable Development Goals (SDGs). Specifically, positive effects are observed for SDG 1 (No poverty), SDG 3 (Good health and well-being), SDG 4 (Quality education), SDG 5 (Gender equality), SDG 7 (Affordable and clean energy), SDG 8 (Decent work and economic growth), SDG 9 (Industry, innovation and infrastructure), SDG 10 (Reduced inequalities), SDG 12 (Responsible consumption and production), and SDG 13 (Climate action). In contrast, the interventions show no significant impact on SDG 2 (Zero hunger), SDG 6 (Clean water and sanitation), SDG 11 (Sustainable cities and communities), SDG 14 (Life below water), and SDG 15 (Life on land).

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### 4.2.3. Kenya

The deployment of electric mobility solutions at the Kenya demonstration site is expected to generate overall positive social impacts, as evidenced by both quantitative indicators and qualitative feedback from SDG-based surveys. The findings suggest that the transition to electric transport can improve economic conditions for users while supporting employment and gender inclusion, if affordability and access barriers are adequately addressed.

From an economic and labour perspective, electric motorbikes offer substantial cost advantages compared to petrol alternatives. Maintenance costs are reduced by approximately 30%, while running costs decrease by around 72%. Given that motorcycle riders are highly sensitive to daily operating expenses, these reductions are expected to translate directly into higher net incomes, making affordability a central driver of adoption. In addition, the emergence of local manufacturing and service ecosystems, including the production of electric motorbikes and the operation of charging and battery-swapping hubs operated by companies such as ROAM, creates new employment opportunities, particularly for skilled technical and engineering roles.

Livelihood outcomes are closely linked to operating cost savings and access to financing. While electric motorbikes have higher upfront purchase costs, government-backed measures such as subsidies, tax incentives, and reduced import duties can help offset these barriers. Complementary financing mechanisms, including affordable monthly rental or leasing models, further enhance accessibility and support wider uptake among low- and middle-income riders.

Gender equality impacts are assessed as positive, with evidence of increased female participation in the electric mobility value chain. The employment of women in engineering and manufacturing roles within electric motorbike production contributes to improved gender inclusion in a traditionally male-dominated sector. However, continued efforts are required to ensure that these opportunities are scaled and extended across the broader transport and energy ecosystem.

Overall, the social impacts of green transport technologies at the Kenya demonstration site are assessed as predominantly positive, with no significant adverse social impacts identified in the surveys, provided that supportive policy frameworks and inclusive business models are maintained. This aligns with the broader assessment of renewable energy interventions, which consistently highlight the potential for these solutions to foster community cohesion, strengthen trust, and improve relationships between stakeholders and local institutions.

Results from the quantitative survey, which involved 100 respondents, indicate high perceived community benefits arising from the renewable energy interventions, particularly in relation to SDGs associated with social impact—namely SDGs 1, 3, 4, 5, 10 and 16. The survey employed a scoring system ranging from –1 (negative impact), through 0 (no impact), to 1 (positive impact) to assess the project's perceived influence on each SDG, similar to the approach used for environmental impacts in Section 4.1.3. The mean scores for the SDGs were as follows: No Poverty (SDG 1) at 0.87, Good Health and Wellbeing (SDG 3) at 0.86, Quality Education (SDG 4) at 0.82, Gender Equality (SDG 5) at 0.75, Reduced Inequalities (SDG 10) at 0.64, and Peace, Justice and Strong Institutions (SDG 16) at 0.61. It should be noted that Zero Hunger (SDG 2) was not included in this assessment. These findings reinforce the conclusion that, when paired with inclusive design and transparent governance, green transport technologies can deliver substantial social benefits and contribute meaningfully to the achievement of multiple SDGs.

# 5. Climate–Energy Modelling – Synopsis & Relevance

Task 8.3 establishes an integrated climate adaptation and mitigation modelling framework extending to 2050. The approach combines:

- High-resolution climate projections for temperature, wind, and precipitation;
- Multi-model climate ensembles (NorESM2, EC-Earth3, MRI-ESM2.0);
- Machine-learning downscaling tailored to African regions;
- Multi-criteria decision analysis (MCDA) to support climate-smart energy planning.

## 5.1 Madagascar

The modelling framework is directly relevant to the design and operation of decentralized renewable energy systems in Madagascar, where climate variability poses risks to energy access and service reliability. Downscaled climate projections are embedded into system design and operation to support:

- Climate-resilient nanogrid sizing (PV generation, battery storage, cooling demand);
- Optimised water pumping strategies under changing precipitation patterns;
- Long-term reliability of WEF services, including agri-processing and cold storage.

By integrating climate projections into energy system design, the Task 8.3 framework ensures that renewable-based solutions in Madagascar remain robust and effective under future climate conditions up to 2050.

