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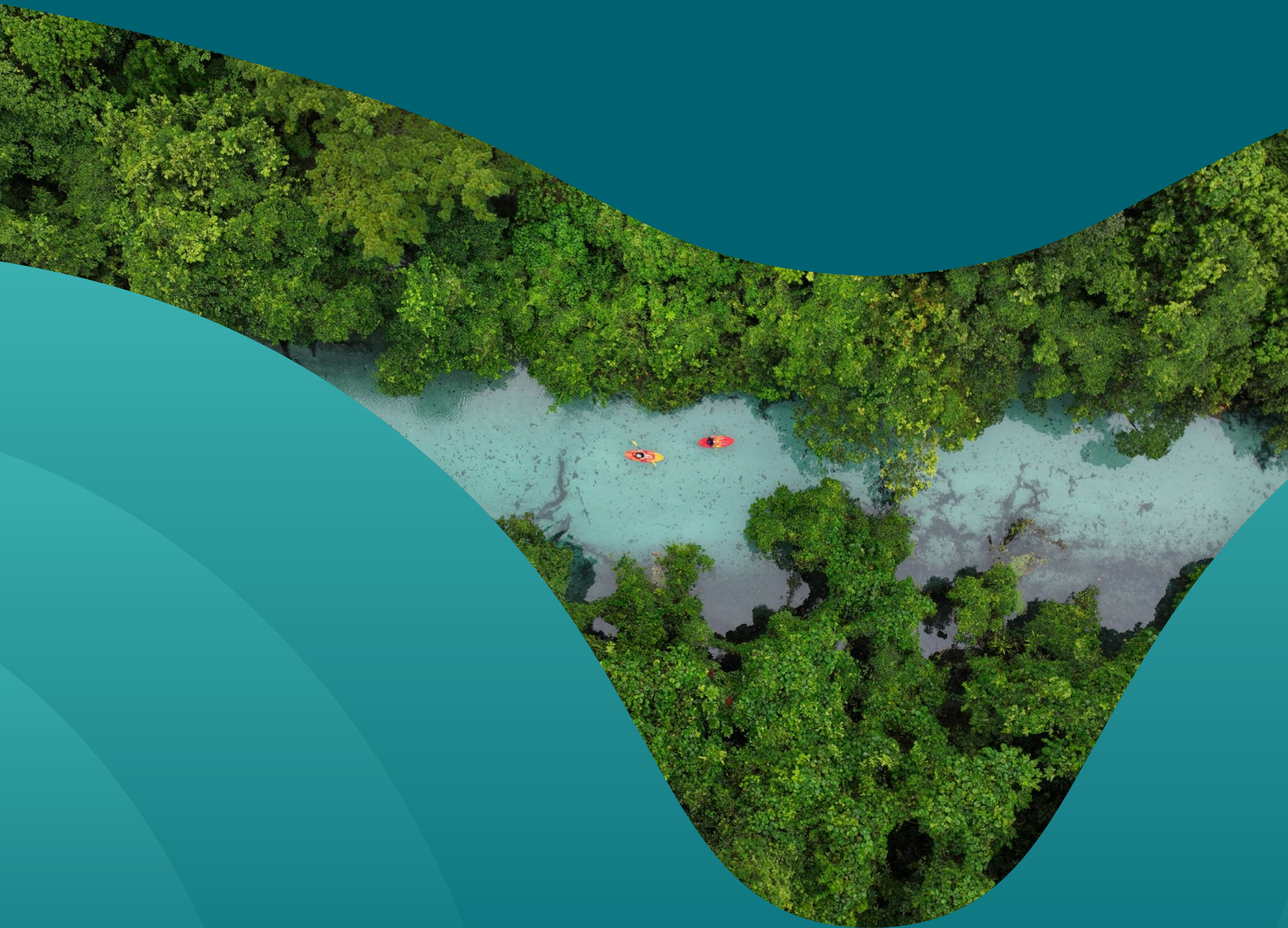

Small Island Developing States at a Crossroads:

# TOWARDS EQUITABLE ENERGY ACCESS IN LEAST-ELECTRIFIED COUNTRIES

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**IRENA Headquarters**
Masdar City
P.O. Box 236, Abu Dhabi, United Arab Emirates
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# ABBREVIATIONS

| | |
|---|---|
| **GW** | gigawatt |
| **GWh** | gigawatt hour |
| **IRENA** | International Renewable Energy Agency |
| **kW** | kilowatt |
| **kWh/m$^2$** | kilowatt hours per square metre |
| **kWp** | kilowatts peak |
| **MW** | megawatt |
| **O&M** | operations and maintenance |
| **PGK** | Papua New Guinean kina (currency) |
| **PV** | photovoltaics |
| **SHS** | solar home system |
| **SIDS** | Small Island Developing States |
| **STEM** | science, technology, engineering and mathematics |
| **USD** | United States dollar |
| **VUV** | Vanuatu vatu (currency) |

# ABOUT IRENA'S *SMALL ISLAND STATES AT A CROSSROADS* SERIES

Small Island Developing States (SIDS) account for less than 1% of global greenhouse gas emissions, yet they are home to some of the world's most climate-vulnerable populations. Sea level rise and extreme weather extremes may render some of these territories uninhabitable by the end of the century unless urgent action is taken to mitigate global heating. This makes SIDS important climate action ambassadors.

Renewable energy offers vast opportunities for SIDS. Its deployment will be instrumental in building sustainable energy systems and opening socio-economic opportunities in these special geographic contexts. Those opportunities include energy security, climate resilience, economic development and energy access. Renewables translate directly into better quality of life and services, with an environmental footprint smaller than that of fossil fuels. They also fit well within the socio-cultural context of SIDS, whose populations' welfare is closely tied to the health of the land and the oceans that surround them. All of these benefits can unfold if the right technical, capacity and financial support is provided.

The *Small Island Developing States at a Crossroads* series focuses on the present and potential socio-economic and environmental benefits, barriers and opportunities of the transition to renewables in SIDS. **Volume I: The socio-economics of transitioning to renewables** focuses on contexts that are largely electrified, relying heavily on imported fossil fuels, while **Volume II: Towards equitable energy access in the least-electrified countries** features contexts having significant unelectrified populations and the opportunity to leapfrog to renewables-based energy access.

# KEY FINDINGS

While most upper-middle- and high-income small island developing states (SIDS) have achieved universal electrification, mostly through imported fossil fuels, several low- and lower-middle-income SIDS still have unelectrified and under-developed regions, which are facing economic vulnerabilities exacerbated by poverty, food insecurity, water-borne illness, lack of healthcare, volatile agriculture, deforestation and climate vulnerabilities. The least-electrified SIDS are now at a crossroads to achieve universal energy access: they can increase access through imported fossil fuels or scale up their significant progress in decentralised renewable energy solutions. The former worsens the adverse impacts of the status quo, while the latter provides an opportunity for significant economic, well-being, health and environmental benefits to the most marginalised regions of the unelectrified SIDS.

Although the focus of energy development aid to SIDS has shifted towards renewables, it has not prioritised the least-electrified SIDS. In fact, there is minimal correlation between country-specific aid and energy access gaps, with the least-electrified countries experiencing stagnation of progress. Achieving a just and equitable clean energy transition in the SIDS requires focused support to least-electrified SIDS in terms of results-based finance and capacity building for renewable energy value chains and productive end-use development.

Local practitioners of decentralised renewable energy solutions in the least-electrified SIDS have begun establishing local value chains for biomass-gasification-, small-scale-hydro- and solar-photovoltaic-based electricity generation. Customised capacity building and results-based finance that strengthens local manufacturing of renewable energy components, as well as small-scale agri-processing equipment, will support faster adoption of reliable and affordable clean energy solutions, advancing universal energy access and a just energy transition in the SIDS.

The women in rural regions of the least-electrified SIDS face severe social and physical hardships. Yet, decentralised renewable energy value chains and productive end uses have been proven to give rural women opportunities for increased income generation, reduced physical drudgery, reduced indoor air pollution from cooking and greater access to higher-quality healthcare.

Rural regions of the least-electrified SIDS are impaired with rural poverty and malnutrition, and their dependence on the volatile prices of imported food. Yet, they are extensively experienced in smallholder agriculture, in producing cash crops such as cashews, cassava and rice. This dichotomy is partly due to lack of electricity stunting the financial robustness and productivity of local agriculture value chains.

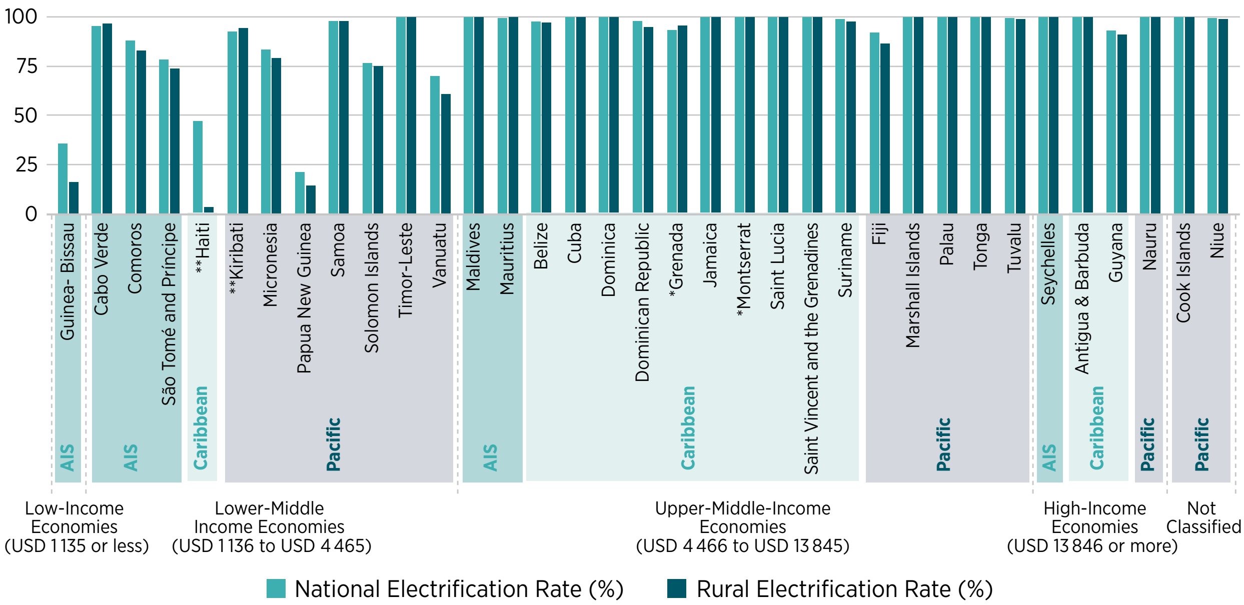
The land layout of each SIDS is a noteworthy classification to understand opportunities and barriers to energy access. About two-thirds of the SIDS, across all three geographic regions, are archipelagos or semi-archipelagos. These archipelagos or semi-archipelagos have hundreds of islands. The remainder of the SIDS, however, are either mainland or main island countries with many smaller islands, and a few are single island countries. For the least-electrified SIDS covered in this publication, Guinea-Bissau is part of the west African mainland with small islands, Papua New Guinea is a large island with smaller islands and Vanuatu is an archipelago of many small islands. The SIDS' physical proximity to and political relationships with their developed-nation neighbours impacts both energy access value chains and end uses.

# 1. INTRODUCTION

Small island developing states (SIDS) face urgent environmental, economic and social pressures. They present unique challenges and opportunities in terms of electricity access and infrastructure development. All SIDS have small populations and a narrow resource base, rely heavily on the natural environment, rely on fossil fuel imports and have limited economies of scale. Such factors affect the SIDS' adaptive capacity and resilience to climate change. Even though they contribute minimal greenhouse gas emissions, they are among the most vulnerable to the severe impacts of climate change.

SIDS' economic and infrastructure development, governance systems, economic inclusion, reliance on neighbouring larger economies and innate physical aspects also shape the socio-economic metrics and outcomes of their energy transitions. As such, the challenges and inequities of climate- and economic-resilient development are magnified in the case of least-developed, low-income and lower-middle-income SIDS. These countries' economic structures, domestic production, labour markets, lack of energy access and other basic infrastructure, and limited adaptive capacity make them especially susceptible to climate change, external global shocks and internal instability. While on-grid electrification is close to 100% in most SIDS, it is far less in some low- and lower-middle-income SIDS (see Figure 1).

**Figure 1** National and rural electrification rates in SIDS, 2020/2021




**Sources:** All from (UN, 2021), except (*), which denotes national and rural electrification rates (%) from (Energy, 2020), and (**), which denotes rural electrification rates (%) from (Energy, 2020) or (World Bank, 2021). Country classifications based on (World Bank, 2024).

**Note:** AIS stands for Atlantic, Indian Ocean and South China Sea.

While most upper-middle- and high-income SIDS have achieved universal electrification, mostly through imported fossil fuels, several low- and lower-middle-income SIDS still have unelectrified and under-developed regions. Here, economic vulnerabilities are exacerbated by poverty, food insecurity, water-borne illnesses, lack of healthcare, volatile agriculture, deforestation and climate vulnerabilities. The least-electrified SIDS are now at a crossroads as they seek to achieve universal energy access: they can increase access through imported fossil fuel, exacerbating the status quo, or scale up their progress in decentralised renewable energy solutions, securing significant socio-economic benefits for marginalised regions (Figure 2).

**Figure 2** Energy transition crossroads for the least-electrified SIDS

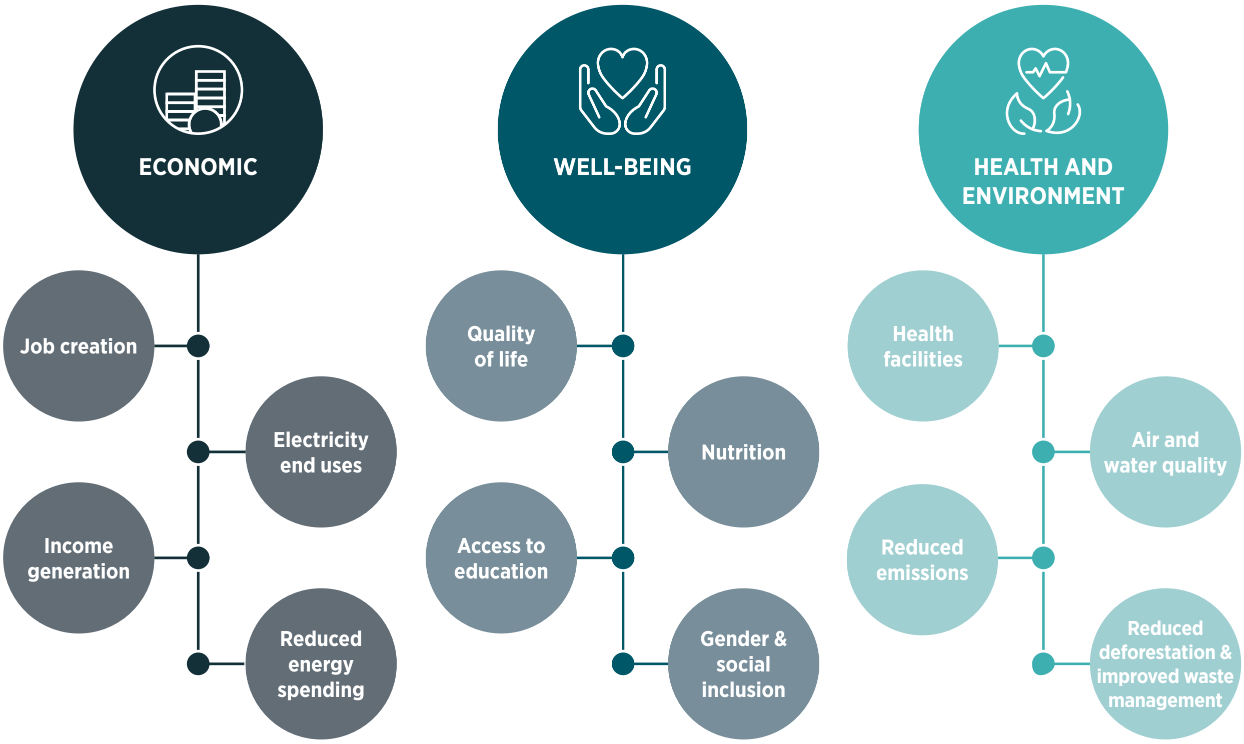

**Note:** SIDS = small island developing states.

This publication focuses on three countries – Guinea-Bissau, Papua New Guinea and Vanuatu – and examines the socio-economic benefits of energy access solutions in terms of progress potential, barriers, opportunities and recommendations for scaling up proven solutions. The three cases are representative of the diversity of the SIDS' geographies, namely, mainland with smaller islands, main island with smaller islands and an archipelago of smaller islands, which have implications for options and outcomes of energy access solutions. The socio-economic and environmental opportunities for universal energy access in these SIDS can offer insights to upper-middle- and high-income SIDSs, which have last-mile populations without energy access amid high national electrification rates.

# 2. SOCIO-ECONOMIC AND ENVIRONMENTAL BENEFITS

Renewable energy contributes to sustainable development across three key domains: economy, well-being, and health and environment. On the economic front, it reduces fuel expenditure, generates direct employment, and encourages productive end uses that generate income and indirect jobs. In terms of well-being, renewable energy contributes positively by alleviating strenuous labour and increasing educational and gender-related opportunities. On the health and environmental front, it improves the operation of and air quality in medical facilities, and reduces ecological impacts via lower emissions and better waste management practices (Figure 3). Each benefit stream, while promising, has its unique challenges, including technological adoption, integration into community norms, ensuring consistent energy delivery, and accounting for the full environmental footprint of renewable technologies. Addressing these will be key to fully realising the transformative potential of renewable energy.

**Figure 3** Socio-economic benefits of renewable energy in energy access contexts




## 2.1 ECONOMIC BENEFITS

As SIDS navigate intricate socio-economic and environmental landscapes, the adoption of off-grid technologies emerges as a promising avenue for addressing pressing energy needs, including fostering more sustainable economic growth, enhancing livelihoods and boosting climate resilience. This section delves into the pivotal intersection of off-grid solutions and the specific context of the SIDS. It explores multi-faceted dimensions, including job creation, electricity end uses, income generation and resilience.