## 5.2 Sierra Leone

Sierra Leone's climate–energy modelling results show that the country's strong dependence on hydropower makes its electricity system uniquely sensitive to future climate variability. The modelling framework combines physically based climate projections, machine-learning downscaled rainfall estimates, and a long-term Open-Source Energy Modelling System (OSeMOSYS) energy system optimisation to test how Sierra Leone's power system performs under different hydro-climatic futures. This integrated approach reveals that changes in precipitation, drought frequency, and seasonal inflows directly affect hydropower availability, exposing significant vulnerabilities in a system where water-driven generation forms the backbone of supply.

The simulations show that hydropower output declines under both moderate and high-emission climate scenarios, with run-of-river plants such as Betmai and Singimi being the most affected. Storage hydropower, particularly Bumbuna II, remains comparatively stable, maintaining high-capacity factors even in drier years, but overall system adequacy still deteriorates as climate stress increases. Seasonal drying and more frequent short droughts reduce firm hydropower output, requiring the system to rely increasingly on reservoir storage and, eventually, on alternative non-hydro sources.

As hydropower becomes less reliable, the least-cost power system reconfigures itself. The optimisation results show a marked shift toward greater utilisation of storage hydropower, combined with the addition of new fuel-based backup capacity, typically oil-fired or biomass technologies, to maintain system reliability under adverse climate conditions. This transition becomes even more pronounced in a high-emissions case, where hydrological volatility forces earlier and larger investments in thermal generation. These additions ensure adequacy but come at significant economic and environmental cost, illustrating how climate change indirectly pushes the system toward higher-carbon fallback options when hydropower falters.

As a result, overall system costs rise sharply: climate-stressed scenarios require two to three times more total expenditure than the baseline, driven by capital investments in backup plants, higher fixed operation and maintenance costs, and occasional heavy reliance on imports during dry years. Emissions follow a similar pattern. Under high-emission climate pathways, cumulative direct emissions grow considerably, reaching close to 0.95 $MtCO_2$ by 2050 compared with only 0.13 $MtCO_2$ in a baseline climate with reliable hydrology. These increases reflect the unavoidable role of fossil-based flexibility when hydropower can no longer satisfy demand consistently.

The findings have strong implications for energy policy. The analysis reveals a critical planning gap: national expansion plans assume relatively stable hydropower yields, yet even moderate rainfall reductions or seasonal shifts significantly undermine system reliability and affordability. Without accounting for climate-conditioned hydropower variability, long-term planning underestimates both the need for diversification and the true cost of future energy security.

The results indicate that diversification is essential. A climate-resilient energy strategy for Sierra Leone include a broader mix of resources, notably solar PV paired with storage, as well as maintaining some flexible thermal capacity to cover prolonged drought periods. Strengthening regional interconnections, such as through the West African Power Pool, can also help buffer hydrological risk. Integrating climate risk into long-term planning allows the system to hedge against uncertainty, secure backup capacity in advance, and avoid costly emergency investments triggered by extreme dry years.

Although the modelling provides powerful insights, it is designed as a directional stress test rather than a precise forecast. It assumes perfect foresight and cost-optimal behaviour, and does not fully capture market dynamics, extreme hydrological shocks, or broader energy demand changes outside the on-grid system. This implies that real-world challenges may be even more severe than the model suggests, reinforcing the need for future work using multi-model climate ensembles, stochastic hydrology, and expansion of the system boundary to include off-grid and demand-side considerations.

## 5.3 Kenya

Kenya has a strong and diversified renewable energy resource base, which provides favourable conditions for the electrification of the transport sector and the deployment of electric mobility solutions. Results from Task 8.3 indicate that the availability of low-carbon electricity is a key enabling factor for achieving climate mitigation benefits from electric motorbikes and buses.

Kenya's renewable energy potential includes the following key resources:

- Solar energy: Kenya ranks among the countries with the highest solar potential globally, with an average global horizontal irradiation of approximately 2,400 kWh/m$^2$ per year, enabling reliable solar electricity generation across most regions.
- Hydropower: Hydropower has historically played a central role in Kenya's electricity supply, with an estimated technical potential of around 6,000 MW distributed across major river basins, including the Tana, Athi, and Lake Victoria regions. Future reliability may be influenced by climate variability.
- Geothermal energy: Although Kenya is a global leader in geothermal development, more than 90% of its estimated geothermal resource remains untapped, indicating substantial potential for further low-carbon baseload expansion.
- Wind energy: Kenya has an estimated wind energy potential of approximately 4,600 MW, particularly in arid and semi-arid regions where average wind speeds exceed 6 m/s. By 2023, installed wind capacity reached around 436 MW, contributing roughly 10% of national electricity generation. Climate projections suggest that wind power density could increase by up to 20% in some regions, further strengthening expansion opportunities, while over 90% of the resource remains undeveloped.

From a climate–energy systems perspective, the availability of renewable electricity significantly enhances the climate performance of electric mobility. Modelling results indicate that transport electrification in Kenya can deliver substantial greenhouse gas reductions when powered by renewable sources, reinforcing the importance of integrated energy and transport planning.

Social and socio-economic impacts, assessed through SDG-based surveys, provide additional context for the relevance of climate–energy pathways. Key findings include:

- Economy, employment and labour: Positive impacts for both Kenya and Madagascar in terms of economic growth and employment creation, although labour conditions were not explicitly assessed.
- Gender equality: Positive impacts for Kenya and slightly positive impacts for Madagascar, based on both qualitative and quantitative survey results.
  Health and safety: Health impacts, partly captured under SDG 3, are positive for both countries, with additional positive effects on road safety identified for Kenya.
- Vulnerable groups: Impacts related to vulnerable groups, partly reflected under SDG 10, are assessed as positive for Kenya and slightly positive for Madagascar.

# 6. Significance of impacts

Across various regions of Africa, countries are pioneering new approaches to energy access and climate resilience, with particular emphasis on the expansion and integration of renewable energy sources. These efforts are yielding far-reaching benefits, both environmentally and socio-economically, and are reshaping local communities' trajectories toward sustainable development. This section explores the broader context and impacts of renewable energy deployment in three countries, highlighting common achievements, innovative strategies, and the ongoing challenges that shape the future of energy and climate systems within diverse African settings.

## 6.1. Madagascar

The ENERGICA demonstration in Madagascar shows clear positive environmental and social significance associated with the deployment of solar nanogrids for agri-processing, water pumping and cold-chain services. Although the operational period of the project remains relatively short to observe long-term transformative impacts, the available assessments from LCA, SDG-based community surveys and climate-energy modelling indicate a strong potential for sustained improvements in rural livelihoods, environmental quality and climate resilience.

From an environmental perspective, the shift from diesel-based services to solar nanogrids delivers substantial reductions in climate emissions, fossil resource depletion and air-pollution-related indicators across all three productive-use applications. The LCA results show that reductions in climate impacts can reach 60–93%, depending on the service (rice milling, water pumping, cooling), together with notable decreases in acidification, photochemical ozone formation and freshwater ecotoxicity. These gains are especially significant in a context where rural energy supply is highly constrained and where diesel-based systems are both expensive and logistically unreliable. The modelling insights from Task 8.3 further highlight that the nanogrid systems — when sized with climate-aware design parameters — can remain resilient under projected 2050 climate conditions, even as temperature rise increases cooling demand and hydrological variability affects pumping loads. This strengthens the long-term significance of the environmental benefits observed.

Social impacts also show predominantly positive significance, though the magnitude varies across SDG dimensions. Survey results reveal high social acceptance of renewable energy installations and a willingness to adopt improved energy services, including mechanisms for co-financing and solidarity support to low-income households. The introduction of reliable milling, refrigeration, ice-making and safe drinking-water services contributes directly to reducing post-harvest losses, increasing productivity, and improving daily living conditions. These benefits address long-standing structural barriers in the Diana Region, where the absence of cold chains, unreliable water access and high energy expenditures constrain local economic development. Gender impacts are assessed as positive, though conditional on continued support for women's participation in management structures, skills training and micro-enterprise opportunities linked to energy services. Without deliberate inclusion strategies, existing inequalities in skills, access to finance and decision-making could limit the distribution of benefits.

Cultural and community dynamics also shape impact significance. While acceptance levels are high, the need to avoid installations near culturally sensitive areas — such as tombs — remains essential for maintaining community trust and preventing grievances. The project's approach to co-design and early consultation has proved effective in aligning infrastructure with local norms, reinforcing the positive social trajectory observed during implementation.

The overall findings highlight that the Madagascar nanogrid demonstration project holds considerable significance for long-term environmental improvements, alongside moderate to high importance for social advancement and a notable positive impact on energy security and resilience in rural areas. These benefits, as observed throughout the project's operational period, are expected to intensify with ongoing commitment to inclusive practices, robust maintenance planning, and the incorporation of climate-aware system design. Such measures will likely reinforce and extend the positive outcomes, helping to shape sustainable development pathways for rural communities.

Assessment against the SDGs revealed substantial positive effects, particularly for SDG 4 (quality education), SDG 7 (affordable and clean energy), SDG 11 (sustainable cities and communities), and SDG 12 (responsible consumption and production). The provision of reliable electricity is shown to have a transformative influence on essential services and the overall functioning of local communities. Importantly, the available data did not identify statistically significant differences among socio-demographic groups, suggesting that the benefits of improved energy access are broadly distributed and inclusive within the community.

## 6.2. Sierra Leone

The ENERGICA demonstration in Sierra Leone centres on the implementation of an integrated biogas digestion and solar-powered water purification system in a peri-urban environment. As the project was still in its early operational phase during data collection, the current assessment draws on insights from three key informant interviews, reflecting anticipated impacts rather than those fully observed to date.