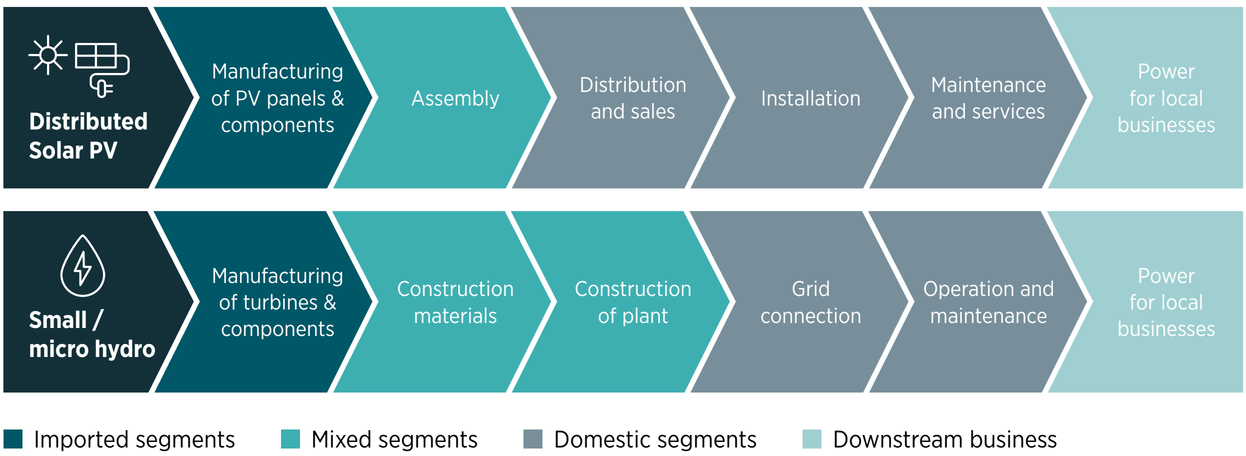
## Job creation

Renewable energy offers substantial opportunities for job creation and income generation, allows savings on the costs of imported energy and confers a degree of energy independence. Such benefits can reverberate beyond the energy sector. Renewable energy enables productive economic opportunities in agriculture, fisheries, tourism and other sectors of the economy. These benefits collectively contribute to a more robust and sustainable economic framework, encouraging self-sufficiency and resilience in local economies.

Renewable energy deployment can facilitate job creation on two fronts: in the value chain of a technology itself (direct and indirect jobs) and in the induced productive activities that the technology enables, including businesses related to food production and distribution. Figure 4 highlights the value chains for technologies such as distributed solar photovoltaics (PV) and small-scale hydropower; locally sourced, imported or mixed-origin segments are distinguished. The figure suggests that developing countries could find greater local employment and income generation opportunities in distribution and sales, installation, and operation and maintenance (O&M) than in equipment manufacturing.

Operating distributed solar PV typically involves importing panels and many components; assembly is occasionally local, accompanied by localisation of sales, installation and O&M. As shown by the case study on Papua New Guinea (section 3.2), in 2019, the country had more than 20 solar businesses, ranging from large solar specialists to department stores, which imported and distributed quality-verified off-grid solar products, alongside more than 100 shops, which sold generic solar products. In small hydropower, some projects source inputs locally, even though import of critical components such as complex turbines and advanced electronics remains common. In most cases, the construction and installation, and O&M segments of the value chain are localised, with support from foreign experts. Regardless of the technology, the energy supplied by the projects contributes to job creation in the downstream businesses.

**Figure 4** Illustrative value chains for selected renewable energy technologies




**Source:** IRENA, 2013; IRENA, 2017; IRENA, 2023a.
**Note:** PV = photovoltaics.

Although the absolute numbers are for the most part not large (not surprising in the context of small economies), substantial job creation potential exists within the off-grid renewable energy value chain in SIDS. Decentralised and off-grid solutions typically require more labour than large-scale renewable energy projects. Their labour-intensive nature means renewable energy deployment in off-grid settings and regions with weak grid infrastructure presents a substantial job creation opportunity in SIDS. Mini-grids powered by biomass gasification, hydropower and solar PV are especially conducive for local value chain development since major components can be manufactured in local machine shops using locally available material with appropriate skill building. These initiatives not only support local economies, they also contribute to sustainable development in marginalised regions by establishing skills that are transferable to other infrastructure development sectors, and making renewables-based electricity more reliable through locally available troubleshooting and repair skills. In this way, these initiatives boost the adoption and productive end use of decentralised renewables, improving the local value chain.

This report includes case examples that illustrate the employment opportunities generated by renewable energy projects in the SIDS. Section 3.1, for instance, highlights the hybrid solar PV–diesel mini-grid project in Bambadinca, Guinea-Bissau, which created 23 new local jobs besides training 11 technicians to manage, operate, and maintain the mini-grid. Section 3.2 examines a 30 megawatt (MW) biopower project in Papua New Guinea, projecting the creation of more than 700 jobs in the installation phase and more than 470 jobs during the operation phase. It also showcases a small hydropower project powering the Ambua and Rondon Ridge resorts in Papua New Guinea, which employed 30 workers for construction and installation.

## Electricity end uses

Renewable energy deployment is of course not an end unto itself. It is a catalyst for economic advancement and resilience, primarily by supporting productive activities in key sectors and thus creating a diverse range of job opportunities. Section 3.2 will show that the Bambadinca hybrid PV mini-grid project, for instance, powers 84 micro-enterprises, which range from a cybercafe to a carpentry business. The project has also helped lower the cost of goods that require energy inputs (such as ice, the cost of which has decreased by over 50%), in turn reducing household expenditures.

In **agriculture**, renewable energy has the potential to modernise practices and enable mechanisation. However, challenges exist in integrating modern renewable energy systems with traditional farming methods, which ensures these energy sources remain reliable under local environmental conditions and helps in the development of infrastructure consistent with existing agricultural landscapes. A notable example is in Cabo Verde, where the Climate Change Adaptation Facility project has made strides in addressing these challenges. It implemented solar pumping systems on two of the most vulnerable islands, to address the unreliability of rainfed agriculture, which was being affected by prolonged drought. These systems have not only reduced energy costs but also made water supply more reliable. In turn, they have boosted climate resilience for more than 500 farmers, enabling them to irrigate about 15 hectares (approximately 37 acres) of arable land (IRENA-FAO, 2021). Section 3.1 will show how combining solar PV for electrification of institutions and solar pumps for agriculture in the Oio region of Guinea-Bissau improved agricultural productivity and created more than 600 jobs.

**Tourism**, a vital economic driver in many SIDS, can utilise renewable energy to lower emissions from resorts and associated services. However, integrating renewable technologies in remote and pristine environments poses a challenge, as does developing ecotourism while preserving natural attractions. As section 3.2 shows, the solar PV projects at the Lake Murray and Bensbach lodges in Papua New Guinea have been a boon to local employment, creating 6 000-8 000 person-days of work annually in diverse roles in the resorts, with about 30% female employees and 95% local hires. These projects reduced physical labour intensity and provided crucial job training. Similarly, the Ambua and Rondon Ridge resorts in Papua New Guinea, powered by a hydropower mini-grid, have each generated 12 000-15 000 person-days of employment annually; this has significantly benefitted the local community with diverse job opportunities and reduced the reliance on physical labour.

Fisheries can also leverage renewable energy for crucial operations such as cold storage and processing. This will boost productivity and reduce spoilage. Key challenges here include the sustainability and reliability of energy solutions, training for workers in new technologies and the implementation of environmentally responsible systems to protect marine life.

Renewable energy significantly contributes to community well-being by alleviating the burdens associated with conventional energy sources. For instance, shifting from tasks such as collecting firewood or manually processing agricultural products to using renewable energy frees up substantial time for education, leisure and other productive activities. This change is especially beneficial in rural areas, where such tasks often fall on women and children. The adoption of renewable energy technologies generates considerable time savings and reduces physically demanding work; this in turn improves quality of life, empowers women and creates educational opportunities. Integrating renewable energy into daily life thus marks a transformative step towards improving well-being, especially in rural and developing areas.

### Income generation

The emergence of decentralised renewable energy solutions in rural areas can be a powerful catalyst for income generation, especially in the context of the agri-food chain. Leveraging renewable energy can improve agricultural productivity significantly through improved irrigation, increased work hours and better food preservation methods. Such advancements often result in an abundance of agricultural outputs and by-products, opening up new income-generating opportunities for local communities. For instance, access to reliable power can enable the use of processing equipment, which adds value to raw produce, making it market ready and more profitable.

Renewable energy projects can inspire entrepreneurial ventures beyond the agri-food chain. The availability of energy opens the door for various business ventures, for example, agri-tourism or the manufacture of goods whose production was once hindered by energy constraints. This creates a ripple effect of economic benefits, including job creation and skill development, as the workforce adapts to new technologies and market demands.

As shown in section 3.2, employees at the Ambua and Rondon Ridge resorts, powered by a hydropower mini-grid, are receiving at least minimum wage. The advent of hydropower has spurred additional local economic activity, with community members selling food and handicrafts to tourists at markets near the lodges. Similarly, the installation of solar water pump systems and PV systems for electrification in the Oio region of Guinea-Bissau (see section 3.1) significantly increased farmers' incomes, by 159%, by boosting agricultural production and introducing new income-generating activities.

### Reduced energy spending

Decentralised renewable energy systems in SIDS present a significant opportunity to reduce spending on fuels that are either unsustainable or imported. The transition from conventional fuel sources such as wood, charcoal, kerosene and diesel to modern forms of renewable energy can be economically transformative, especially in remote areas, where transportation often represents more than half the cost of fuel and the prevalent use of inefficient appliances exacerbates energy costs. Studies indicate that households switching to off-grid renewable energy solutions witness a decline in spending on conventional fuels in the majority of cases, with some reporting up to a 40% reduction, particularly when improved cookstove projects are implemented. This shift not only represents a financial saving, but also a step towards greater energy independence for these communities. Sometimes the reduction in energy spending is passed on through the goods produced using the energy. As shown by the example of the Bambadinca-based hybrid solar PV–diesel mini-grid in section 3.1, well-designed systems can lead to a price decline for goods that require energy inputs.

Renewables also play a crucial role in bridging the information gap faced by many rural communities. With better access to information, farmers and producers can make more informed decisions about what to grow, when to harvest and how to price their goods. Although it must be acknowledged that large buyers and other intermediaries often wield considerable market power, better knowledge, often facilitated by renewables-powered connectivity, makes improved access to markets, both local and beyond, possible. Communities can consequently reduce their reliance on food imports by capitalising on local production, which bolsters the local economy.

Farmers should also be provided with targeted training and support services to maximise the benefits of renewables-powered connectivity. Access to information alone may not suffice, especially for smallholder farmers, who lack the resources or technical expertise to effectively leverage agricultural data. Such services can bridge the gap between the nominal potential offered by technology and the practical implementation challenges on the ground in SIDS. A holistic approach thus combines renewable energy use with capacity building.

In general, SIDS rely heavily on imported fossil fuels and food imports, which make them vulnerable to supply chain disruptions and volatile commodity prices due to regional and global dynamics. The significantly unelectrified SIDS face an additional vulnerability, to unstable domestic economies and affairs. Decentralised renewable energy solutions serve as a means for marginalised populations to be less dependent on national and international interests in meeting their development needs. Put another way, such solutions reduce vulnerability to the decisions of national and international actors. Community-based enterprise models and financially viable decentralised solutions can support locally developed and owned electrification, with full control over decision making on O&M. Policies aimed at promoting distributed renewable energy systems, such as solar PV, are crucial (see Box 1). Renewable energy deployment can significantly reduce communities' reliance on international fuel markets. Finally, improving local agricultural systems through renewable energy can reduce the reliance on imported food, contributing towards a more resilient and self-sufficient domestic food supply chain.

### **Box 1** Comprehensive policy framework for the development of distributed PV

A mix of policies and measures is needed to drive the deployment of distributed PV and the development of sectors that maximise the socioeconomic benefits.

**Deployment policies** and regulations that make distributed PV affordable or profitable include feed-in tariffs and premiums, individual net-metering, collective net-metering, and peer-to-peer contracts. These should be implemented in a progressive way to ensure they are not benefiting the highest income population and businesses that can afford them while being subsidized by the rest of the population. Fiscal incentives and capital subsidies render technology more affordable but they need to be implemented in a way that does not result in forgone government revenue for the profit of the highest income populations and foreign businesses. Result based financing based on competition has been increasingly utilized to deliver on socioeconomic benefits.

**Enabling policies** include dedicated distributed PV targets in National Determined Contributions (NDCs) and national energy plans. These should be aligned with long-term plans for grid expansion to ensure investments made by utilities do not become obsolete or unsustainable. Policies and announcements to phase out fossil fuels and fossil fuel subsidies directly impact the competitiveness of distributed PV but these should only be introduced together with instruments to support the lowest-income population that relies on subsidies. Policy support to access commercial and public financing is crucial, including those that tap into funds (*e.g.* climate funds) and instruments to disburse these funds (loans with beneficial terms, grants, etc.). Measures to raise awareness among consumers on the benefits of distributed solar PV are needed, in addition to training and development of skills to install PV. Standards and specifications are also required to ensure the quality of PV technology.

**Integrating policies** include measures to integrate the power produced from distributed PV into the grid (*e.g.* grid codes, grid access rules) as well as measures to support system balancing from the power that will be added.

**Policies to maximize socioeconomic benefits** include measures to maximise local value creation (localizing parts of the value chain), measures that support the whole ecosystem of PV deployment with end uses to keep the system feasible and sustainable, measures to support the productivity of the sectors and end uses (tourism, agriculture, fisheries) and end-of-life policies and considerations including the sustainable disposal and recycling strategies for panels and batteries.

**International collaboration** plays a crucial role in supporting lowest-income SIDS in the deployment of distributed PV systems. It includes the transfer of funds (*e.g.* climate funds) and sharing of experiences and knowledge.

## 2.2 WELL-BEING BENEFITS

Integrating renewable energy sources into communities, especially in developing and island nations, brings multi-faceted and far-reaching benefits. A shift from conventional to renewable energy sources not only improves quality of life through the provision of more reliable and flexible energy services, it also has significant positive impacts on health, environment, nutrition, education, gender and social inclusion. Thus, the transition improves overall community well-being, contributes to social progress and raises the average standard of living. Below, we explore various aspects of well-being benefits in detail.

### Quality of life

A shift from conventional energy sources to renewables significantly improves quality of life. It adds to flexibility and convenience for energy services. This transition is often a symbol of social progress and an improved standard of living. For instance, the use of biomass gasification, small-scale hydro, solar PV or small wind for electric cooking reduces the time and effort spent on basic survival tasks; this allows individuals more time for productive or leisure activities. Increasing flexibility and convenience for energy services through renewables such as mini and micro hydropower, and solar PV systems, underscores a commitment to improving daily life and environmental sustainability.

Renewable energy projects, including the Hogave Conservation Centre's micro hydropower project in Papua New Guinea (section 3.2), have resulted in more free time, improved lighting and increased safety, and contributed to richer cultural and religious experiences. The availability of electricity has made evening tasks quicker and increased hours for work, study and community activities. Better lighting in homes and public buildings, provided by renewable projects, makes it possible to dedicate more time to learning and business activities. More lighting in community spaces has reduced crime and made it safer for people to join in community, cultural or religious events at night. Similarly, projects such as the Trans Niugini Tours' renewable energy projects used ecotourism to enable cultural exchange, letting communities show their heritage to visitors; this has contributed to social progress, culture preservation and improvement in the overall quality of life.

### Nutrition

Renewable energy sources can also play a crucial role in improving nutrition and reducing food spoilage or contamination. They contribute to food security by boosting **food production**, adding to its frequency and diversity. For instance, irrigation can boost yield by up to 300%; also, access to water supports a broader range of products such as dairy products, fruits and vegetables, which helps balance diets and reduce malnutrition. Renewables support farmers in making informed decisions on crops and nutrition through improved communication. In section 3.3, we delve into the Guinea-Bissau-based Farmers' Clubs Renewable Energy project in Oio, which has significantly advanced the agriculture and the food value chain by integrating solar water pumps, benefiting 2 600 farmers through enhanced productivity.

Renewables aid in proper handling and **storage** of produce; this extends shelf life, reduces food loss and retains nutrients. Solar dryers, for instance, can preserve green vegetables year round, minimising wastage. In section 3.3 of this report, we explore how the introduction of solar drying technology in Vanuatu, including training for more than 500 women and efforts to improve the quality of products for export, helps strengthen the local food value chain while adding economic value and improving nutrition.

Reliable renewables-based cooling systems, for example, solar refrigerators, are vital for storing and **transporting** livestock vaccines. This aids in disease prevention. Decentralised renewable energy supports **processing** activities (grinding, pressing grains, fruits and vegetables), transforming otherwise inedible produce into nutrient-rich products. For example, processing prosopis trees into flour creates a protein-, carbohydrate- and fibre-rich product that is beneficial for human and animal consumption. Renewable energy and efficient cooking technologies (solar thermal cookers, biogas and improved stoves) are essential in **food preparation**. Heating destroys harmful micro-organisms and parasites in food and water, in turn reducing health risks such as diarrhoea and food-borne diseases significantly. Renewables-based electric cooking supports affordable, time-efficient and drudgery-reducing alternatives to conventional biomass for rural women. This saves time and physical energy, which can instead be invested in other aspects of food security.

### Access to education

Renewable energy has a profound impact on education, especially in rural areas. It helps alleviate the burdens of sourcing conventional energy, a task that falls on children and adults, who can instead allocate more time and resources to education. For example, solar-powered lighting makes it possible to study after dark, while digital educational resources can be accessed using renewable-energy-powered devices. In communities where agricultural activities dominate, the time saved from manual labour can be re-directed towards educational endeavours, leading to overall community development.

Renewable energy initiatives often include educational components. They involve educating communities on the use of sustainable energy, environmental conservation and the technologies themselves. This not only enhances the immediate educational environment, but also fosters a culture of learning and innovation.

As the country cases show, renewable energy has a notable impact on education in the SIDS. Projects such as solar PV–diesel hybrid village electrification under the Bambadinca Sta Claro project and the Farmers' Clubs Renewable Energy project in Oio, Guinea-Bissau (section 3.1), have provided electricity access for educational institutions, making extended school hours possible and improving educational resources. Similarly, the micro hydropower project at the Hogave Conservation Centre in Papua New Guinea (section 3.2) has provided reliable energy, adding to schools' operational capacity and contributing to educational development. These initiatives, explored in more detail in separate sections of the report, exemplify how renewable energy supports not only environmental sustainability but also educational advancement in these communities.

### Gender and social inclusion

The integration of renewable energy is important as a strategic lever for gender inclusion, especially in positioning women as key stakeholders in the energy sector. Women – as integral contributors to these island communities' climate resilience – often encounter systemic barriers, which limit their active participation in the sector. Their involvement as leaders, technicians, engineers and entrepreneurs in this field is significantly impeded by, for example, restricted financial access, prevailing cultural norms, and a lack of educational opportunities and role models. Women's labour force participation rate in the three SIDS regions is consistently lower than men's, although with significant inter-region variation. The Pacific shows the widest variation, from 31.5% in Samoa (against 55% for men) to 83% in the Solomon Islands, whereas rates are typically lower in countries in the Atlantic, Indian Ocean and South China Sea. Women's participation in Pacific power utilities is limited: only 18% of the total workforce and 24% in managerial roles. However, women are significantly over-represented in secretarial and administrative positions, holding nearly 90% of these roles. These data highlight a gender imbalance across different job levels in the sector (Mahoney, 2022). Data on women's participation specifically in the renewable energy sector in the SIDS were not available.

Key efforts to improve women's participation in the energy transition include promoting women's access to education in the science, technology, engineering and mathematics (STEM) fields, and decision-making roles within the sector. The Island Women Open Network – an initiative by the Sustainable Energy and Climate Resilience Initiative, the United Nations Industrial Development Organization, and regional organisations – focuses on gender mainstreaming in the sustainable energy sector across various regions in the SIDS. It emphasises the importance of women's participation in achieving sustainable energy goals and operates through regional sustainable energy centres. The network engages in a range of activities, from policy mainstreaming to capacity building and advocacy, and is linked to other regional and national programmes focused on increasing women's participation in the energy sector.