From a social perspective, respondents consistently anticipated that the project would bring notable improvements to community well-being, principally through enhanced access to clean water and better personal hygiene. Such advancements are closely linked to expected reductions in waterborne diseases, aligning with the objectives of SDG 3. The provision of clean, reliable energy and lighting was also highlighted as a significant benefit, with the potential to support children's educational outcomes by improving their ability to study after dark and facilitating access to information.

In terms of gender and social inclusion, interviewees identified the project's potential to promote gender equality (SDG 5). By reducing community reliance on firewood collection and limiting charcoal use, the system may help alleviate both the physical and time burdens traditionally placed on women and girls. Furthermore, these technological shifts could open up opportunities for small income-generating activities accessible to both men and women. Nonetheless, some uncertainty remains regarding the extent of these benefits, given that the project is still at an early stage.

The anticipated economic impacts are also positive. The system is expected to generate employment opportunities, including roles for technicians, operators, and security staff, while also reducing household fuel and electricity expenditures. These changes could enhance financial resilience among low-income households, thereby contributing to poverty reduction (SDG 1) and supporting decent work and economic growth (SDG 8). Respondents also expressed optimism that improved access to reliable energy services would help address inequalities (SDG 10) by reaching previously underserved populations.

From an environmental standpoint, the biogas system offers significant advantages over traditional diesel generators, chiefly through reductions in air pollution and greenhouse gas emissions, supporting SDG 13. The project's approach to valorising organic waste via anaerobic digestion not only supports safer waste management practices but also helps relieve pressure on landfill sites, contributing to SDG 12. The integration of waste treatment with energy production was seen as a particular strength, delivering a range of environmental co-benefits.

However, some limitations and uncertainties persist. Delays in achieving full operational status and the early maturity of the demonstrator mean that impacts on infrastructure (SDG 9) and long-term project performance remain unclear. As such, the findings presented here are best viewed as emerging perceptions and indicative of possible future impacts, rather than definitive evidence. Continued monitoring and evaluation will be essential to substantiate these anticipated benefits and to inform future scaling and replication efforts.

## 6.3. Kenya

The ENERGICA project operated for 4 years and this maybe too short to see long term impact but perceived impact. Findings of perceived impact analysis indicate that electric motorbikes and electric buses can be useful in the improvement of the environmental and socio-economic conditions in cities in Kenya in the long term. Electric motorbikes and buses can cut emissions in cities, reducing air pollution and improving public health in urban areas heavily affected by traffic fumes. Electric motorbikes and buses can improve the quality of life by reducing noise pollution, making busy streets and residential areas quieter and more liveable. Electric motorbikes can also support safer working conditions for riders through predictable fuel costs and less exposure to exhaust fumes. Electric motorbikes and buses can used as a way to create new economic opportunities e.g., local manufacturing, assembly, charging services, and battery-swap jobs which strengthens community economic livelihoods. Electric motorbikes can also improve economic livelihoods through lowering daily operating costs for riders' operators. In the long term, these shifts can lower national emissions, enhance energy security, support more equitable access to clean and affordable transport and improve economic livelihoods.

There will be trade-offs in scaling electric motorbikes and buses e.g. increase in mineral resource in areas where mining of minerals takes place. Human health issues associated with toxicity of heavy metals if batteries are poorly disposed. Proper battery recycling could reduce these negative impacts. Scaling up will also have trade-offs of an increase in required public economic resources for infrastructure for charging and electricity generation. The development of Integrated Community Energy Systems (ICES) in WP2 has potential to supplement government efforts.

The SDG impact assessment revealed substantial positive effects across several Sustainable Development Goals, notably SDG 1, 3, 8, 9, and 13. The benefits are especially pronounced for SDG 8 and SDG 9, underscoring the economic and technological contributions of e-motorcycles, such as increased income opportunities and the integration of innovative approaches within the transportation sector. A notable statistical finding is that respondents with higher levels of education tended to report marginally higher SDG impact scores. However, the assessment did not identify other significant socio-demographic factors influencing these results.

# 7. Environmental & Social Management Plan (ESMP) — Key Actions & KPIs

To systematically evaluate sustainability performance, it is essential to identify clear and measurable key performance indicators (KPIs). These indicators help track progress, highlight improvement areas, and ensure alignment with long-term sustainability goals. Table 1 presents selected KPIs along with their recommended measurement frequencies to support consistent and meaningful assessment.