Other programmes, for example, the Gender Equality in the Renewable Energy Sector in Small Island Developing States funded by the Canadian government, aspire to boost women's employment in renewable energy, especially in STEM-related roles. Collectively, these initiatives are vital for fostering a more inclusive and equitable energy transition in SIDS, recognising women's role as transformative agents in the green energy transition.

Renewable energy projects in the SIDS are crucial for advancing gender and social inclusion. Key examples from Papua New Guinea and Vanuatu, as discussed in sections 3.2 and 3.3 of this report, highlight these impacts. In Papua New Guinea, projects such as the Trans Niugini Tours and the Nazarene Foundation Hospital, both powered by renewable energy sources, have added to safety and security, and increased employment opportunities for women and minorities. These initiatives have also improved essential services such as maternal healthcare (section 3.2). In Vanuatu, a solar fruit drying project has trained about 500 women in using solar-powered dryers, empowering them economically and socially. This project not only aids in food preservation, it also supports women's roles in agricultural sustainability and adaptation to climate change (section 3.3).

## 2.3 HEALTH AND ENVIRONMENTAL BENEFITS

The synergy between health and renewable energy is increasingly recognised as a key driver of progress. Central to this is the provision of clean, decentralised energy solutions, which significantly improve health outcomes. Renewable energy's role in mitigating both indoor and outdoor air pollution is especially notable, since it replaces conventional, pollutant-heavy cooking and heating methods with cleaner alternatives, in turn reducing health risks associated with respiratory diseases and contributing to environmental preservation. In healthcare facilities, especially in under-resourced regions, powering essential medical equipment and maintaining vaccine cold chains requires renewable energy to be reliable and accessible. Renewable energy substantially contributes to nutritional improvement by contributing to food security, adding to the quantity and diversity of food production, and ensuring safe food storage and processing. This transition from conventional energy sources to renewables is not merely an environmental or economic shift, but also a step towards betterment of public health.

The deployment of renewable energy technologies enables a more holistic approach to tackling various environmental challenges. These technologies not only address immediate energy needs, they also contribute to long-term environmental sustainability by reducing emissions and deforestation, and improving waste management. As renewable energy sources replace conventional energy forms, they create a positive ripple effect on both local and global ecosystems.

## Health facilities

Renewable energy sources, especially decentralised solutions, contribute significantly to the improvement of healthcare services, especially in low- and middle-income countries, where a substantial number of healthcare facilities lack reliable electricity. The use of renewables in healthcare facilities is not just about providing basic electricity for lighting and communication; it extends to powering essential medical devices and equipment, refrigeration for vaccines and ensuring life-saving equipment can be operated. For example, during the COVID-19 pandemic, renewable energy solutions were critical in enabling the electrification of health facilities and the provision of cold chains for vaccine deployment in various countries. This effort was crucial in regions such as Sub-Saharan Africa and South Asia, where a significant portion of health facilities either completely lack electricity or have unreliable power sources.

The healthcare sector, which relies heavily on a reliable power supply, needs robust and reliable renewable energy systems. Critical to this is the development of support infrastructure and the availability of trained professionals to manage the systems effectively, especially in regions where power outages can have severe consequences. The Kudjip Nazarene Hospital in Papua New Guinea (section 3.2), powered by a 200 kilowatt (kW) mini hydro plant, created significant employment opportunities during the construction phase, as well as for ongoing O&M. Local and female workers demonstrated substantial participation. The hospital's self-reliance on renewable energy has enabled it to expand and upgrade its services, adding to the community's well-being and reducing economic vulnerability.

## Air quality and reduced emissions

Renewable energy sources are pivotal in reducing indoor and outdoor air pollution. At the household level, replacing conventional cooking methods, which use coal and solid biomass fuels, with renewable energy alternatives significantly decreases indoor air pollution. Traditional cooking practices often involve open fires or inefficient stoves, whose use generates harmful pollutants such as carbon monoxide in substantial quantities, especially in poorly ventilated spaces. This indoor air pollution is a major health hazard; it is linked to diseases such as pneumonia and chronic obstructive pulmonary disease, and even cancer, and affects millions globally. Switching to clean cooking stoves, for instance, has been shown to reduce respiratory infections in children by 25%. Renewables also reduce outdoor air pollution by replacing fossil-fuel-based energy generation, in turn decreasing pollutants such as sulphur dioxide and nitrogen oxides, which are significant contributors to smog and acid rain.

In 2019, the Pacific Islands small states reported a notably high death rate, of about 193 per 100 000 population, due to indoor and ambient air pollution – a death rate far exceeding that in Caribbean small states, 38.3.

Vanuatu, Guinea-Bissau and Papua New Guinea, the three countries included in this report, had some of the highest death rates – 260, 229 and 190 deaths per 100 000 population, respectively. Solomon Islands, Micronesia and Kiribati also reported high death rates due to air pollution – 281, 254 and 247 per 100 000 population, respectively.

Transport, power generation, waste burning, and the use of coal and conventional biomass for cooking and heating in households are all key causes of air pollution; they can all be alleviated through greater reliance on renewables. Many of the examples in the country case studies show that the introduction of renewables such as small hydro, solar water pumps, solar PV systems and biomass gasification has displaced diesel, leading to significant reductions in indoor and outdoor pollution.

Continuing to rely on conventional energy solutions to address the need for energy access in the least-electrified SIDS would significantly raise fossil fuel consumption. The result would be higher emissions and a divergence from the targets set under the Nationally Determined Contributions, which seek to minimise greenhouse gas emissions. Papua New Guinea, for instance, has set an ambitious goal of becoming carbon neutral by 2050, highlighting an urgency to move away from fossil fuels, towards more sustainable energy practices. Projects such as the Trans Niugini Tours' mini hydropower initiatives and solar PV installations at the Lake Murray and Bensbach lodges (section 3.2) are prime examples of progress in the right direction. These projects demonstrate a commitment to reducing greenhouse gas emissions, play a crucial role in the country's strategy to achieving carbon neutrality by 2050 and provide consumers with much-needed energy access. Prioritising renewable energy adoption can help the SIDS meet their energy access goals while adhering to the global climate commitments, thereby avoiding the environmental and climatic impacts of increased fossil fuel use.

### Reduced deforestation and improved waste management

Renewable energy technologies, especially biomass energy systems, offer solutions to effectively manage organic waste, which includes food scrap, agricultural residues and animal manure. Traditionally, untreated animal waste contributes to soil and water pollution and emits methane, a potent greenhouse gas. Biomass gasification digesters showcase how renewable energy can provide dual benefits: energy generation and effective waste management. Such systems significantly reduce the carbon footprint by substituting diesel-generated electricity, besides mitigating health hazards by treating large volumes of manure.

Deforestation in many SIDS is often spurred by agricultural expansion and infrastructure development. In Papua New Guinea and Guinea-Bissau, logging and firewood collection, hunting, grazing and fire are other key reasons for deforestation. Renewable energy technologies can reduce the reliance on wood-based fuels and other conventional forms of biomass, which contribute to deforestation. Renewable energy can provide alternatives to fossil fuels, which can indirectly lessen the pressure.

Nevertheless, there are several challenges to maximising renewable energy's environmental benefits. Cultural acceptance and behavioural change are key to widespread adoption. Economic and financial constraints often hinder initial investments, especially for lower-income groups or in under-developed regions. Further, infrastructure and technological limitations in remote or rural areas can impede the integration and effectiveness of these systems. Also, the successful implementation of these technologies requires developing effective policy and regulatory frameworks, conducting thorough environmental impact assessments, and increasing education and awareness about renewable energy's benefits.

# 3. CASE STUDIES

Socio-economic assessments play a pivotal role in understanding the diverse opportunities and challenges faced by small island developing states (SIDS) in their transition towards sustainable development. Given their vulnerability to external shocks and geographical isolation, comprehensive analyses are required to shed light on the complex interplay of capacities, organisational frameworks and socio-economic determinants influencing SIDS' development trajectories. Common challenges include susceptibility to the impacts of climate change, a limited resource base in some cases and dependence on external aid. Examining the socio-economic landscapes of countries such as Guinea-Bissau, Papua New Guinea and Vanuatu provides insights into the dynamics shaping their paths to progress.

Guinea-Bissau, situated in West Africa, grapples with economic challenges, but it possesses excellent natural resources and can leverage its renewable energy potential to foster socio-economic growth. Papua New Guinea, located in the southwestern Pacific, features a complex mix of linguistic diversity, resource abundance and infrastructure constraints. Vanuatu, nestled in the South Pacific, faces the dual challenge of environmental vulnerability and economic reliance on agriculture and tourism, but has immense potential for diversification and sustainable practices.

The following section presents socio-economic assessments in these countries; it highlights progress, challenges and increasing awareness of potential barriers while fostering a deeper understanding of the socio-economic dynamics at play. Specifically, this analysis emphasises the socio-economic benefits of biomass gasification, small hydropower and solar photovoltaics (PV), and aims to analyse how these renewable energy sources can be harnessed to drive inclusive economic growth, boost energy security and mitigate environmental impact in the unique context of each nation. It does so by showcasing examples of scalable practices and highlighting adjustments required to overcome barriers and maximise the socio-economic potential of sustainable energy alternatives.



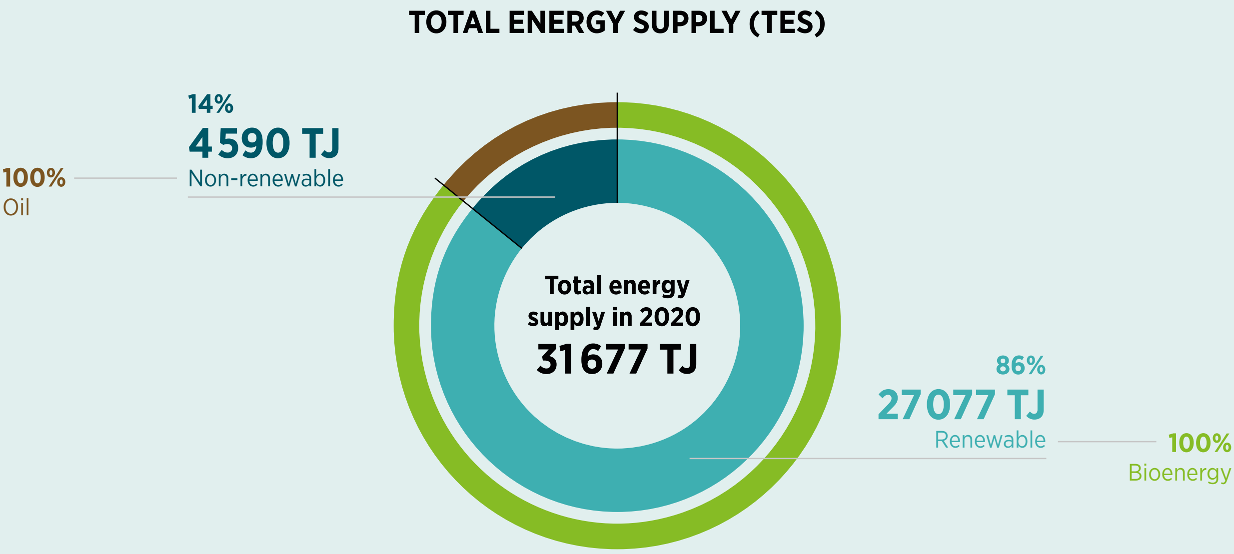
## 3.1 GUINEA-BISSAU: WEST AFRICAN MAINLAND WITH SMALLER ISLANDS

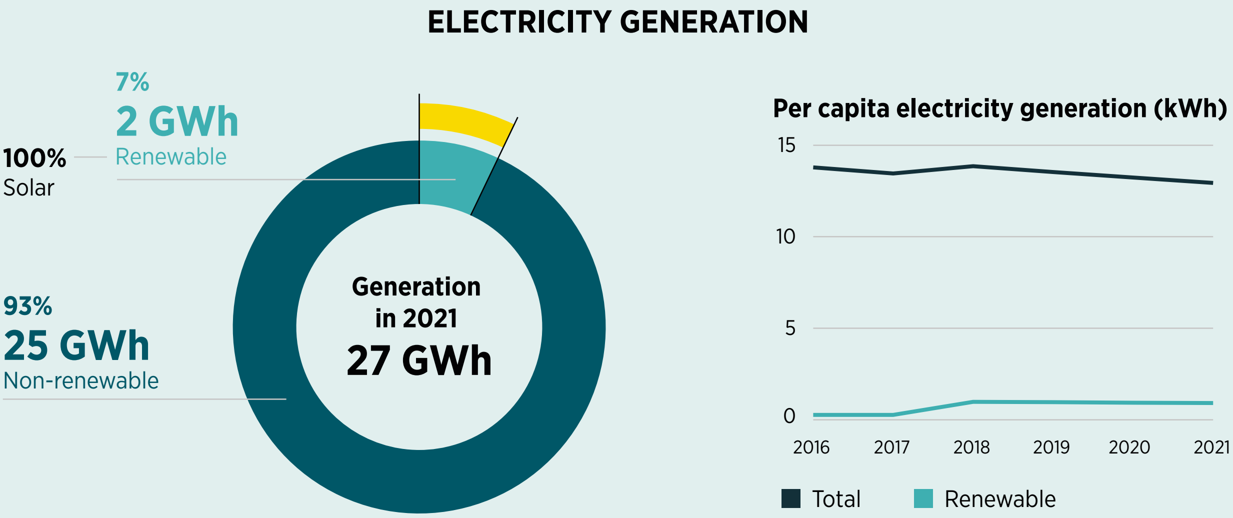
Nestled along the West African coast, Guinea-Bissau is a country with more than 20 languages and ethnic groups. The mainland accounts for the bulk of its territory, but it also features an archipelago comprising more than 100 islands, of which about half are inhabited by nearly 2% of the national population (Shryock, 2021).

Despite its natural beauty and fertile land, Guinea-Bissau faces socio-economic challenges; 64.4% of its approximately 2 million inhabitants live below the poverty line, making it one of the poorest countries globally. Guinea-Bissau's health system ranks second in the world in terms of fragility; food insecurity is high, with a chronic malnutrition rate of nearly 20%. Although most people live in rural areas, where fishing and agriculture represent the main livelihoods, under-nourishment prevails, with nearly 70% of the population unable to afford a healthy and nutritious diet (World Food Programme, 2023).

Guinea-Bissau's modest electrification rate of 35.7% (as of 2021) underscores the urgent need for sustainable and inclusive energy solutions (ESMAP, 2023). The country has remarkably low per capita greenhouse gas emissions, yet it ranks as the world's fourth-most vulnerable country to climate change. This paradox reflects the pressing need for innovative strategies to address the looming threat of climate change while harnessing Guinea-Bissau's untapped renewable energy potential. Traditional biomass, mainly wood and charcoal, dominates the overall energy mix of Guinea-Bissau; they account for 86% of the total energy usage (Figure 5). The country's power sector is dominated by non-renewable sources; off-grid solar PV represented about 7% of the overall electricity generation in 2021. Since 2019, Guinea-Bissau's on-grid electricity has been supplied entirely by Karpowership, a Turkish company providing off-shore thermal electricity generation using powerships (Karpowership, n.d.). In 2023, the power supply was briefly disrupted due to unmet payments (Reuters, 2023). The situation reflects the benefits that Guinea-Bissau would gain from producing its own electricity using renewable energy – reduced electricity costs, greater energy access for agri value chains and improved waste management.

**Figure 5** Guinea-Bissau's energy profile in 2020




**Source:** IRENA, 2023b.
**Note:** kWh = kilowatt hour; TJ = terajoule.

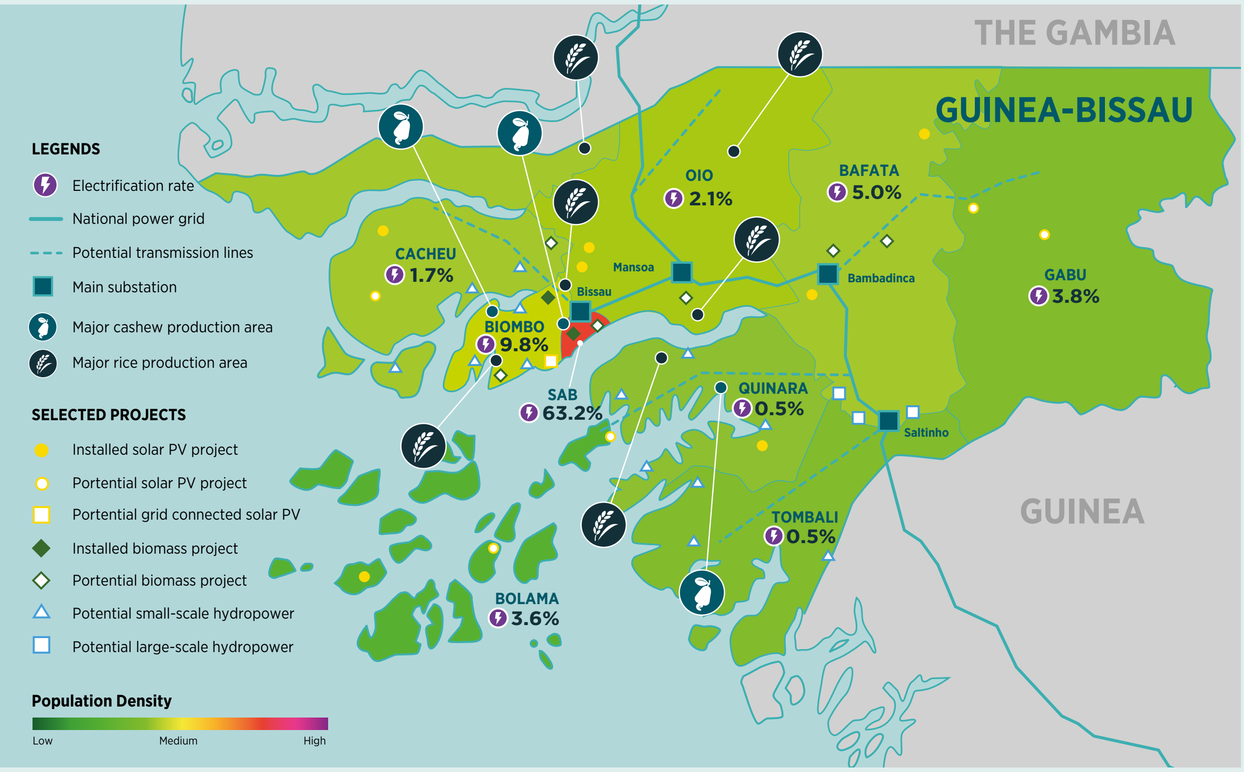
Recognising the imperative to harness its abundant natural resources, Guinea-Bissau's government has embarked on a bold mission outlined in its National Sustainable Energy Investment Plan. This ambitious initiative seeks to attract USD 700 million in investment by 2030 as a catalyst for the nation's renewable energy development (UNIDO, 2018). The concurrent National Renewable Energy Action Plan envisions a 50% penetration of renewable energy in the grid's peak demand by 2030 and electricity access for 80% of the population. This blueprint foresees connecting 9% of the population to renewable energy mini-grids and stand-alone systems, offering a beacon of hope for a more sustainable and inclusive energy future (ECREEE, 2018).