*Table 1. Relevant themes, action, key performance indicators for sustainability and frequency of measurement*

| Demo site | Theme | Action | KPI / Target | Frequency |
|---|---|---|---|---|
| **Madagascar** | Climate-aware design | Integrate downscaled T/Wind/Precip. into nanogrid sizing (PV, storage, cooling loads) | Climate-adjusted capacity margin ≥ +10% vs historical | Annual re-optimisation |
| | Cooling demand | Plan for 11–18% demand uplift under warming. | Unserved energy ≤ 1% | Quarterly |
| | Water pumping resilience | Align pump scheduling with seasonal/diurnal precipitation projections | Service uptime ≥ 95%; $m^3$/month tracked | Monthly |
| | LCA discipline | Include embodied impacts in decisions (avoid operation-only bias) | Procurement with recycling & take-back; PV/battery EPR | Design & annual audit |
| | Gender & inclusion | Targeted training; quotas in energy committees; micro-enterprise support | Women's participation ≥ 40%; 50 women entrepreneurs per district | Semi-annual |
| | Cultural siting | Co-design sites; avoid sacred/tomb areas; leader consultations | 0 installations on sensitive sites; ≥ 95% grievance resolution in 30 days | Continuous |
| **Sierra Leone** | Technical Reliability | Install smart meters and sensors on digester, gas flow, and water unit; preventive plan | System uptime ≥ 95%; unplanned downtime ≤ 5%; metered kWh (biogas CHP), $Nm^3$ biogas, and $m^3$ treated water recorded | Monthly |
| | Environmental Performance | Replace diesel use for electricity; optimize gas capture and flare backup | ≥ 60% reduction in GHG vs. baseline per tonne of waste treated; ≥ 70% reduction in fossil energy use | Quaterly |
| | Resource Circularity | Expand segregated organic waste collection and valorisation routes; Nutrient management plan for digestate | ≥ 80% of collected organic waste processed; ≥ 70% of digestate safely reused as fertilizer within agronomic rates | Yearly |

| Demo site | Theme | Action | KPI / Target | Frequency |
|---|---|---|---|---|
| | Water Quality & Access | Operate solar photocatalytic unit with reuse loop for process water | ≥ 90% compliance with WHO parameters; ≥ 80% of target HHs or institutions served; ≥ 90% reduction in freshwater intake when reuse loop active | Monthly |
| | Social Inclusion & Gender | Reserve places for women and vulnerable groups in training/committees; targeted outreach and scheduling | ≥ 40% women's participation; ≥ 30% of new jobs to women/youth; ≥ 75% overall user satisfaction | Yearly |
| **Kenya** | Climate impact | Carry out inventories | >90% reduction in $CO_2$ Emissions per Passenger-Kilometer (pkm) compared to petrol or diesel vehicles | Annual |
| | Charging station utilization | Collect and analyze data from stations | 70-80% of capacity used | Monthly |
| | Battery Health | Collect and analyze data from stations | 100% of Roam batteries | In real time |
| | Distance travelled | Collect data from riders/drivers using hire purchase schemes (log books) | At least 10% more than petrol or diesel vehicles | Monthly |
| | Operational costs for riders | Collect data from riders/drivers using hire purchase schemes | At least 30% less than petrol or diesel vehicles | Monthly |
| | Health and safety | Use accident report from Police | Zero Accidents | Quarterly |
| | Passenger satisfaction | Do random surveys | 75% satisfaction of public electric vehicles | Yearly |

## 7. 1 Risk Register (Selected)

Managing sustainability initiatives often involves navigating a range of operational, environmental, and social risks that can affect system performance and long-term outcomes. Identifying these risks early enables more effective mitigation strategies and supports resilient decision-making. Table 2 summarizes key sustainability-related risks alongside their respective mitigation.

*Table 2. Risks and mitigation actions for scaling up solar nanogrids in Madagascar, biogas from foodwaste in Sierra Leone and electric transport in Kenya.*

| Demo site | Risk | Mitigation | Status/Owner |
|---|---|---|---|
| **Madagascar** | Cultural siting (installations near tombs) | Avoidance mapping; early leader consultations; culturally respectful siting | Project siting lead / Community board |

| Demo site | Risk | Mitigation | Status/Owner |
|---|---|---|---|
| | Battery longevity under tropical conditions | Thermal management; duty-cycle matching; O&M training; supplier warranty and take-back | Technical lead / Supplier |
| | Affordability shocks (seasonal incomes) | Flexible PAYGo; buffer fund; productivity services (milling/cold) to stabilise incomes | Finance/Community committee |
| | Safety perception and incidents | H&S protocols; user training; signage; live demos; incident reporting | HSE lead |
| **Sierra Leone** | Inadequate organic waste supply/quality | Mutual agreement with municipalities/markets; community awareness; segregated collection; buffer feedstock plan | Operation lead |
| | Digestate misuse or run-off | Training on usage, soil testing, buffer zones; application within agronomic rates; wet-season protocols | Technical & Agronomy Leads |
| | Affordability for low-income users | Lifeline tariffs; cross-subsidy; donor-backed vouchers; PAYGo options | Finance & Community Board |
| | Health & safety incidents | Gas detection; ventilation, confined-space permits; regular drills | Technical & Operation lead |
| | Social resistance/theft | Inclusive engagement; community benefit-sharing; local security; CCTV where appropriate | Community Board |
| | Technical downtime (pumps, sensors) | Preventive maintenance; spares kit; supplier warranties; local technician roster | Technical lead |
| **Kenya** | Grid reliability and capacity | Deploy solar-powered or hybrid charging stations to reduce dependence on the national grid. | ROAM/Integrated community energy systems |
| | Pollution and resource use intensity | -Increase the level of renewable energy in electricity generation in Kenya<br>-Promote battery recycling programs and partnerships with certified recyclers | ROAM/Integrated community energy systems |
| | Extreme weather and natural disasters | -Design charging stations with weather-resistant infrastructure (elevated | ROAM/Integrated community energy systems |