Significant socio-economic and ecological gains are possible if the above goals are reached. **Economic benefits** can be realised in the form of job creation, greater use of electricity in agriculture and micro-enterprises, improved incomes and spillover benefits for other industries. In a country where only 1% of the population has access to clean cooking, renewable energy alternatives can support environmental benefits through reduced deforestation and improved health outcomes especially for women and girls (ESMAP, 2023). Further, reliable and affordable electricity for schools and health centres can lead to transformative outcomes for **well-being at individual and societal levels**; they can enable women's participation in technical areas and decision making in renewable energy, foster environmental benefits due to reduced emissions and reduced deforestation, and add to climate resilience.

Barriers must be overcome. For example, an analysis conducted prior to the launch of the National Renewable Energy Action Plan concluded that, although Guinea-Bissau is among the least-electrified SIDS, it has received significantly less energy-focused aid than SIDS where electrification rates are much higher. For instance, total energy aid commitments over 2002-16 were over 58 times higher per capita for Nauru than Guinea-Bissau (at USD 4 577 per capita versus USD 78 per capita, respectively), even though Nauru has a status as a high-income country with a relatively high electrification rate (now at 100%) (Atteridge & Savvidou, Development aid for energy in Small Island Developing States, 2019). With Guinea-Bissau's electrification rate having changed only marginally since this analysis, it is evident that significant resources are still required to help the country to fulfil its aims.

The subsequent subsections will examine the untapped potential and progress (Figure 6) in Guinea-Bissau and explore the socio-economic opportunities and challenges that the country faces in deploying decentralised biomass gasification, off-grid solar PV and hydropower units. An understanding of these dynamics can help in appreciating the nuanced landscape in which Guinea-Bissau seeks to navigate towards a greener and more resilient energy future.

**Figure 6** Population density, regional electrification rate, national grid, selected renewable energy projects and major cashew and rice production areas in Guinea-Bissau




**Sources:** (Instituto Nacional de Estatística (INE), 2020); (INE; UNDP, 2019); (ALER, 2018); (Gambia River Basin Development Organisation, 2021); (UNIDO, 2017); (World Bank, 2018); (World Bank, 2020); (Yomichan, 2020).

**Note:** PV = photovoltaics.

**Disclaimer:** The map is provided for illustration purposes only. The boundaries shown do not imply any endorsement or acceptance by IRENA.

### 3.1.1 Biomass gasification

Biomass gasification using cashew shells, rice husk and wood chips holds immense potential to advance energy access in Guinea-Bissau. The country is one of the largest cashew producers in the world (Hanusch, 2016). Cashew shell gasification, with West Africa contributing to 85% of the global harvest (Diedhiou *et al.*, 2014), demonstrates potential net electricity production of 1.4 gigawatt hours (GWh)/year in a 500 kW) system. Cashew shell gasification has been successfully piloted in the country, with examples dating back to the early 2000s (see Box 2). Currently, over 80% of the population depends on the cashew production industry, whose workforce is mostly women. However, the frequent and severe price fluctuations for cashews in global commodity markets adversely affect the majority of the country's farmers. Incomes could be stabilised if cashew products are processed locally (France 24, 2023); this, however, requires reliable electricity. The country, which fully relies on the Turkish Karpowership for electricity, would benefit from generating electricity by gasifying cashew waste. Clean biomass gasification would allow cashew-processing units to be powered using their own waste. This would reduce the need for expensive transmission and distribution lines, which are also time consuming to install.

Besides cashew waste, other agricultural and forestry by-products could boost electricity production. A comprehensive 2017 study in the Bafatá region indicated the potential to generate 14.7 GWh a year using rice husk alone. Notably, rice husk gasification stands out for its simplicity, requiring no pre-processing and boasting a proven track record as a reliable gasifier fuel. Further, the utilisation of wood chips from sawmilling offers an efficient alternative to conventional combustion and steam cycle processing, especially for electricity generation. This approach stands out as a more environmentally friendly solution (Frederiks, 2017).

#### *Socio-economic and environmental benefits: Opportunities and barriers*

The socio-economic and environmental benefits of biomass gasification in Guinea-Bissau could be significant. Biomass is a relatively low-cost, reliable and clean energy solution that contributes to development outcomes. Biomass gasification is an attractive alternative since it is affordable and leverages the value of waste or by-products. Production costs for cashew shell, rice husk and wood chip gasification compare favourably to the costs for diesel, especially for larger systems. Further, the investment costs associated with biomass gasification are relatively low.

Besides economic advantages, biomass gasification addresses environmental concerns by mitigating carbon dioxide ($CO_2$) emissions and preventing methane emissions from uncontrolled decomposition of organic waste. While challenges such as tar emissions need attention, biomass gasification can be a sustainable alternative to diesel gensets and firewood burning (Frederiks, 2017).

Barriers to widespread adoption include technical challenges related to fuel quality, low loads and load variation. Gasifiers' limited flexibility in terms of biomass specification necessitates well-defined and planned projects. Lessons can be drawn from cases of biomass gasification projects in Guinea-Bissau where capacity gaps such as insufficient local servicing capacity led to prolonged shutdowns and limited access to technology resulted in prohibitive repair costs. Lessons can also be drawn from examples where limited project development skills hindered successful outcomes, highlighting the need for capacity building adapted to the local context. Addressing these challenges requires more robust training that prioritises equipping local system operators with troubleshooting skills to tackle technical issues and targeted capacity building for transferable skills that also have value outside of the energy system. Successful and sustainable implementation of biomass gasification hinges on overcoming these barriers; this highlights the importance of technical and management skill building for not only operational efficiency but also broader socio-economic benefits, and the development of transferable technical skills at the local level (Frederiks, 2017).

**Box 2** Biomass gasification for cashew production: The SICAJU gasifier

In 2007, the Bissau-based SICAJU cashew-processing plant initiated a biomass gasification system that harnessed waste cashew shells' energy potential to generate electricity and process steam for the plant. Despite challenges, for example, a temporary shutdown and a malfunctioning steam engine, the SICAJU cashew waste biomass gasifier stood as an exemplar of innovation and resilience for about two years. The overarching question of securing funds for repairs and reinstatement remains, underscoring the critical importance of sustained support for such impactful endeavours.

| **SICAJU CASHEW WASTE BIOMASS GASIFIER** | |
|---|---|
| **Location** | Bissau, Guinea-Bissau |
| **Technology** | A 70 kW cashew biomass boiler (1.5 tonnes/hour at 12.4 kilogramme force per square centimetre [$kgf/cm^2$]) and a steam engine |
| **Project partner** | World Bank |
| **Investment/financing** | World Bank credit scheme |
| **Commissioned** | 2007 |

**Economic impact.** The SICAJU biomass gasifier demonstrated a remarkable edge over conventional alternatives. It boasted significantly lower operating costs when compared with operations using electricity supplied by the national utility or a diesel generator. Notably, potential for further cost reduction emerged, by incorporating additional loads onto the existing cashew factory load. This exemplified the economic prowess inherent in this biomass system.

**Well-being and social impact.** Beyond its economic implications, the SICAJU system provided a cost-effective electricity source for the pivotal cashew-processing plant – an economic linchpin for the region. The social impact of the project, which operates at approximately 50% capacity when supplying exclusively to the factory, could be expanded exponentially by extending its reach to additional residential or commercial loads, fostering a more inclusive and interconnected society. While precise data on job creation and gender inclusion are not available, employment generation is an evident social outcome; further, in scaling and replicating the approach, the addition of gender-aware planning and training can also support positive outcomes for local women.

**Health and environmental impact.** The ripple effects of the SICAJU gasifier extended beyond the economic and social realms, presumably positively influencing the health of the local population and the environment by curbing emissions. That said, the case also provides a useful example of potential socio-environmental risks that must be mitigated; for instance, the local community complained about fumes, which could be avoided by adding a gas-cleaning system upstream. The system's ability to reduce waste from the cashew factory underscored its alignment with circular economy principles; this demonstrated how a biomass gasification plant can integrate renewable energy initiatives with waste reduction and economic advancement objectives. The model could be scaled up further to support residential and additional commercial loads beyond the cashew factory – improving its cost efficacy and expanding socio-economic impacts.

**Sources:** Kyle, 2009; Frederiks, 2017; Simonse & Artigas, 2018.

### 3.1.2 Micro/mini hydropower

No hydropower capacity has been installed in Guinea-Bissau to date (IRENA, 2023c), but it has estimated theoretical potential capacity of 652 MW (Hoes, 2014). An under-construction 21.2 MW hydropower facility on the Corubal River will be integrated into the Gambia River Basin Development Organization's production and transport system once it is completed. It will be integrated through a connection to the transmission network interconnecting Guinea-Bissau, Senegal, the Republic of Guinea and the Gambia. Environmental impact assessment for the planned project was completed in November 2023 (Coba Group, 2023; ALER, 2018).

For micro and mini hydropower, the Corubal and Geba rivers were the focus of a 2013 feasibility study under the Economic Community of West African States' Small Scale Hydroelectric Power Plant Programme and the project of the Global Environment Facility and the United Nations Industrial Development Agency for the promotion of small to medium investments in renewable energy technologies in the electricity sector. The study indicated potential of about 30 MW, enabling 270 GWh of hydroelectricity production annually (ALER, 2018). The government of Guinea-Bissau has identified sites of 2.5 MW each for multi-function use – for electricity generation and irrigation – in the eastern regions of Surrire and Manquerina, while in the protected regions of Cacheu, Gabú, Tombalí and Quínara, the government is partnering with the Global Environment Facility to advance micro and mini hydropower with a total installation of 2 MW (ALER, 2018).

Given the fragmented nature of the national grid, the low rural electrification rate and high hydropower potential, small-scale hydropower could be highly beneficial for expanding clean and reliable energy access in Guinea-Bissau. With 70% of Guinea-Bissau being forest area (FAO, n.d.), the country boasts significant forest carbon stocks and high mangrove coverage (the second highest in Africa), as well as threatened and endangered species, including the manatee and hippopotamus, among others. Small-scale hydropower can support the protection and sustainable use of ecologically critical ecosystems in Guinea-Bissau, while contributing to national emission reduction targets, potentially through nature-based carbon sequestration and storage, besides displacement of polluting energy sources.

#### *Socio-economic and environmental benefits: Opportunities and barriers*

Increased implementation of pico, micro and mini hydropower in Guinea-Bissau can bring important socio-economic benefits for rural communities, including economic benefits due to job creation and agricultural end uses, and spin-off benefits in tourism, services and other industries. Further, in a country that relies heavily on fuel wood, charcoal and diesel, a transition to hydropower and other forms of renewable energy can reduce emissions and deforestation, contributing to climate change mitigation and adaptation, biodiversity protection and benefits for forest-dependent communities. Given micro and mini hydropower rely on intact forested watersheds, this incentivises ecological conservation and restoration.

Micro and mini hydropower can also offer a clean alternative to charcoal and wood for cooking, which are used by 95% of households, predominantly in rural areas (Eva Rehfuess, 2006). As of 2021, only 1% of the population had access to clean cooking (ESMAP, 2018). Clean cooking and reduced use of kerosene lighting can bring important health benefits to the population; reliable and affordable energy access from small-scale hydro improves health services and facilities.

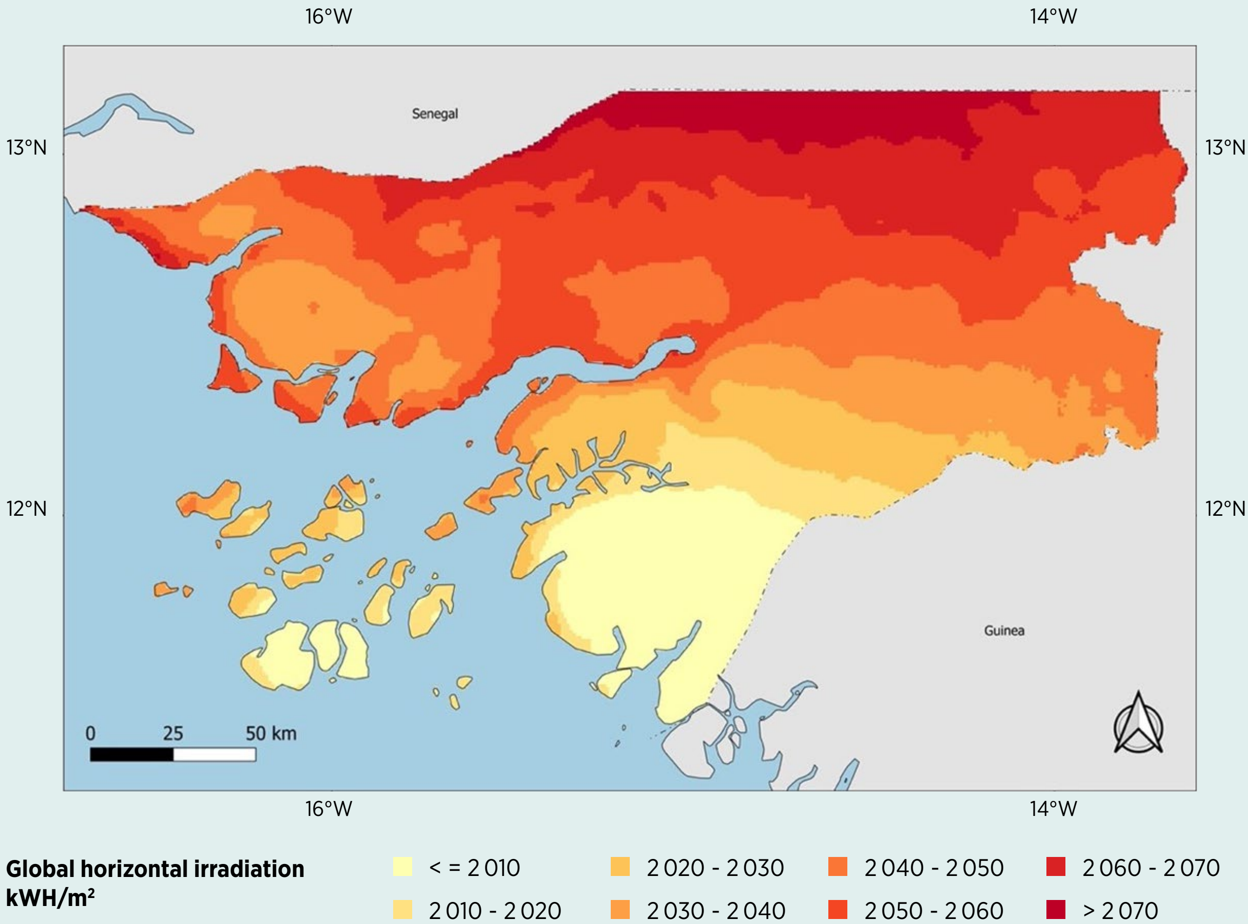
Further, the implementation of micro and mini hydropower can bring benefits for gender equity. Improved energy access benefits rural women and girls by reducing the burden of domestic labour, improving health outcomes via clean cooking, boosting income generation and educational opportunities, and increasing safety via improved lighting (ENERGIA, n.d.). Targeted policies and programmes and gender-informed project development can help advance gender equity at all stages of micro and mini hydropower, that is, planning, implementation, maintenance and policy making.

As in many SIDS contexts, topography may pose logistical and cost-related challenges to implementing small-scale hydropower in Guinea-Bissau, which has extensive areas of forested hills, ideal for pico and micro hydro sites. However, given that hydropower is a largely untapped resource, local technical capacity, related expertise and manufacturing capabilities are limited for the time being. This initial barrier can be overcome as new projects are implemented via collaborative initiatives, including south-south knowledge sharing, to allow learning from comparable country contexts.

### 3.1.3 Solar PV

Guinea-Bissau has good solar potential. It is characterised by annual global horizontal irradiation between 1 966 kWh/square metre (kWh/m$^2$) and 2 081 kWh/m$^2$, with an average of 2 042 kWh/m$^2$ (see Figure 7). The maximum solar PV development potential was estimated to be 1 400 MW considering a solar PV installation density of 50 MW/square kilometre (km$^2$) for solar PV, maximum concentration capacities of 5 000 MW and a 50% land utilisation factor (IRENA 2024); meanwhile, the actual installed capacity is 1.17 MW as of 2022 (IRENA, 2023b). Guinea-Bissau's untapped solar potential is not only sufficient for meeting domestic demand, it can potentially support export to other West African countries (Energy Capital & Power, 2021), if additional grid interconnections are built (with significant potential for job creation in construction and related fields).

**Figure 7** Average annual global horizontal irradiation in Guinea-Bissau




**Source:** Global Solar Atlas (ESMAP, 2019); base map: UN boundaries. Maps available also on the IRENA Global Atlas for Renewable Energy.

**Note:** km = kilometre; kWh/m$^2$ = kilowatt hours per square metre.

**Disclaimer:** The map is provided for illustration purposes only. The boundaries shown do not imply any endorsement or acceptance by IRENA.

### *Socio-economic and environmental benefits: Opportunities and barriers*

Guinea-Bissau's high solar PV potential, combined with a very low electrification rate and an enabling policy, has spurred interest from international investors and stakeholders. This has led to increasing uptake in recent years. With 85% of Guinea-Bissau's 9.9 million people living in rugged rural areas with limited health facilities (ADB, 2023), solar PV presents a much-needed opportunity to provide reliable electricity for health facilities in remote, off-grid communities.

A variety of small stand-alone and grid-connected solar systems have been implemented in Guinea-Bissau for solar home lighting, solar heating, irrigation via solar water pumping and other productive uses in the fisheries and agriculture sectors. Various international organisations and lending agencies have invested in solar PV mini-grids, for example, in Bissora (500 kilowatts peak [kWp]), Contubuel (100 kWp), Bubaque (650 kWp), Bolama (360 kWp), Gabu and Canchungo, and Bambadinca (312 kWp, featured in Box 3). The Farmers' Clubs Renewable Energy project in Oio focused on 24 communities in Bissorã; it boosted agricultural productivity and improved quality of life for 2 600 small-scale farmers and their families. The project installed 39 solar water pump systems and electrified 51 community institutions, including schools and health centres, with PV systems (ALER, 2017). Together, these projects have yielded substantial benefits.

The Bambadinca Sta Claro mini-grid project (see Box 3) and the Farmers' Clubs Renewable Energy project in Oio (see Box 4) exemplify the link between renewable energy deployment and socio-economic development, especially in **job creation and income generation**. The Bambadinca Sta Claro mini-grid project catalysed the creation of 23 local jobs and facilitated training for 11 technicians in managing the mini-grid; in turn, it enhanced local capacity and self-sufficiency. It powered 84 micro-enterprises, leading to a 14% reduction in household energy expenditures and stimulating economic activities. The Farmers' Clubs Renewable Energy project focused on advancing agriculture through renewable energy; it significantly boosted farmers' incomes, by 159%, and created 14 direct jobs in processing centres, alongside 509 indirect jobs through project-related activities.

The above projects have demonstrated significant benefits in terms of **well-being, social cohesion and community development**. The Bambadinca project has transformed daily life in the related community by providing reliable electricity access. It fostered a vibrant local economy by making it possible for schools and businesses to extend hours. This access has also strengthened social bonds and aided in cohesion by making it possible to have social gatherings and extend community activities into evening hours. The cost of energy-dependent goods, for example, ice, fell by over 50%, bringing indirect financial benefits to the community. Similarly, the Farmers' Clubs project has revolutionised agricultural practices through renewable energy, directly boosting food security and incomes; this has resulted in an improved overall standard of living for farmers and their families. Electrification of schools, health centres and community centres has not only improved educational and health services, it also aided in the creation of communal spaces for learning and social interaction, thereby knitting the community closer together.