| Demo site | Risk | Mitigation | Status/Owner |
|---|---|---|---|
| | | platforms, waterproof enclosures).<br>-Develop disaster response protocols and insurance coverage for assets.<br>-Be on standby for relocation of modular station | |
| | Access to capital | -Advocate for government incentives (tax breaks, grants) for e-mobility projects.<br>-Leverage public-private partnerships (PPPs) and climate finance (Green Climate Fund, carbon credits). | Riders and the community in Kenya |
| | Public resistance leading to theft or vandalism of charging stations | Conduct community engagement and awareness campaigns to build trust and ownership.<br>Employ local security personnel and integrate CCTV and IoT monitoring at stations.<br>Offer community benefit-sharing models (e.g., local employment, revenue sharing). | ROAM and community in Kenya |
| | Policy, regulated tariffs and taxation risks e.g. shift in focus from motorbike to electric buses | Align with national climate and transport strategies to secure policy support e.g. be prepared to invest in electric buses | ROAM/Integrated community energy systems |

# 8. Monitoring and Evaluation

Successful integration of new technologies and infrastructure within local communities relies on building trust, encouraging participation, and considering relevant social and policy factors. This section provides an overview of common challenges, possible approaches for engagement, and broader considerations for effective policy alignment and ongoing monitoring.

## 8.1. Madagascar

Monitoring and evaluation activities for the Madagascar demonstration site are designed to ensure that nanogrid systems deliver reliable environmental, technical and social benefits while supporting adaptive management. The framework emphasises continuous operational monitoring, inclusive social feedback mechanisms, and periodic environmental verification aligned with D8.1.

**Technical performance monitoring**

Digital dashboards track key performance indicators across the three service categories:

- Energy generation and consumption (PV output, storage performance, load profiles)
- System uptime and reliability for milling, water pumping and cooling
- Volume of water delivered, tons of rice milled, and hours of cold-chain services provided
- Battery cycling, temperature exposure and any technical anomalies
- Monthly summaries allow operators and community committees to evaluate utilisation patterns, detect emerging technical issues and adjust system settings. Climate-aware performance indicators — such as seasonal variance in cooling demand or pump loads — are also reviewed to ensure alignment with Task 8.3 projections.

**Social monitoring and inclusion metrics**

Dedicated social performance indicators are tracked to assess affordability, user satisfaction and the inclusiveness of service access. Key metrics include:

- Household expenditures on energy services and their affordability over agricultural seasons
- User satisfaction with reliability, service quality and accessibility
- Participation of women in energy committees and productive-use activities
- Number and resolution time of grievances submitted through local mechanisms
- Perceived safety and comfort in using new technologies
- These indicators are reviewed quarterly with Energy Transition Boards and local leaders to identify barriers for vulnerable users and ensure equitable service provision.

**Environmental impact verification**

Annual environmental verification relies on simplified LCA benchmarks derived from D8.1 and updated with operational data. The process includes:

- Tracking fuel displacement and avoided diesel-based emissions
- Assessing reductions in local air-pollution-relevant indicators
- Evaluating energy efficiency improvements in milling, water pumping and cooling
- Reviewing supply-chain sustainability (battery health, PV performance, recycling commitments)
- This helps ensure that environmental gains observed in controlled assessment conditions remain valid under real-world use.

**Community validation and feedback**

Community scorecards are used twice per year to capture local perspectives on service quality, inclusiveness, cultural appropriateness and perceived benefits. These participatory tools help validate

M&E findings, strengthen accountability and align services with community expectations. Feedback gathered through these mechanisms is integrated into system optimisation plans and training activities for local operators.

**Mitigation and adaptive management**

Monitoring results are used to adjust system design, operations and social engagement methods. This may involve load-shifting strategies for water pumping, cooling-demand management during warmer months, tariff adjustments for affordability, or targeted support to expand women's participation in energy-linked livelihoods. The adaptive approach ensures that systems maintain high performance and remain resilient as climate conditions shift or community needs evolve.