The **health and environmental impacts** of the above projects underscore the significant benefits of integrating renewable energy solutions into community infrastructure. The Bambadinca project connected the local health centre to the mini-grid, significantly improving healthcare delivery and outcomes by ensuring reliable electricity for medical equipment and lighting. This leap in healthcare infrastructure, coupled with the project's emphasis on clean energy, reduced both emissions and reliance on polluting diesel generators. This has mitigated environmental degradation. Similarly, the Farmers' Clubs project has improved environmental sustainability by promoting solar and biofuel technologies in agriculture, which help conserve water, boost agricultural productivity and reduce the carbon footprint through the use of renewable energy sources.

## Box 3 Solar PV-diesel hybrid village electrification: The Bambadinca Sta Claro mini-grid, Guinea-Bissau

The Bambadinca hybrid solar photovoltaic (PV) mini-grid project is increasingly cited as a success story from West Africa. It illustrates the potential of distributed renewable energy to generate economic, social, health and environmental benefits. The Bambadinca Community Development Association and the Bafatá Regional Directorate of Energy manage the project jointly through a unique public community partnership model.

| BAMBADINCA STA CLARO SOLAR PV-DIESEL MINI-GRID | |
|---|---|
| **Location** | Bambadinca, Bafatá region, Guinea-Bissau |
| **Technology** | 312 Wp of solar PV capacity with 1 101 kilowatt hours (kWh) of battery storage capacity and diesel generators |
| **Project partners** | Directorate General of Energy, Faculty of Sciences of the University of Lisbon, TESE – Development Association, Bambadinca Community Development Association, Guinean Association for Studies and Dissemination of Appropriate Technologies, Architecture Atelier Pedro Novo and AP.art. |
| **Investment/financing** | A EUR 2.2 million grant |
| **Commissioned** | 2015 |
| **Status** | Operational |

Prior to the project, in 2011, 96% of Bambadinca's population relied on candles and batteries, and only 60 of 1 000 households could access electricity with a diesel generator, which operated for five hours every day. At that time, households spent nearly 24% of their monthly income on energy. The mini-grid project has increased the number of households and institutions with electricity access from 5% to over 85% and reduced household expenditure by 14% on average.

**Economic impact.** The project created 23 new local jobs and provided training for 11 technicians in managing, operating and maintaining the mini-grid, including through internships at the national utility. The mini-grid enables 84 micro-enterprises to access energy, facilitating new businesses, which range from a cybercafe to a carpentry business. The project has also resulted in a decrease in the price of energy-dependent goods (*e.g.* ice, whose cost reduced by over 50%), with indirect benefits in terms of household expenditure.

**Well-being and social impact.** As of 2022, the mini-grid had more than 650 customers, including families, businesses and community institutions. It provides continuous electricity access and has enabled schools to extend their hours, improving educational outcomes. Gender equity outcomes include an increased access to clean and affordable energy for women, gender-inclusive training and skill building opportunities, and new income-generating opportunities for women.

**Health impact.** The local health centre operated far better after it was connected to the mini-grid. This improved health services for the local community.

**Environmental impact.** The mini-grid provides a clean, efficient energy source to the community and has reduced emissions and reliance on polluting energy sources such as diesel generators.

The socio-economic, health and environmental impacts generated by the Bambadinca hybrid PV-diesel mini-grid project clarify the far-reaching potential of decentralised renewable energy deployment for boosting energy access as well as spurring sustainable development in the contexts of the small island developing states. With focus on local capacity-building opportunities, micro-enterprise end uses, gender-inclusive skill building and health sector end uses, the approach applied here can be replicated and scaled up elsewhere in Guinea-Bissau, and in other SIDS seeking to leapfrog clean energy access for sustainable development. The public community partnership model utilised in the project also warrants further investigation for potential replicability.

**Sources:** (World Access to Modern Energy, 2023); (Associação Lusófona de Energias Renováveis (ALER), 2022); (SAARC Energy Centre, 2021).

Like other decentralised renewable energy solutions, solar PV can reduce emissions and deforestation in Guinea-Bissau while generating important development outcomes from clean, affordable and reliable energy access. Alongside mini-grids for rural electrification, applications in agriculture and other productive end uses can generate much-needed improvements for food security, rural livelihoods and economic as well as ecological resilience for Guinea-Bissau's rural communities.

As with the implementation of other distributed renewable energy technologies in other SIDS contexts, unfavourable geography and dispersed populations present logistical challenges and potential cost barriers to solar PV implementation (as well as challenges to securing components for repairs, such as replacement batteries). Project implementation costs are much higher in Guinea-Bissau due to the cost of transport, and development partners are required to budget accordingly.

### **Box 4** Renewable energy for advancing agriculture: The Farmers' Clubs Renewable Energy project in Oio, Guinea-Bissau

The Farmers' Clubs Renewable Energy project, implemented by Ajuda de Desenvolvimento de Povo para Povo in Oio, Guinea-Bissau, marked a significant shift towards integrating renewable energy (solar and biofuel) into agricultural practices. This initiative targeted 24 communities in Bissorã, directly benefiting 2 600 small-scale farmers and their families.

| **FARMERS' CLUBS RENEWABLE ENERGY IN OIO** | |
|---|---|
| **Location** | Bissorã, Oio region, Guinea-Bissau |
| **Technology** | Solar water pump systems, photovoltaic systems for electrification, biofuel-powered generators |
| **Project partners** | Ajuda de Desenvolvimento de Povo para Povo, Guinea-Bissau |
| **Commissioned** | 2014 |
| **Status** | Operational |

**Agricultural and community impact.** Of 39 solar water pump systems installed, 15 are used for irrigation purposes, another 15 for drinking water and 9 were designed for both uses. Solar photovoltaic systems helped electrify 51 local institutions such as schools, health centres, mosques and community centres that were equipped with LED TVs, satellite antennas and DVD players for educational and cultural purposes. Seven processing centres were constructed; these had biofuel-powered generators and various agricultural machines. Micro-credit funding plans were established to support the project's long-term viability and impact.

**Economic impact.** The project significantly enhanced the economic landscape. A doubling of agricultural production and the introduction of new income-generating activities led to farmers' incomes rising 159%. The project created 14 direct jobs in processing centres and facilitated 509 indirect jobs via project staff and service provider roles. The initiative organised eight training sessions on renewable energies to further spur income generation, highlighting its comprehensive approach to sustainable economic development.

**Social and environmental impact.** The project significantly improved community living standards and environmental sustainability. It increased access to water and boosted agricultural productivity by processing more than 136 000 kilogrammes of agricultural products. It also contributed to awareness and change by educating 12 686 people on key environmental issues and renewable energy. The project generated more than 18 657 kWh of solar energy annually for community facilities, demonstrating the practical benefits of renewable energy.

The Farmers' Clubs Renewable Energy project demonstrates the profound socio-economic and environmental benefits of integrating renewable energy into agricultural systems, significantly improving the livelihoods and well-being of Guinea-Bissau's communities.

**Source:** ALER, 2022; SAARC, 2022; WAME,2023.

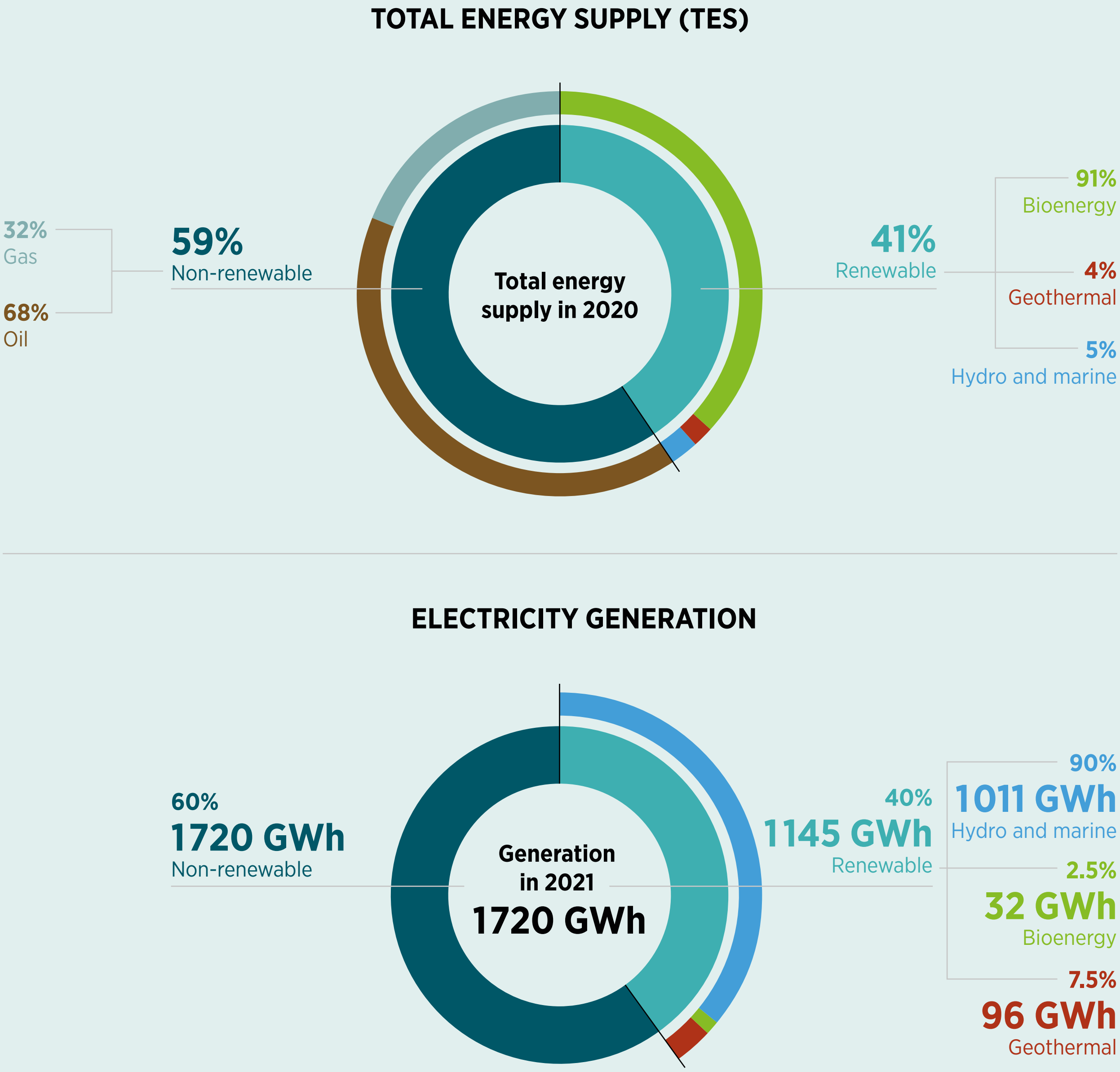

## 3.2 PAPUA NEW GUINEA: LARGE ISLAND WITH SMALLER ISLANDS IN THE PACIFIC

Papua New Guinea is the world's third-largest island country. It consists of the eastern half of the island of New Guinea plus smaller off-shore islands in the southwestern Pacific Ocean. Papua New Guinea's population was 9.95 million in 2021. It had a substantial rural population, which constituted 87% of the total population (World Bank, 2021). The United Nations Development Programme estimates that 56.6% of the population of Papua New Guinea, which is categorised as a lower-middle-income country, is multi-dimensionally poor[1] (United Nations, 2023).

The vast majority of Papua New Guinea's population lacks access to reliable and affordable electricity (Tracking SDG7, 2021). The national and rural electrification rates are, respectively, 21% and 14%, among the lowest of any country in the Pacific. Yet, Papua New Guinea boasts abundant renewable resources. While the country is a key fossil fuel producer in the Pacific region, renewable energy represented approximately 40% of the total electricity generation in 2021. Almost all of the renewable electricity generation came from hydropower, with smaller contributions from geothermal and bioenergy. Renewables and oil each account for 41% of the total energy supply of Papua New Guinea, with the remainder contributed by natural gas. Over 91% of the renewable energy supply is from bioenergy (primarily traditional biomass), with hydropower and geothermal combining to supply less than 10% (Figure 8) (IRENA, 2023c).

[1] *Multi-dimensional poverty includes a range of hardships faced by individuals in their daily life, including, but not limited to, challenges such as compromised health, limited access to education, substandard living conditions, disempowerment, low-quality employment, the risk of violence and residing in environmentally unsafe areas, among others.*

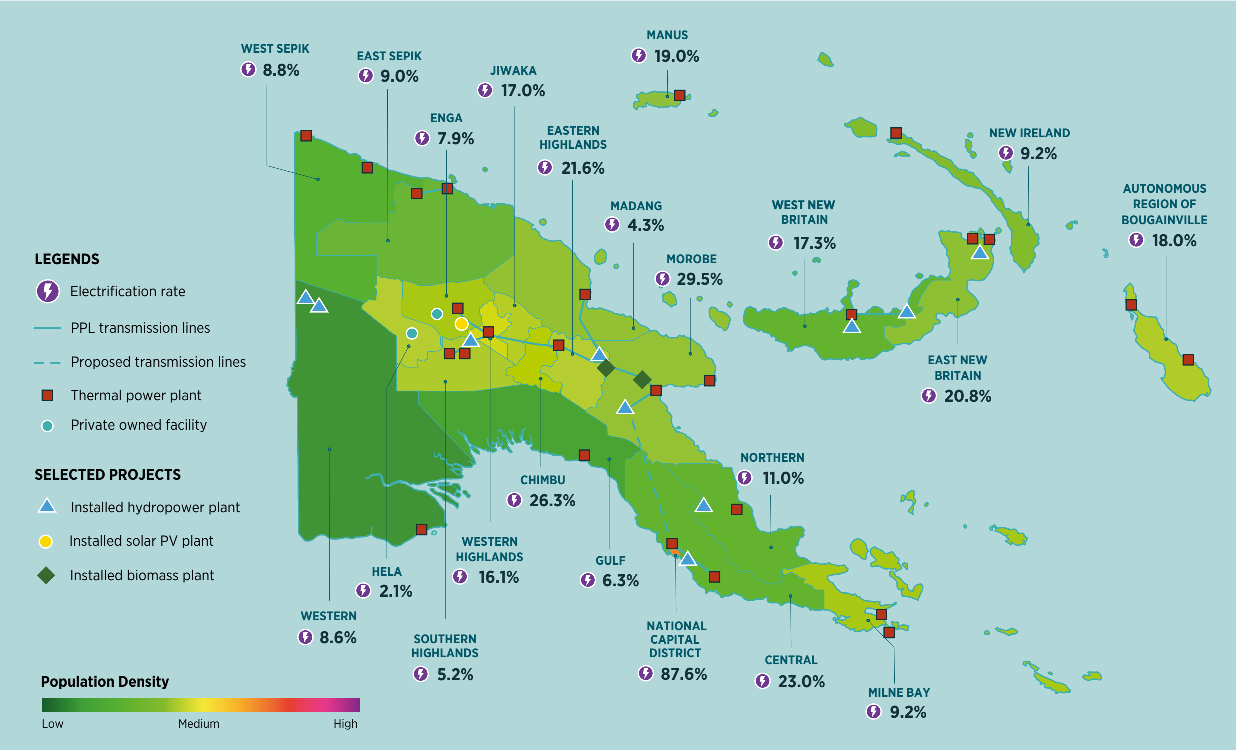
**Figure 8** Papua New Guinea's energy profile, 2020




**Source:** IRENA, 2023c.
**Note:** GWh = gigawatt hour.

Three principal grids service the urban centres of the National Capital District, the Highlands and the Gazelle Peninsula (Figure 9). Papua New Guinea's low electrification rate can be partly attributed to its topography. The main island is characterised by steep, soaring mountains reaching elevations exceeding 4 000 metres; this poses significant challenges and inflates the cost of constructing new infrastructure (Standish & Jackson, 2024). Further, aging infrastructure and frequent power outages adversely impact the grid's reliability, hindering large businesses and small and medium enterprises from thriving (Murdock, 2022). Papua New Guinea (PNG) Power Limited, the utility provider in Papua New Guinea, operates 17 micro-grids across the country; these micro-grids primarily operate on diesel, which is costly, prone to price volatility and environmentally damaging. This reliance contributes to pollution, poses health risks and generates significant economic costs (Shetty, 2022).

**Figure 9** Population density, regional electrification rate, national grid and selected renewable energy projects in Papua New Guinea




**Source:** (DHS, 2018), (National Statistical Office of Papua New Guinea, 2021), (Nepal & Sofe, 2023), Interview with local informants.

**Note:** PPL = PNG Power Limited; PV = photovoltaics.

**Disclaimer:** The map is provided for illustration purposes only. The boundaries shown do not imply any endorsement or acceptance by IRENA.

The Government of Papua New Guinea has set an ambitious target of achieving 70% renewable energy generation by 2030. Increased foreign investment or aid is crucial to reach this target. Despite its high renewable energy potential and current low energy access rate, Papua New Guinea has historically received less energy-focused aid than other SIDS where electrification rates are higher. Moreover, the existing aid has predominantly been allocated to grid-based renewable energy projects, with less emphasis on rural electrification (Atteridge, 2019).

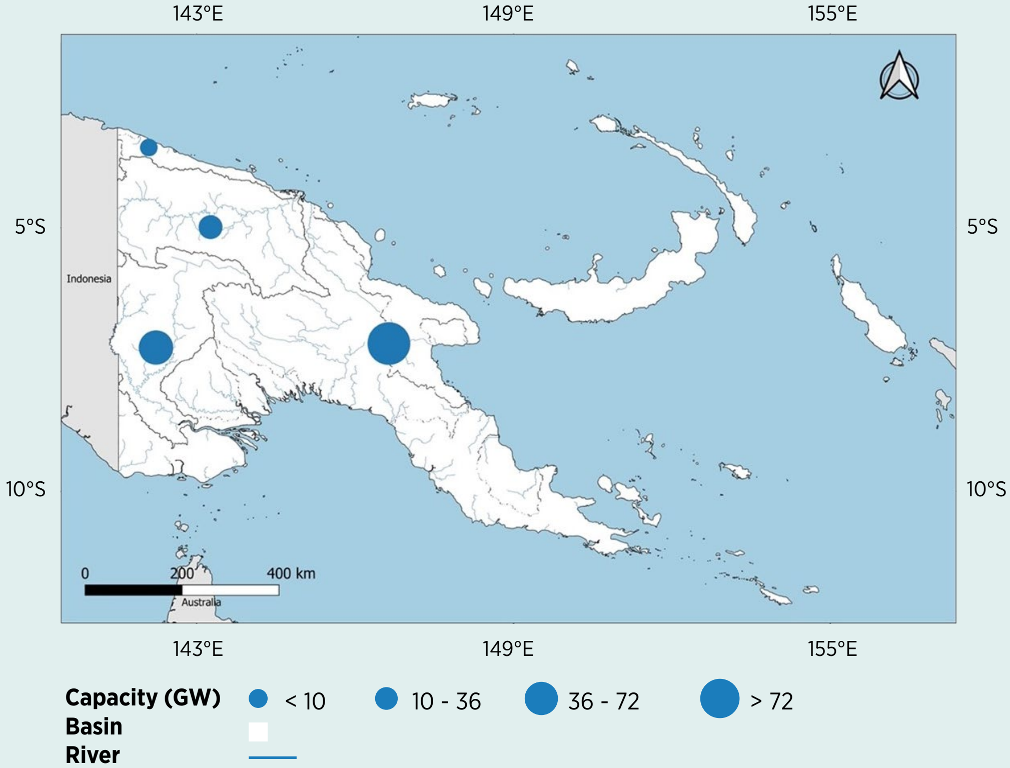
In addition to abundant renewable energy resources, Papua New Guinea is home to the world's third-largest rainforest, is one of the world's 17 megadiverse countries and accounts for about 5% of global biodiversity (Wignaraja & Wagener, 2022). While tourists are drawn by its diverse culture and breathtaking natural landscapes and unique wildlife, reliable electricity access could help boost tourism's contribution to the national economy.

Expanding electricity to Papua New Guinea's rural areas requires major investments in power generation, network upgrades and the deployment of small-scale, off-grid renewable energy solutions (Rawali *et al.*, 2019; USAID, 2022). Renewable energy technologies, including small-scale hydropower, solar PV and bioenergy, serve as practical solutions for electrification. These technologies are poised to make a significant socio-economic impact given several unelectrified areas have large populations and boast potential hydropower sites, and solar power is universally available, alongside a strong agricultural base conducive to clean and efficient bioenergy production. These technologies can benefit Papua New Guinea through job creation, income growth, improved well-being and inclusion, and environmental sustainability.

### 3.2.1 Small-scale hydropower

As of the end of 2022, Papua New Guinea had 261 MW of installed hydropower capacity (IRENA, 2023c), with significant untapped potential (see Figure 10), which could theoretically support up to 251 GW of capacity (Hoes, 2014). Large hydropower plants are operating in each of the three main national grids of Papua New Guinea, in Port Moresby, Ramu and Gazelle Peninsula (Oxford Business Group, 2017). The country's mountainous terrain makes it geographically suited for additional hydropower development, including micro and mini hydro facilities (Samanta *et al.*, 2017).

**Figure 10** Papua New Guinea's hydropower potential




**Source:** Hydropower potential – Hoes, 2014; hydrological basins of the world – AQUASTAT [FAO], 2022a; major rivers of the world – AQUASTAT [FAO], 2022b; base map – UN boundaries.

**Note:** GW= gigawatt; km = kilometre.

**Disclaimer:** The map is provided for illustration purposes only. The boundaries shown do not imply any endorsement or acceptance by IRENA.

*Socio-economic and environmental benefits: Opportunities and barriers*

Micro and mini hydropower can generate a wide range of socio-economic and environmental benefits in Papua New Guinea. Hydropower projects could contribute substantially to **local employment** and skill development. Specifically, each of the mini hydropower projects at Trans Niugini Tours' Ambua and Rondon Ridge lodges (120 kW each, see Box 5) not only required a diverse workforce of approximately 30 for construction and installation, they also continue to provide employment opportunities through ongoing operational roles. Similarly, the Hogave Conservation Centre's micro hydropower project (20 kW turbine, see Box 6) engaged a 20-person team from the local community, indicating a commitment to inclusive employment and skill building. The Kudjip Nazarene Hospital's mini hydro plant (200 kW, see Box 7) also required a significant workforce for its development, further illustrating the role of such projects in stimulating local job markets. These instances underscore the dual benefit of renewable energy projects, which not only foster immediate employment opportunities but also enhance the local skill base, thereby contributing to long-term economic stability and growth in the region.

## Box 5 Ecotourism powered by mini hydropower: Trans Niugini Tours, Papua New Guinea

With a mission to promote nature-based tourism for domestic and international travellers, Trans Niugini Tours, an ecotourism company operating since 1975 in the ecologically rich, biodiverse highlands of Papua New Guinea, owns several lodges, which are powered by renewable energy and diesel mini-grids. Two of its resorts are powered by mini hydropower systems.

| AMBUA LODGE MINI HYDRO PLANT | | RONDON RIDGE LODGE MINI HYDRO PLANT | |
|---|---|---|---|
| **Location** | Hela Province | **Location** | Western Highlands Province |
| **Technology** | 120 kW, Turgo impulse wheel turbine | **Technology** | 120 kW, Turgo impulse wheel turbine |
| **Project partners** | Tamar Designs, Tasmania | **Project partners** | Tamar Designs, Tasmania |
| **Investment/model** | PGK 200 000, self-financed eco-enterprise | **Investment/model** | PGK 300 000, self-financed eco-enterprise |
| **Commissioned** | 1985, with the start of the lodge | **Commissioned** | 2005, with the start of the lodge |
| **Status** | Operating for over 250 000 hours | **Status** | Operating for over 150 000 hours |

Trans Niugini Tours has leveraged small-scale hydropower for decades, generating significant economic, social, health and environmental outcomes for sub-regions, which have otherwise remained marginalised and under-developed.

**Economic impact.** The development of the mini hydro systems at the Ambua and Rondon Ridge ecotourism resorts has significantly impacted local **employment** and skill development. The construction of each mini hydro project demanded a workforce of approximately 30 workers over 12 months; it encompassed a wide range of roles, from managers and engineers to technicians, masons and logistics personnel. Beyond construction, each mini hydro system sustains ongoing employment for a local technician, who is responsible for operation and maintenance; this demonstrates a commitment to long-term job creation. Similarly, these resorts have generated between 12 000 to 15 000 person-days of employment annually for the past five years, offering a range of positions, from receptionists to gardeners and security staff. With 20% female employment and local hires representing 95% of the overall staff, these initiatives have not only reduced reliance on physically demanding labourer roles, but also introduced valuable pre-job and on-the-job training.

The introduction of mini hydro systems and ecotourism lodges has notably supported **income generation**. Workers involved in the hydro projects have transitioned into hospitality roles at the lodges; their household incomes have in turn risen to at least the minimum wage in Papua New Guinea. The surrounding communities have benefited economically by selling food and handicrafts to tourists at daily markets near the lodges. Local vendors earn an estimated PGK 20 000 annually. All of this demonstrates the positive ripple effects of sustainable tourism and energy projects on local economies and individual livelihoods.

By utilising mini hydropower to replace diesel, each lodge secured approximately PGK 600 000 annually in **energy cost savings**; further savings resulted due to energy-efficient lighting and appliances. This strategy, which helped power the Ambua Lodge independently for nearly four decades, has allowed the eco-enterprise to expand to seven ecotourism lodges nationwide. Such sustainable energy practices have effectively reduced economic vulnerability, highlighting the benefits of eco-friendly operations in increasing businesses' longevity and success in the ecotourism industry.

**Well-being and social impact.** The mini hydro systems have proven pivotal in helping the Trans Niugini Tours' lodges remain financially viable in the long term; this has in turn improved **local livelihoods and quality of life**. This sustainability has helped in the expansion of local eco-tours, directly benefiting adjacent communities. By transitioning from wood to electricity for essential needs, the lodges have significantly reduced labour intensity and improved employees' well-being, marking a clear stride towards better living standards and work conditions in the region.

The integration of mini-hydro-powered lodges has been instrumental in increasing collective **knowledge and know-how** in remote communities. These establishments draw a diverse visitor base, enabling a wide exposure to external information and cultures for the locals. The resultant growth in ecotourism, supported by targeted training provided by Trans Niugini Tours, has enriched the local skill base, adding to community resilience and adaptability amid evolving tourist demands.

The advent of eco-tourism initiatives, made evident by the establishment of lodges, has indirectly bolstered **gender and social equity** in the area. Improved safety measures, introduced to accommodate tourists, have concurrently improved security for women and ethnic minorities. This has helped in the creation of an environment of inclusivity. Employment practices within these lodges that favour diversity further cement social inclusion, while community-engaging tourism events promote cultural sharing and unity, under-pinning the broader social benefits of eco-tourism development.

**Health impact.** The establishment of lodges in remote areas has spurred significant improvements in access to health facilities, air quality and nutrition. Improved health facilities have been developed to deliver professional healthcare for lodge visitors; this offers local communities access to advanced healthcare services previously beyond reach, albeit at a high cost. The transition from wood to clean electricity for cooking and heating has improved air quality; the lodges meeting their operational needs with clean electricity has helped reduce respiratory ailments among the local population. Further, lodge visitors' specific food-related requirements have provided an incentive to improve and expand local food production; this has led to better nutrition by diversifying and elevating the quality of food available.

**Environmental impact.** The lodges' use of clean and efficient energy sources for comprehensive electricity needs, including for lighting, fans, water pumps, refrigeration, and heating and cooling systems, significantly reduces emissions and curtails reliance on polluting diesel generators. Eco-tourism activities such as bird watching and environmental research help raise environmental awareness among visitors and employees alike, reinforcing the importance of preserving natural habitats. Meticulous waste management practices highlight the lodges' commitment to minimising their environmental footprint. These measures reflect a holistic approach to ecotourism that prioritises environmental stewardship while promoting sustainability in the energy sector.

**Source:** Interview with Trans Niugini Tours, 2023.

## Box 6 Forest centre powered by micro hydropower: Hogave Conservation Centre, Papua New Guinea

The Hogave micro hydro single wire earth return system was commissioned in 2013 by the project partner, the Hans Wilsdorf Foundation, together with the Eastern Highlands Provincial Government and other stakeholders. The project was part of a spin-off benefit for the Hogave Community's effort to conserve their natural environment.

| HOGAVE CENTRE MICRO HYDRO PROJECT | |
|---|---|
| **Location** | Lufa District, Eastern Highlands Province |
| **Technology** | A 20 kW, Pelton wheel turbine |
| **Project partners** | Hans Wilsdorf Foundation |
| **Investment/financing** | PGK 1 500 000 |
| **Commissioned** | 2013 |
| **Status** | Shut down in 2017 due to damage from mudslide; resources being sought for rehabilitation |

Previously, the village community relied solely on firewood, candles or small generators for their daily activities. A few had generators that operated once or twice a week. To begin with, six buildings (a workshop, a small tuckerbox, an elementary school, a church and a guest house) were chosen to access electricity from the hydro plant, which operated 24 hours/day, because they were built per modern standards (*i.e.* timber and roofing iron).

**Economic impact.** The project created jobs by engaging a 20-person team, evenly selected from local tribes, for full-time roles under the project manager's supervision. These individuals were allocated to various construction tasks and received targeted training. This enhanced community's skill sets. Skilled labour was specifically employed for critical tasks such as the fabrication of the powerhouse and weir gate, and welding of transmission pipes. Volunteer Ergon Energy engineers from Australia provided essential support during the initial construction phases. In an inclusive effort, women and children contributed by transporting materials to the site, which was accessible by foot only. Post commissioning, two individuals were appointed to oversee system maintenance; this ensured ongoing employment. Wages for local construction workers helped raise **income generation**.

The implementation of hydro power in the community led to significant **energy cost savings**; the guest house saved PGK 3 000 annually on diesel costs and the broader community saved an additional PGK 1 000. Behind these savings was the utilisation of about 15-20 kW from the hydropower grid. However, economic vulnerability posed challenges for the project's sustainability, as heavy rainfall and flooding damaged critical infrastructure such the weir and penstock pipes. This damage hampered the operation of small and medium enterprises.

**Well-being and social outcomes.** The mini-grid improved **quality of life** and livelihoods within the community; it especially benefited operations at the guest house by helping to deliver constant electricity. The mini-grid helped increase educational and religious participation by allowing the elementary school and church to extend their hours. Notable improvements also occurred for **gender equity**; women gained greater access to clean energy, inclusive training programmes were delivered, and new income generation opportunitie were created. The Conservation Centre, associated with the guest house, attracts both domestic and international researchers; this enriches the local community's knowledge and increases exposure to global perspectives. Further, the implementation of improved safety and security measures, driven by the Conservation Centre and other local institutions, has indirectly bolstered the safety of women and minority ethnic groups, in turn advancing gender and social equity. Employment opportunities at the guest house for women and local minorities, along with the organisation of tourism events featuring cultural activities such as traditional dance performances, have significantly strengthened social inclusion and cultural exchange in the area.

**Health impact.** The project sought to improve healthcare access and conditions through the establishment of a local health centre near the community, with plans to connect it to the mini-grid. However, these plans were stalled by natural disasters and funding shortfalls. The introduction of micro hydropower has facilitated a shift from wood burning to electric cooking, significantly improving air quality by reducing pollution. This transition also eliminated diesel use, further reducing air pollution and respiratory issues; this especially benefitted areas surrounding the conservation centre, where the mini-grid operates. The micro hydropower system's development inspired plans for a roadside container storage facility to sell frozen meat to remote villagers; however, these plans, too, were hindered by natural disasters and financial limitations.

**Environmental impact.** The mini-grid system significantly contributed to environmental improvement by providing the community and the conservation centre with a clean and efficient energy source; it effectively lowered emissions and minimised reliance on diesel generators. The system operating within a conservation area helped the project ensure that forests and vegetation were preserved in their pristine state. This further underlined the project's commitment to environmental protection. Finally, the guest house's transition to gas-based cooking and solar heating played a crucial role in reducing deforestation.

**Sources:** Interview with Hogave Conservation Centre, 2023.

Local companies and the workforce are actively involved in constructing, installing, and operating and maintaining Papua New Guinea's hydropower value chain. PNG Forest Products and PNG Power exemplify this by developing small and medium hydro projects in Morobe and Oro Provinces, respectively. There is significant potential to further integrate the manufacturing segment of the hydropower value chain domestically, with the support of a vibrant entrepreneurial scene and manufacturing centres. This strategy, driven by a need to overcome importation challenges and leverage national strengths, promotes self-sufficiency and growth in the renewables sector.

Besides job creation, the projects significantly contribute to local **income generation** and economic development. The Trans Niugini Tours' mini hydropower projects not only created jobs but also boosted household incomes and local businesses. The Hogave Conservation Centre project provided wages during construction and stimulated nearby businesses, enhancing the community's economic base. Similarly, the Kudjip Nazarene Hospital's mini hydro plant boosted income from employment and increased local market activity.

Hydropower can help generate significant **energy cost savings and reduce economic vulnerability**. Replacing diesel with renewable sources enabled the mini hydropower systems at Trans Niugini Tours' lodges to generate annual savings of approximately PGK 600 000 per lodge. This added to the financial viability and resilience of the ecotourism enterprise. The Hogave Conservation Centre's micro hydro project, despite its challenges, showed potential for energy cost reduction for the community, before it was halted due to a natural disaster. The experience underscores the delicate balance between harnessing natural resources and the susceptibility to environmental risks.

Improvement in **quality of life** for the local communities could also be attributed to the hydropower projects. The mini hydropower systems at Trans Niugini Tours' lodges have not only facilitated a sustainable energy supply, they also helped reduce physical drudgery. Similarly, the Hogave Conservation Centre's micro hydro project had contributed significantly to improving living standards before it was damaged by a severe mudslide. It improved living standards by providing round-the-clock electricity, positively impacting educational and religious activities in the community. The Kudjip Nazarene Hospital's mini hydro plant improved the overall community well-being with its reliable electricity, which supported medical services and helped ensure a safer, more comfortable environment for both staff and patients.

Small hydropower projects were also vital in promoting **gender equity and inclusion**. For instance, the ecotourism venture by Trans Niugini Tours employed women in a small but not insignificant proportion (20%) in the development of its mini hydropower projects; this contributed to female empowerment in a traditionally heavily male-dominated field. In the Hogave Conservation Centre's project, women were actively involved in the construction phase; this gave them unique opportunities to contribute to community development. Similarly, the mini-hydro-powered Kudjip Nazarene Hospital employs an equal number of male and female staff, thus ensuring gender balance in its workforce and promoting women's participation in healthcare services.

**Health improvements** are a notable benefit of the renewable energy projects studied. The Kudjip Nazarene Hospital's mini hydropower system has enabled the provision of high-standard medical services with its reliable power supply; this increased healthcare accessibility and quality in the Jiwaka Province significantly. Similarly, the implementation of clean energy solutions in the Trans Niugini Tours lodges and at the Hogave Conservation Centre has improved air quality, reducing respiratory issues linked to conventional wood and diesel burning.

Regarding **environmental impacts**, the above renewable energy projects have made significant strides in ecological preservation. The Trans Niugini Tours and Kudjip Nazarene Hospital mini hydropower initiatives have helped reduced deforestation and emissions by eliminating the reliance on diesel generators and wood burning. The Hogave Conservation Centre's project, although short lived, demonstrated a commitment to mitigating environmental impacts through the use of clean energy. These examples collectively underscore the positive influence of renewable energy on Papua New Guinea's natural environment.

Some key barriers musts be overcome to improve the socio-economic benefits brought by micro and mini hydropower in Papua New Guinea. The rugged and remote geography, while suitable for decentralised energy solutions, poses significant logistical and cost challenges for widespread implementation. Financial limitations, stemming from insufficient government and private investment, as well as foreign exchange issues, further constrain the development of these renewable energy projects. Land ownership presents a complex challenge, with 97% of land held under customary claims by local tribes and clans. This leads to intricate and often unresolved negotiations for land use, which impedes infrastructure development. The lack of local expertise and familiarity in managing community-based micro hydro systems restricts their development and sustainability. These barriers must be overcome if hydropower's socio-economic benefits are to be realised in the region.

**Box 7** Rural hospital powered by mini hydro: Nazarene Hospital, Papua New Guinea

The Kudjip Nazarene Hospital is located in Jiwaka Province of Papua New Guinea. It was established in 1967. Soon after, an 80 kW mini hydropower plant was installed to meet the hospital's energy needs. The hydro system was operated and rebuilt several times, until in 2007, the micro hydro plant was decommissioned and replaced by a new 220 kW mini hydro plant with a grant from Australia; the new mini hydro plant powered the hospital as well as staff housing.

| NAZARENE HOSPITAL MINI HYDRO SYSTEM (2ND SYSTEM) | |
|---|---|
| **Location** | Kudjip, Jiwaka Province, Papua New Guinea |
| **Technology** | A 220 kW, cross-flow stable-speed turbine |
| **Project partners** | Kudjip Nazarene Hospital, Church of the Nazarene and Australia PNG Partnership |
| **Investment financing** | PGK 10.2 million |
| **Commissioned** | 2013 |

**Economic impact.** The project employed approximately 400 workers over 28 months to construct and install its civil works, penstock, turbine assembly, and distribution and transmission lines. The roles included non-technical and technical jobs, including skilled positions such as managers, engineers, machinists, technicians, masons and logistics persons, and unskilled labour receiving on-the-job training. Almost all, some 98%, of the individuals employed were from Jiwaka Province. The mini hydro systems currently employ five part-time local technicians for operation and maintenance. The hospital itself generates employment for a broad range of professions and skill levels, including doctors; nurses and ancillary, maintenance and security staff. Without the hospital, many of the local employees would likely be working as subsistence farmers or labourers, which involves greater physical drudgery.

Besides creating more jobs, the project also impacted income generation. The skills acquired by the workers involved in the mini hydro implementation could be transferred to the industrial and construction sector; this meant greater employment opportunities for the project workers after the project had been implemented. The hospital's expansion also improves income for the surrounding communities, which sell food and other products to the hospital staff and patients every day. Markets have been established near the hospital; they are open from 7 a.m. to 6 p.m., seven days every week. The mini hydropower project has helped the hospital to significantly reduce expenses associated with the previous electricity supplier.