## 8.2. Sierra Leone

Monitoring and evaluation activities for the Sierra Leone demonstration site centre on tracking the technical reliability, environmental benefits, and social outcomes of decentralised renewable energy systems. The approach integrates ongoing data collection through digital dashboards with participatory community feedback and regular field assessments to ensure robust, context-specific insights.

Environmental and technical monitoring involves the use of smart metering and remote sensors to capture real-time data on system performance. Core metrics include energy generation and consumption profiles, system uptime and fault rates, and the contribution of renewables to overall supply. The framework also monitors reductions in diesel usage and associated greenhouse gas emissions, as well as improvements in local air quality indicators.

Social impact is assessed through regular community consultations, including scorecards and focus group discussions, to understand satisfaction with service quality, inclusivity, and benefits such as enhanced energy access for productive uses. These participatory tools help triangulate quantitative data, identify emerging needs, and inform responsive management strategies.

Findings from monitoring and evaluation are systematically reviewed to guide adaptive management. This may include refining load management strategies, adjusting tariff structures to support affordability, or introducing new training modules for local operators. The iterative process ensures that the energy systems remain resilient, equitable, and aligned with evolving community priorities in Sierra Leone.

## 8.3. Kenya

Monitoring and evaluation activities for the Kenya demonstration site are designed to track the technical performance, environmental outcomes, and social impacts of electric mobility solutions, while supporting adaptive management and continuous improvement. The framework combines real-time dashboards with periodic evaluations and stakeholder feedback mechanisms.

**Environmental and technical monitoring**

Environmental and technical dashboards are used to monitor the operational performance and climate impacts of electric motorbikes and buses. Key indicators include:

- Energy use per vehicle, reported in kWh per day, week, and month.
- Operating cost per kilometre, comparing electricity-based mobility with fossil-fuel alternatives.
- Downtime and maintenance frequency, to assess system reliability and operational efficiency.

- Grid impact, including peak load contribution and the share of renewable energy used for charging.
- Greenhouse gas reductions, expressed as tons of $CO_2$ avoided annually compared to conventional vehicles.
- Average charging time, measured per charging session, to assess usability and service efficiency.

These indicators are reviewed regularly to ensure that electric mobility systems perform as intended and deliver expected environmental benefits.

**Social monitoring and inclusion indicators**

Social performance is monitored through a dedicated dashboard capturing economic, gender, health, and equity-related impacts. Key indicators include:

- Employment creation, including direct and indirect jobs associated with vehicle manufacturing, charging infrastructure, and operations.
- Gender inclusion, measured as the share of women among riders, technicians, and staff.
- Affordability, assessed through cost per trip compared to conventional transport options.
- User satisfaction, based on surveys covering reliability, comfort, and safety.
- Community acceptance, including public perception and incidence of vandalism or conflict.
- Training and capacity building, measured by the number of people trained in electric mobility technologies.
- Health benefits, including reductions in exposure to urban air pollution.
- Safety metrics, such as accident rates compared to petrol motorbikes.
- Equity of access, including coverage in low-income and underserved neighbourhoods.
- Impacts on the informal economy, particularly changes in income levels for boda boda riders.

**Evaluation approach**

Impact evaluation combines quantitative and qualitative methods to assess performance over time:

- Before–after comparisons, using baseline and post-implementation data.
- Control group analysis, comparing electric motorbike and bus fleets with conventional petrol and diesel fleets.
- Periodic reviews, including quarterly technical audits and annual social impact assessments.
- Stakeholder feedback, through continuous engagement with riders, operators, and local communities.

**Mitigation and adaptive management**

Monitoring results inform both environmental and social mitigation strategies. Environmental mitigation focuses on optimising charging patterns, increasing renewable electricity use, and reducing grid stress. Social mitigation measures address affordability, safety risks, and unequal access through targeted financing mechanisms, training programmes, and inclusive service planning.

# 9. Conclusions

The ENERGICA project demonstrates that integrated, community-aligned renewable energy solutions can deliver substantial environmental, social, and climate-resilience benefits across diverse African contexts. By piloting solar nanogrids in Madagascar, biogas-based waste-to-energy systems in Sierra

Leone, and electric mobility solutions in Kenya, the project shows that decentralised clean technologies are both technically viable and socially meaningful when grounded in local priorities and supports by inclusive governance structures.

Across all demonstration sites, environmental assessments confirm significant improvements relative to fossil-fuel baselines, including major reductions in climate emissions, fossil resource dependence, and air-pollution-related impacts. These findings highlight the strong potential of distributed renewable systems to support national and community-level climate commitments.

Social analyses similarly reveal broadly positive outcomes, such as improved service reliability, strengthened livelihoods, higher community satisfaction, and growing acceptance of clean energy technologies. Where challenges persist, especially around affordability, gender inclusion, and infrastructure gaps, the project identifies clear pathways for inclusive design and equitable distribution.