**Well-being and social impact.** The mini hydropower system has helped the hospital become financially viable over the long term. This in turn has allowed the management to improve the services at the hospital and expand its infrastructure. The expansion also means that more external medical professionals visit the hospital, allowing local staff to gain more exposure and training.

Reliable and improved lighting provides a sense of security for hospital staff and nearby communities in the evening hours. The mini hydropower system also improves the standard of living of the hospital staff by fostering a clean and safe environment for them to work and live in. Besides the direct employment created by the hospital's expansion, employment is created for the community because people from other provinces come to the hospital for treatment. It gives the community an opportunity to meet and interact with them. The hospital also has a nursing college, which trains individuals to become nurses.

The mini hydropower plant also promotes gender equity and inclusion by providing a safe environment for women to live and work in. Care work and hospital jobs are also more likely to create employment for women. Women's health access improved significantly, with better maternity services. More generally, electricity access along with appropriate equipment tends to reduce the housework burden for women in parts of Papua New Guinea.

**Health impact.** The Kudjip Hospital impacted health outcomes by improving access to health facilities, nutrition outcomes and air quality. The local community and Jiwaka province have the advantage of having access to readily available and relatively higher-standard health services, since the Kudjip Hospital is well known for providing some of the highest-quality health services in Papua New Guinea. The hospital also raises awareness about nutrition and balanced diets to overcome malnutrition; this awareness is raised during treatment and also via mobile clinics. Air quality has improved since clean electricity has replaced wood for cooking and heating, or electricity generation produces less exhaust since fossil-fuel-based generators, for example, diesel generators, are used much less.

**Environmental impact.** The hospital's reliance on the mini-grid for all electricity needs, including for lighting, fans, water pumps, refrigeration, heating and cooling, and the resultant reduced reliance on polluting sources such as diesel generators, contributes to emissions mitigation goals. It has also contributed to reduced deforestation as the hospital and its staff now use non-timber-based solutions for cooking, heating and lighting. The hospital also has a reforestation initiative on its properties to reduce soil erosion and increase rainwater absorption.

**Source:** Interview with Nazarene Hospital, 2023.

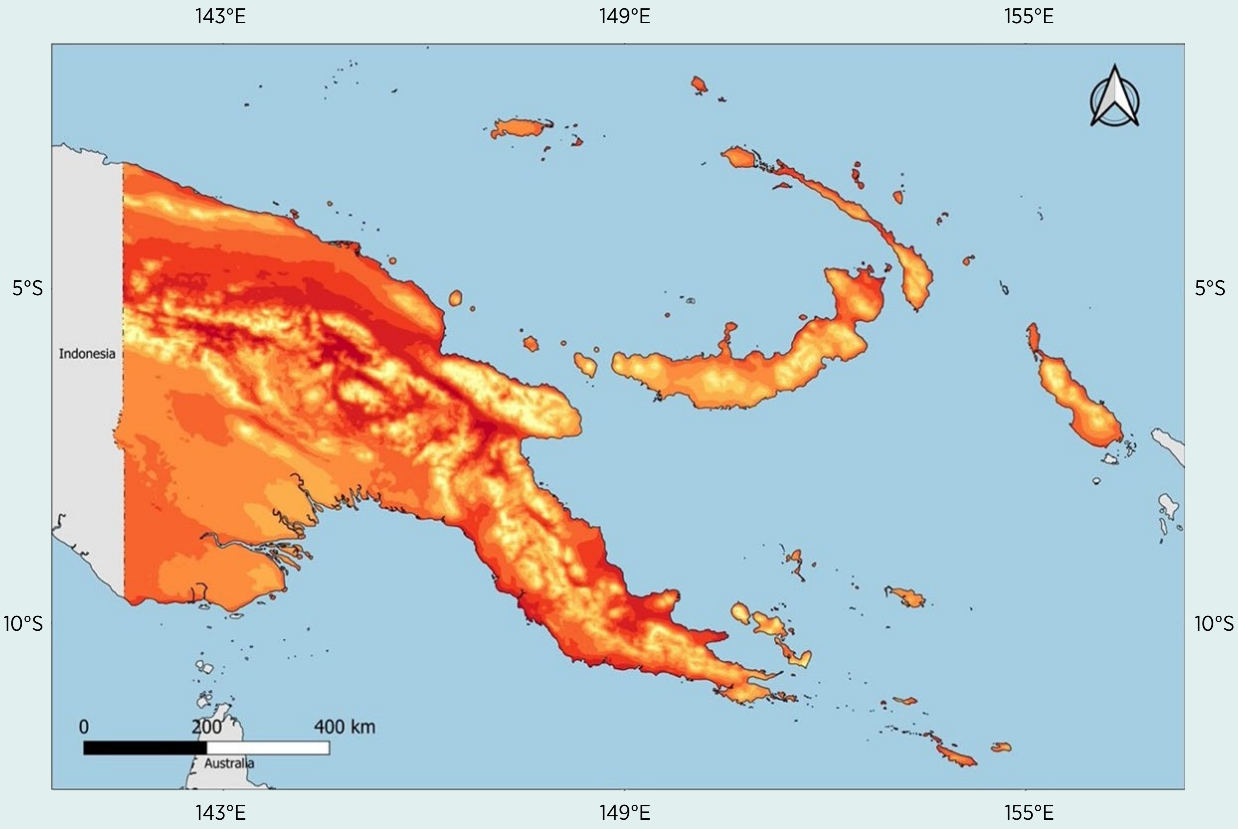
### 3.2.2 Solar PV

Papua New Guinea has good solar potential. It is characterised by annual global horizontal irradiation between 908 $kWh/m^2$ and 2 100 $kWh/m^2$, with 1 630 $kWh/m^2$ on average (see Figure 11). The maximum development solar PV potential is estimated to be approximately 6 825 MW considering an installation density of 50 $MW/km^2$, maximum concentration capacities of 5 000 MW and a 50% land utilisation factor (IRENA, 2024). The actual installed solar PV capacity was 3.89 MW as of 2022 (IRENA, 2023c), when the country had 4 MW of installed solar PV capacity. Further implementation is needed if Papua New Guinea is to reach its ambitious renewable energy targets; increased investment in solar PV mini-grids can unlock additional benefits from energy access beyond home lighting.

*Socio-economic and environmental benefits: Opportunities and barriers*

Solar PV systems, for example, mini-grids or solar home systems, are proving to be a catalyst for **income generation** in rural Papua New Guinea. For instance, these systems enable rural entrepreneurs to produce and sell ice, a valuable commodity in areas without standard refrigeration. Improved lighting due to solar installations allows shopkeepers to extend their business hours by operating into the evening; this opens a possibility for them to boost sales. Farmers engaged in the poultry business benefit significantly from solar lighting, which can boost livestock productivity and health. Further, the availability of solar power gives entrepreneurs opportunities to venture into the sale of frozen goods such as fresh meat and fish. A tangible example of this impact is seen in Trans Niugini Tours' eco-tourism initiatives (see Box 8). Their stand-alone solar PV plants not only help them operate their lodges, they also contribute to local economic activity, with the surrounding communities generating an income by selling food products and handicrafts to tourists visiting the lodges. This exemplifies how solar energy can be a cornerstone in both business development and community upliftment.

**Figure 11** Average annual global horizontal irradiation in Papua New Guinea




**Global horizontal irradiation kWH/m²**

< = 1250 | 1250 - 1350 | 1350 - 1450 | 1450 - 1550 | 1550 - 1650 | 1650 - 1750 | 1750 - 1850 | 1850 - 1950 | > 1950

**Source:** Global Solar Atlas (ESMAP, 2019); base map: UN boundaries. Maps available also on the IRENA Global Atlas for Renewable Energy.

**Note:** kWh/m² = kilowatt hours per square metre.

**Disclaimer:** The map is provided for illustration purposes only. The boundaries shown do not imply any endorsement or acceptance by IRENA.

Solar PV projects have contributed to **job creation** in Papua New Guinea. The construction and installation of the solar PV assemblies at the Lake Murray and Bensbach lodges (38 kW and 20 kW, respectively) required approximately five workers each, for a period of one month, including a manager, engineers, electricians, technicians and logistics personnel, and 80% of the total workforce was sourced from local communities. Beyond the installation phase, these solar PV plants have generated a considerable number of employment opportunities over the years. The lodges, powered by these sustainable energy sources, have created 6 000 to 8 000 person-days of employment annually, offering roles ranging from receptionists and kitchen staff to gardeners and security personnel. Notably, each resort has about 30% female employees and 95% local hires, illustrating the inclusive nature of job creation fostered by these solar-powered enterprises (see Box 8).

**Box 8** Ecotourism powered by solar photovoltaics: Trans Niugini Tours, Papua New Guinea

**Overview:** Trans Niugini Tours owns and operates seven lodges, giving visitors an opportunity to experience Papua New Guinea's biodiverse highlands. These lodges are powered by decentralised renewable energy and diesel mini-grids. Two of its resorts are powered by standalone solar photovoltaic (PV) systems.

| LAKE MURRAY LODGE SOLAR PV PLANT | | BENSBACH LODGE SOLAR PV PLANT | |
|---|---|---|---|
| **Location** | Western Province | **Location** | Western Province |
| **Technology** | 38 kW solar PV and 80 kWh battery capacity | **Technology** | 20 kW solar PV and 50 kWh battery capacity |
| **Project partners** | Energy Matters, Australia | **Project partners** | Energy Matters, Australia |
| **Investment/model** | PGK 250 000, self-financed eco-enterprise | **Investment/model** | PGK 130 000, self-financed eco-enterprise |
| **Commissioned** | 2014, with the start of the lodge | **Commissioned** | 2015 |
| **Status** | Operational | **Status** | Operational |

Trans Niugini Tours has leveraged stand-alone solar PV systems for almost a decade, and it generates local economic activity through its domestic and foreign clients in an otherwise under-developed region.

**Economic impact.** The introduction of stand-alone solar PV plants for projects such as the Lake Murray and Bensbach resorts has significantly contributed to **job creation** and improved job quality in the local communities. The initial setup of each plant required about five workers for a month to handle various tasks, from constructing PV array structures to installing batteries and inverters; the work involved technical and non-technical roles. About 80% of these workers were local hires, highlighting the projects' commitment to local employment. Post installation, the solar plants demand minimal specialised maintenance, primarily to keep the solar panels clean. Over the past five years, these resorts have generated 6 000 to 8 000 person-days of employment annually, offering a range of positions, from receptionists to security staff. Female employment is 30%, while local hires represent 95% of the overall staff. The lodge staff benefitted from both pre-job and on-the-job training.

The solar PV systems facilitated skill development and supported **income generation** within the community. Workers involved in the solar projects successfully transitioned to roles such as cooks and carpenters at local lodges, meaning that employment opportunities were extended past installation. This shift has boosted household incomes from virtually zero to at least the minimum wage. Surrounding communities have capitalised on the influx of tourists to the lodges by selling food products and handicrafts at markets established nearby; the annual income earned is an estimated PGK 10 000.

The adoption of standalone solar PV and battery storage systems has generated significant **energy cost savings**. These systems generate annual savings of PGK 120 000 on average for each lodge as compared with the diesel-powered alternatives. The incorporation of energy-efficient lighting and appliances has further enhanced these savings. This transition to renewable energy sources has strengthened the economic resilience of Trans Niugini Tours, and has enabled the ecotourism operator to remain self-reliant and continue its expansion even through challenging times such as the COVID-19 pandemic.

**Well-being and social impact**. The adoption of standalone solar PV systems for electricity – excluding for cooking, which still utilises firewood – has significantly improved **quality of life** and livelihoods within the community. The systems have helped the lodges become financially viable and aided in the expansion of local ecotours. This has benefitted the neighbouring communities directly and indirectly, boosting the socio-economic status of one of the least-developed sub-regions.

The lodges have become hubs for domestic and international visitors; the local communities have in turn been benefitted since this means an opportunity for them to engage more widely with the outside world. This interaction has increased collective knowledge and **access to information**. The growing local ecotourism, spurred by the solar infrastructure, has prompted communities to enhance their offerings for tourism. Trans Niugini Tours' commitment to training its employees to address customers' needs, reflects an investment in local capability and knowledge enhancement, which is crucial for sustainable tourism development.

The presence of lodges and ecotourism activities in the area has been a catalyst for improving safety and security measures; this has indirectly contributed to the safety of women and minority ethnic populations. By employing women (about 30% of the workforce) and local minorities, the lodges have made significant strides in promoting **gender and social equity**. The organisation of tourism events that celebrate local culture, including traditional dance performances and art exhibitions, enriches the visitor experience and strengthens social inclusion.

**Health impact.** The establishment of the lodges has led to significant improvements in local health facilities, air quality and nutrition. The need for professional healthcare to accommodate lodge visitors has prompted the development of better health services, despite the high costs for local communities. The lodges replacing diesel with clean solar electricity for energy needs led to marked improvement in air quality, reduced respiratory issues and cut down noise pollution from generators. Lodge visitors' demand for specific foods and drinks has provided an incentive to improve local food production; this has led to improved nutrition and food availability in the area.

**Environmental impact.** The lodges shift to power generation based on clean, efficient energy sources has reduced emissions as well as the reliance on polluting diesel generators; this reflects a strong commitment to mitigating environmental impacts. These lodges, by fostering ecotourism and conserving natural rainforests and vegetation, not only protect their business interests, but also reduce deforestation significantly. Through ecotours, including bird watching and research activities, they raise environmental awareness among visitors and employees. The operation of these resorts has encouraged improved waste management practices in the area, demonstrating a holistic approach to environmental stewardship and sustainable tourism.

**Source:** Interview with Trans Niugini Tours, 2023.

Quality-verified off-grid solar products (*e.g.* pico solar-lighting products, plug-and-play solar home systems and component-based systems) were imported and distributed in Papua New Guinea by at least 20 businesses, including large solar specialists, electrical shops, hardware shops, department stores and energy distributors. More than 100 shops were also reported to sell generic (non-quality-verified) off-grid solar products (IFC, 2019).

Renewable energy training initiatives in Papua New Guinea, facilitated by the United Nations Development Programme and funded by the European Union, have significantly advanced local capacities in solar and smart grid technologies from 2020 to 2024. These programmes, which sought to boost electricity access in rural provinces, have trained 46 professionals specifically on installing solar PV systems, maintenance and energy efficiency. Collaborations with local universities and international funding have supported these efforts, highlighting a commitment to expanding renewable energy access and building sustainable communities.

Solar PV projects are also improving **quality of life** in rural areas. Solar-powered lighting is replacing traditional methods such as kerosene lamps, providing improved lighting at a lower cost. This shift benefits students by enabling them to study hours into the evening, besides improving indoor air quality. Further, solar water pumps are making water more accessible in regions such as the Wahgi Valley; they are helping ease tasks such as drinking, cooking and irrigation. The Trans Niugini Tours' solar-powered lodges and the Lake Murray and Bensbach lodges have positively impacted quality of life in local communities. These standalone solar PV systems have boosted the lodges' operational efficiency and economic viability and promoted local ecotours. This has benefitted communities directly and indirectly, for example, through employment opportunities and improved infrastructure, illustrating renewable energy's transformative power in improving livelihoods.

The adoption of solar power in Papua New Guinea is promoting **gender equity and social inclusion**. Solar solutions lessen tasks such as firewood collection and fetching water, which have traditionally been regarded as tasks performed by women; this has eased the household workload for women, who can also benefit from employment opportunities in the solar value chain as well as in the businesses that benefit from solar. About 30% of the Lake Murray and Bensbach lodges' employees are women; this illustrates how renewable energy can support employment in the tourism sector and further gender inclusion and empowerment. Women being the primary household managers, they are ideal for training in using and maintaining solar systems.

Barefoot College International's initiatives in Papua New Guinea combine renewable energy training with sustainable livelihood development, evident through their quantifiable achievements. The organisation has trained 77 women across 14 Pacific Island countries as solar engineers. In Papua New Guinea, they trained six women, including four as Barefoot Solar Engineers ("Solar Mamas"), along with two additional community members. These women received training and equipment for sustainable beekeeping, in turn establishing a new, eco-friendly income stream (Barefoot College, 2021).

Solar PV projects are helping reduce deforestation and emissions since they rely on clean, renewable energy sources such as solar power instead of polluting energy sources such as diesel generators. The ecotourism venture by Trans Niugini Tours, for instance, promotes natural rainforest and biodiversity preservation, which are essential for the ecosystem's health. Finally, these initiatives raise environmental awareness among visitors and locals and contribute to sustainable practices and conservation efforts in these regions.

Meanwhile, Papua New Guinea's topography and dispersed population pose challenges for rural electrification. With its more than 400 000 $m^2$ of landmass, low population density, mountainous terrain and 600 islands scattered over 3 million $km^2$, there are challenges to implementing solar PV at scale (Rawali, Bruce, Raturi, Spak, & Macgill, 2019). However, these same challenges concurrently highlight an opportunity for decentralised solutions, since the country's geography hinders the extension of grid infrastructure. Land ownership issues, with native claims requiring compensation, add to these challenges. Vandalism and theft of solar equipment are prevalent, highlighting the need for security. The high cost of quality solar products remains a significant barrier for low-income rural communities.

Addressing these challenges requires skill building and training for the appropriate use and maintenance of solar products, which ensures their sustainable operation. Rural development necessitates access to affordable solar solutions for agriculture, education, health and livestock. These steps, coupled with skill development, are key to overcoming barriers and boosting solar energy adoption in Papua New Guinea.

### 3.2.3 Biomass gasification

With a current estimated biomass energy potential of 10.5 tonnes of carbon per hectare per year (IRENA, 2023c), in the 1980s and 1990s Papua New Guinea was a regional leader in generating biomass energy for agro-processing. Biomass waste generated from industries, such as copra, cocoa, coffee and tea, replaced the need for imported fuels, with 80 biomass gasifiers are operating at the time. Agri-enterprises, such as Ramu Sugar Mills and Coconut Products Ltd. utilised utilized their waste to produce energy for their own use (IRENA, 2013b).

### *Socio-economic and environmental benefits: Barriers and requirements*

Bioenergy offers considerable potential for income generation in Papua New Guinea. This is evident in more recent initiatives such as the Biomass Power Project in the Lae region, which utilises sustainable tree plantations to generate electricity (see Box 9), and the use of coffee waste from the Highlands for biomass energy. These approaches demonstrate diverse economic benefits.

The project in Lae is expected to create **local jobs and help save on fuel costs**, while the use of coffee husks as a cooking fuel in villages, resorts and boarding schools offers a more affordable, cleaner alternative to conventional fuels. The region has long struggled with unemployment, especially among youth and women. The creation of more than 500 direct jobs and additional indirect jobs in associated businesses can help revitalise the economy. Considering multiplier effects, 2 560 jobs could be created annually in the wider economy.

Bioenergy from projects such as the Lae power plant could provide electric cooking and lighting solutions for rural households and resorts. Transitioning to biomass energy **reduces drudgery and improves living conditions** for communities, which benefit from sustainable and eco-friendly energy sources simultaneously. The Lae project is estimated to bring numerous additional social benefits, including greater access to roads and support for food security. It generates income opportunities for local farmers through intercropping, besides adding to the reliability of the Ramu grid, in turn improving electricity availability for consumers and businesses. The shift to biomass-based electricity for cooking and heating and to clean cooking technologies could significantly ease the burden of women, who traditionally use firewood; this reduces the time and effort invested in collecting wood to make a fire. This change allows women to reallocate their time to other important tasks, adding positively to their daily lives and contributing to gender equity in household energy management.