Climate-energy modelling further underscores the need to integrate climate projections into long-term energy planning. In Madagascar, climate-aware nanogrid sizing ensures resilience to changing temperature and precipitation patterns. In Sierra Leone, results warn of hydropower vulnerability under future climate variability, reinforcing the importance of diversification toward solar, storage, and flexible backup resources. In Kenya, abundant renewable potential strengthens the case for large-scale electrification of transport as both a mitigation and development strategy.

In sum, the ENERGICA project provides clear evidence that well-designed renewable energy interventions can enhance energy access, strengthen community resilience, and contribute to sustainable development across multiple SDGs. Scaling these technologies will require sustained policy support, inclusive financing models, robust maintenance and monitoring systems, and continued engagement with local communities. By combining technical innovation with socially grounded implementation, ENERGICA offers a replicable model for acceleration just, climate-resilient energy transitions across Africa.

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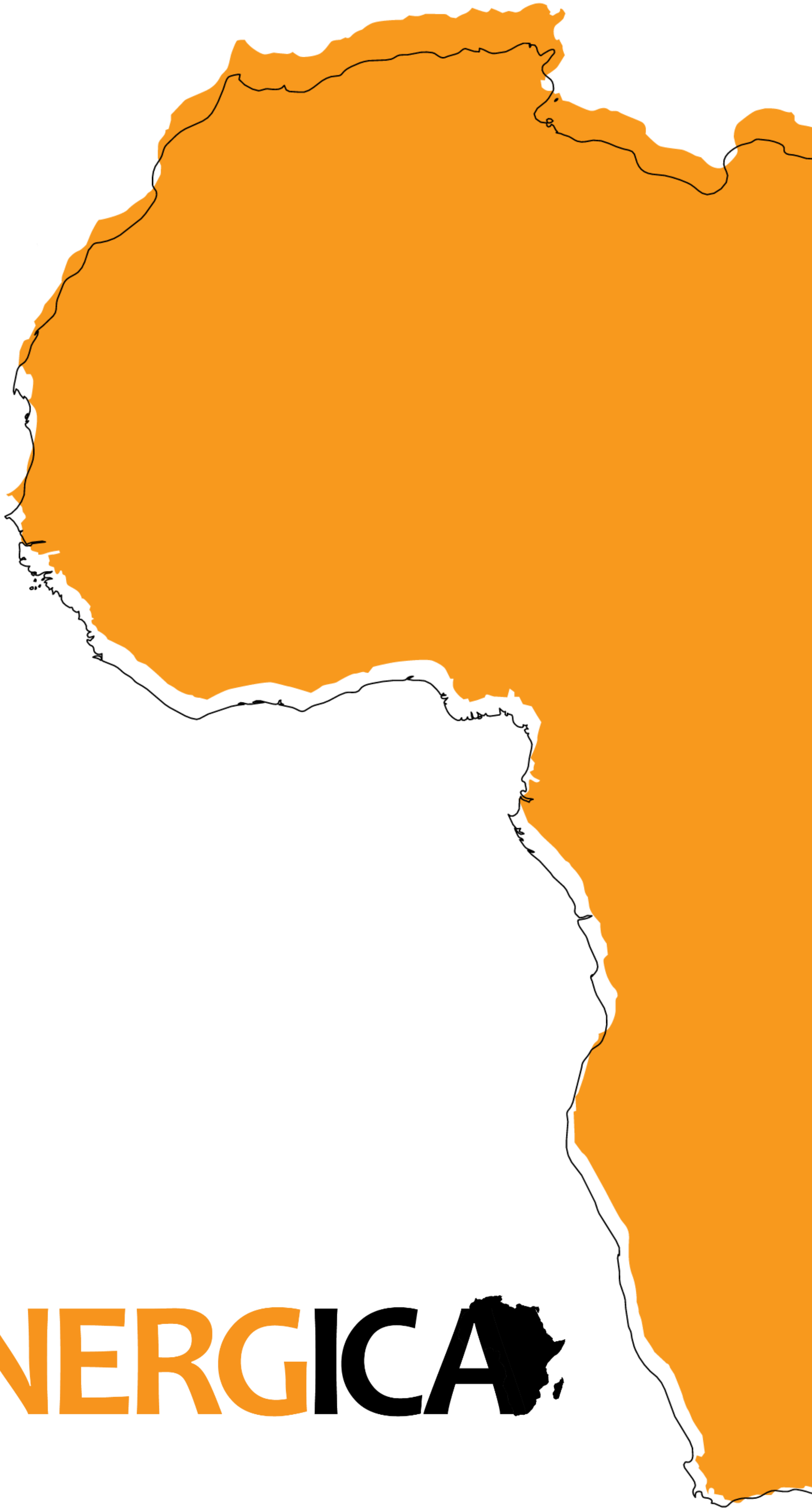

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