### **Box 9** Biomass power project in the Lae region

The biomass project is a 30 MW power station, for supplying electricity to the Ramu grid in Papua New Guinea. The primary fuel source is biomass, obtained from sustainable plantations of two species of eucalyptus tree.

| PROPOSED BIOMASS POWER PROJECT | |
|---|---|
| **Location** | Markham River Valley, Lae, Morobe Province |
| **Technology** | Biomass gasification technology that converts wood chips into a combustible gas, which drives a turbine generator |
| **Project partners** | The project is developed by Markham Valley Biomass Limited, a joint venture of Aligned Energy Limited, PNG Biomass Limited and Oil Search Limited |
| **Investment/financing** | PGK 582 million over seven years. The project is under-pinned by a 25-year power purchase agreement with PNG Power Limited. |
| **Status** | The project is currently at the permitting and power purchase agreement negotiation stage. Construction is likely to commence in 2024, and commercial operation is expected in 2025. |

A stated goal of the project is to boost Papua New Guinea's energy security and independence without compromising environmental integrity. The project aims to improve community well-being by actively involving local landholders in plant development and creating a sustainable energy supply, which benefits communities and protects the environment.

**Economic impact.** The project is expected to create significant economic benefits. For example, it is expected to help avoid the high costs of imported diesel fuel; generate significant local employment; strengthen the local workforce's capacity and productivity through international plantation forestry training; create diverse economic activities and income sources in the region through potential timber veneers and plantation horticulture; and lead to a significant increase in government tax revenues over the project life. Timber products will be sold when biomass supply exceeds the power plant's requirements.

**Well-being and social impact.** The project will benefit communities by boosting access to roads, supporting food security and generating income opportunities for local farmers through intercropping (horticulture crops grown by landowners between the trees in the plantation). The project will also add to the Ramu grid's reliability and capacity; it will improve the availability of electricity supply for the region's consumers and businesses, besides improving supply quality. An independent study estimated that the power plant and the associated plantations would provide over 500 direct jobs and additional indirect jobs in a region whose youth and women had long experienced significant unemployment.

**Environmental impact.** Carbon dioxide emissions will be reduced through the provision of a localised and cleaner alternative to fossil fuels; this contributes to global climate change mitigation efforts. In this case, the project involves 16 000 hectares of tree plantations, which sequester carbon as the trees grow, offsetting some of the emissions released with combustion. Whereas wood-based biomass gasification can risk increasing deforestation, the Markham River Valley project purportedly uses sustainable forestry practices only.

**Health impact.** As an alternative to diesel generators and fossil-fuel-based electricity, the biomass gasification plant is expected to reduce air pollution (*e.g.* nitrogen dioxide and sulphur dioxide), thereby improving health outcomes for local communities.

Regarding replicability and scalability, the anticipated project may help raise awareness among and strengthen buy-in from communities and other stakeholders for future biomass gasification projects. While biomass has not been widely leveraged as an energy access solution in Papua New Guinea, this trailblazing project may showcase a range of economic, social and environmental benefits, inspiring further deployment of biomass technologies.

**Sources:** (Economic Consulting Services, 2017; Bioenergy, 2017).

Maximising biomass energy's socio-economic benefits in Papua New Guinea necessitates addressing specific barriers. First, there is a **lack of public awareness** of biomass energy and demonstration of its benefits and efficient use, especially at the community level. Second, **research and development** must receive investment if biomass energy's capabilities are to be further explored and expanded. Third, **government support** is lacking, as seen in the limited expansion of companies involved in biofuel production. Another notable barrier is the **lack of skills**, which hinders local job creation and income generation opportunities in the biomass sector; skill development requires investing in training and educating local populations so that they can become a part of the value chain.

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## 3.3 VANUATU: PACIFIC ARCHIPELAGO

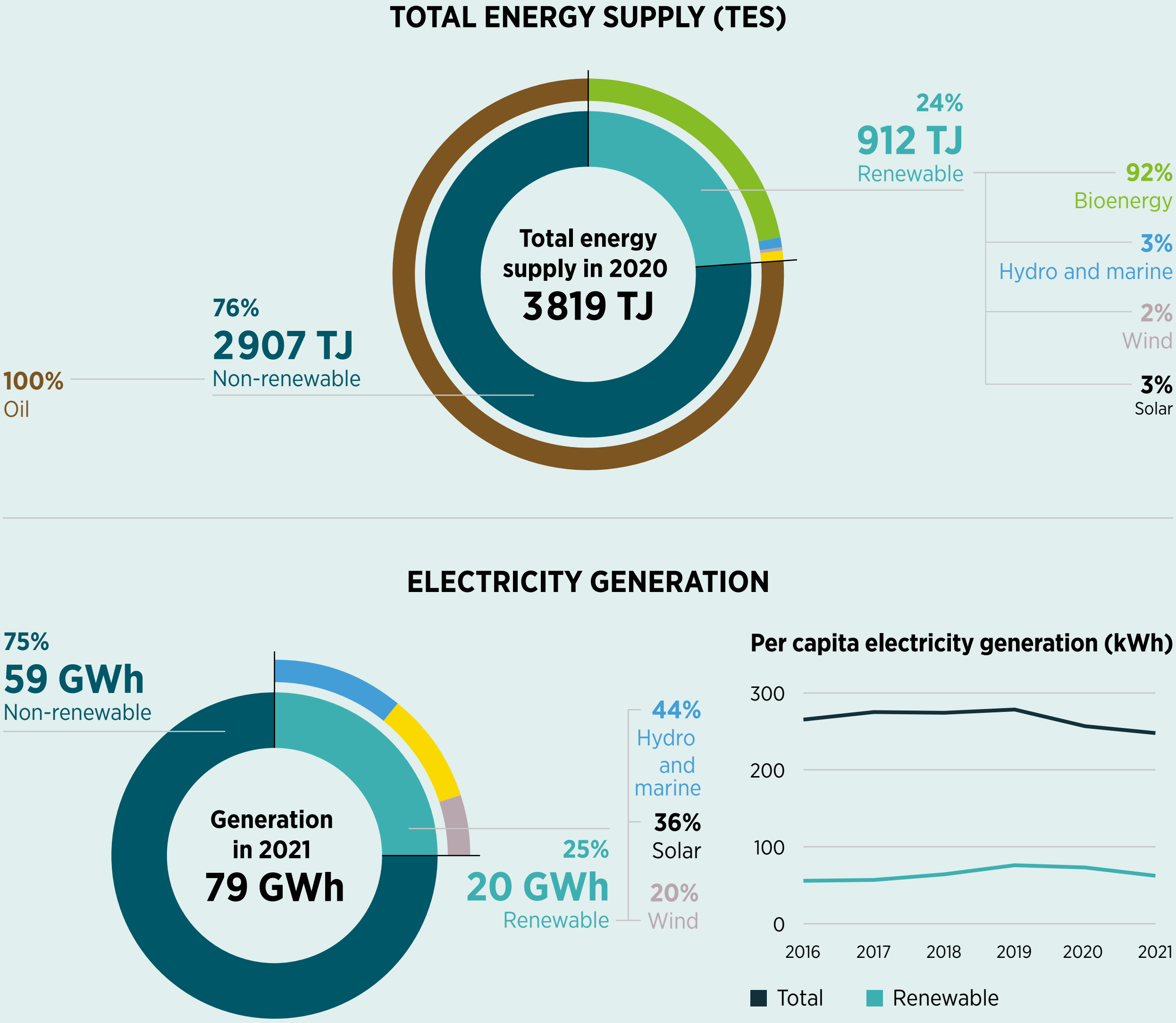
Vanuatu is an archipelago of 83 small islands in the South Pacific Ocean. It is categorised as a least-developed country, with a population of about 340 000 people, three-quarters of whom are rural residents. Only four of the country's 83 islands have electricity access via the national grid. Despite Vanuatu's energy access deficit, it has received significantly less energy-focused aid when considering the overall commitments for energy aid to the SIDS (Atteridge & Savvidou, 2019).

Vanuatu is highly vulnerable to climate change; it already experiences rising sea levels, more frequent and intense extreme weather events, and more erratic rainfall patterns. The country is also spearheading climate advocacy at the international level. In 2023, together with other Pacific SIDS (Fiji, Niue, the Solomon Islands, Tonga and Tuvalu), Vanuatu launched the "Port Vila Call for a Just Transition to a Fossil Fuel Free Pacific", which calls for a just transition to renewable energy and ambitious action towards the phase-out of fossil fuels globally.

Vanuatu's energy sector relies significantly on non-renewable sources, which constituted 76% of the total energy supply in 2020; renewable sources contributed 24% (Figure 12). Renewable energy supply was overwhelmingly dominated by bioenergy, at 92% (mostly traditional biomass), with solar and hydropower contributing much smaller shares. In 2021, 25% of electricity was generated from renewables – hydro and marine (11%), solar (9%) and wind (5%).

By 2030, Vanuatu aims to have 100% grid-based electricity, to be generated from renewable sources, and 100% household electricity access. The country relies heavily on fossil fuel imports; meanwhile, given its fragmented geography, low rural electrification rate and high renewable resource potential, distributed renewable energy presents a promising solution for Vanuatu's energy future. Renewable energy can accelerate access to affordable, reliable energy and clean cooking, reduce reliance on fossil fuel imports, improve air quality and generate local jobs, among other opportunities. The following case study highlights a range of socio-economic and environmental benefits from distributed renewable energy in Vanuatu.

**Figure 12** Vanuatu's energy profile, 2020

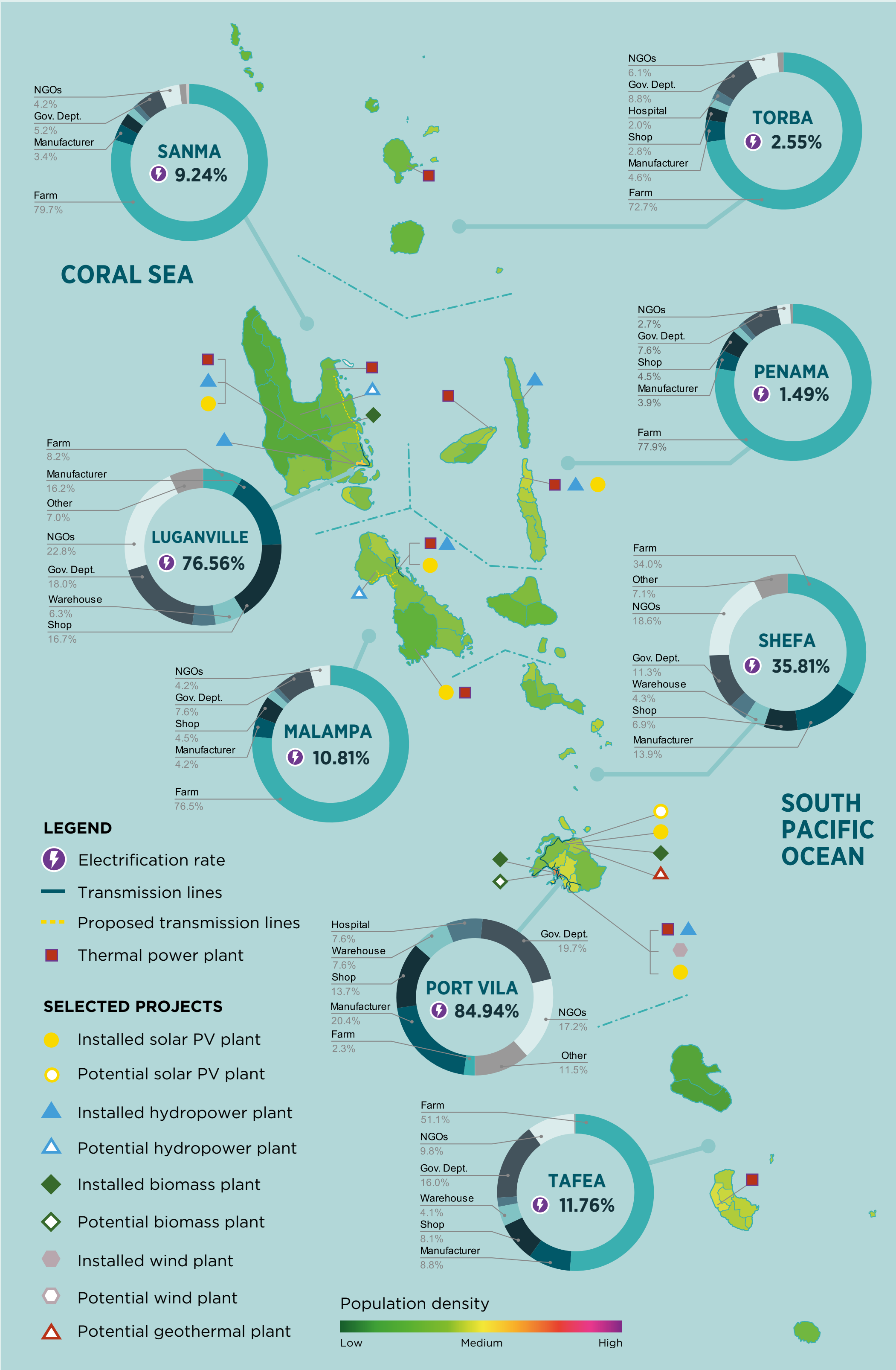



**Source:** IRENA, 2023e.
**Note:** GWh = gigawatt hour; kWh = kilowatt hour; TJ = tera joule.

The three largest regions by population in Vanuatu (Figure 13) are Shefa (excluding Port Vila), whose population is 18.3% of the overall population of Vanuatu, Port Vila, for which it is 16.3% (one of the most densely populated areas in the country), and Taefa, for which it is 15.2%. Vanuatu's workforce is largely concentrated in agriculture; regions such as Sanma, Torba, Penama and Malampa have over 70% of their employment in farming. This reflects an economy anchored in agriculture. Greater introduction of bioenergy in the form of biomass gasification in these regions could deliver the much-needed energy alongside creating economic value by leveraging the synergies with the local agricultural ecosystem.

Urban centres such as Port Vila and Luganville exhibit varied employment profiles. While Port Vila is a manufacturing hub, accounting for 20.4% of employment, and has substantial sectors in government, retail and non-governmental organisations, Luganville is notable for the substantial involvement of non-governmental organisations and a thriving retail sector. These urban locales also boast the necessary infrastructure for healthcare and logistics, with hospitals and warehouses, highlighting their role as the country's commercial and logistical epicentres. In these regions, companies and businesses are increasingly contributing to the renewable energy sector by offering services such as the sales and distribution of off-grid solar products, alongside the construction and installation of renewable energy technologies.

**Figure 13** Population density and working population (>15 years of age) by region (2 urban and 6 rural) and by sector, including selected installed and potential renewable energy projects, in Vanuatu




**Sources:** (VNSO, 2020; URA, n.d.; URA, 2021; IRENA, 2015; JICA, 2019).

**Note:** NGO = non-governmental organisation; PV = photovoltaics.

**Disclaimer:** This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

### 3.3.1 Micro/Mini Hydropower

Vanuatu's installed hydropower capacity was 1.28 MW as of 2022 (IRENA, 2023c). There is still some potential for future expansion given the country's dispersed population and low rural electrification rate.

*Socio-economic and environmental benefits: Opportunities and barriers*

Micro and mini hydropower has significant socio-economic benefits to offer in Vanuatu. It is a clean and reliable decentralised renewable energy technology that can support productive loads. The use of small hydropower could reduce reliance on costly diesel fuel while spurring economic activity (productive end uses and, possibly, the local manufacturing of parts) and creating opportunities for training and job creation.

Micro and mini hydropower can also help the country meet its ambitious targets for clean energy and rural electrification. As with the new 400 kW Brenwe Hydropower Plant (see Box 10) which will displace an estimated 90% of diesel fuel on Malekula Island, micro-scale systems can have significant socio-economic benefits. The project has been a source of **employment** for a small number of expatriate staff and up to 50 locals. The initiative provided valuable on-the-job training, enhancing the employability and skills of the local community.

Women made up 30% of Brenwe's Community Advisory Committee which allowed their perspectives to be integrated in its implementation. This effort was coupled with policies promoting fair employment and a comprehensive **gender** needs assessment to ensure that the initiative not only meets the community's energy requirements but also addresses its diverse needs through inclusive consultation and decision-making processes.

In addition to reducing emissions, micro and mini hydropower offers **environmental benefits** for Vanuatu, specifically watershed conservation opportunities. As increasing pressures from agriculture and economic development threaten endemic species and natural resources, ecological conservation presents an important co-benefit of small-scale hydro implementation in Vanuatu (DEPC Vanuatu, n.d.).

**Box 10** Island-wide electrification using mini hydropower: Brenwe Hydropower Project, Vanuatu

The two largest islands of Vanuatu, Espiritu Santo and Malekula, have identified hydropower as the most cost-effective option for baseload power and are investing in small-scale hydro. In Malekula, a 400 kW hydropower plant will supply an estimated 90% of household electricity needs.

| BRENWE MINI HYDROPOWER PROJECT | |
|---|---|
| **Location** | Malekula Island, Vanuatu |
| **Technology** | 400 kW run-of-river micro hydro system |
| **Project partners** | Government of Vanuatu, Stantec, Asian Development Bank |
| **Investment/Model** | Grant |
| **Commissioned** | 2023 |

**Economic impact.** The project is expected to displace approximately 90% of the diesel energy used for electricity generation in Malekula, lowering energy costs for the community. The project and the associated Malekula transmission line was constructed by a mix of expatriate and local workers. Specifically, the team consisted of 4-6 expatriate supervision staff and up to 50 local workers. Thus, the project not only mobilised essential expertise but also focused on local capacity building through the recruitment and training of local workers. The construction contractor's comprehensive training plan included continuous on-the-job training for local workers.

**Social impact.** The system is expected to increase the residential customer base in Malekula by 90%, significantly expanding energy access on the island while reducing household electricity costs for those who have relied on costly diesel fuel to date.

Women's participation was encouraged, with women constituting 30% of Malekula's Community Advisory Committee, reflecting a commitment to gender equity and inclusion in consultations and decision making. Women's participation is further supported by policies for fair employment. A gender needs assessment ensured that the project is addressing the community's diverse needs.

**Health impact.** The mini hydro system is used for household cooking, significantly benefiting the health of women and children. The system will support local agri-processing loads, increasing access to affordable processed produce.

**Environmental impact.** Because the fuel source of the mini hydro system is the local stream, the community has a strong incentive to maintain the natural, forested watershed of the system.

Overall, the recently commissioned project points to the potential for small-scale hydropower to generate a big impact, in this case providing island-wide electrification alongside numerous socio-economic and environmental benefits. Similar transformative outcomes can be expected from replication in other small island developing state contexts, especially off-grid and diesel-dependent communities that can most benefit from the cost savings and sustainable development enabled by mini hydro.

**Source:** (Malampa Government, 2021); (Hydro Review, 2021; Daily Post Vanuatu, 2023; ADB, 2022).

Challenges and requirements to meet the above socio-economic and environmental opportunities of off-grid hydropower include the following:

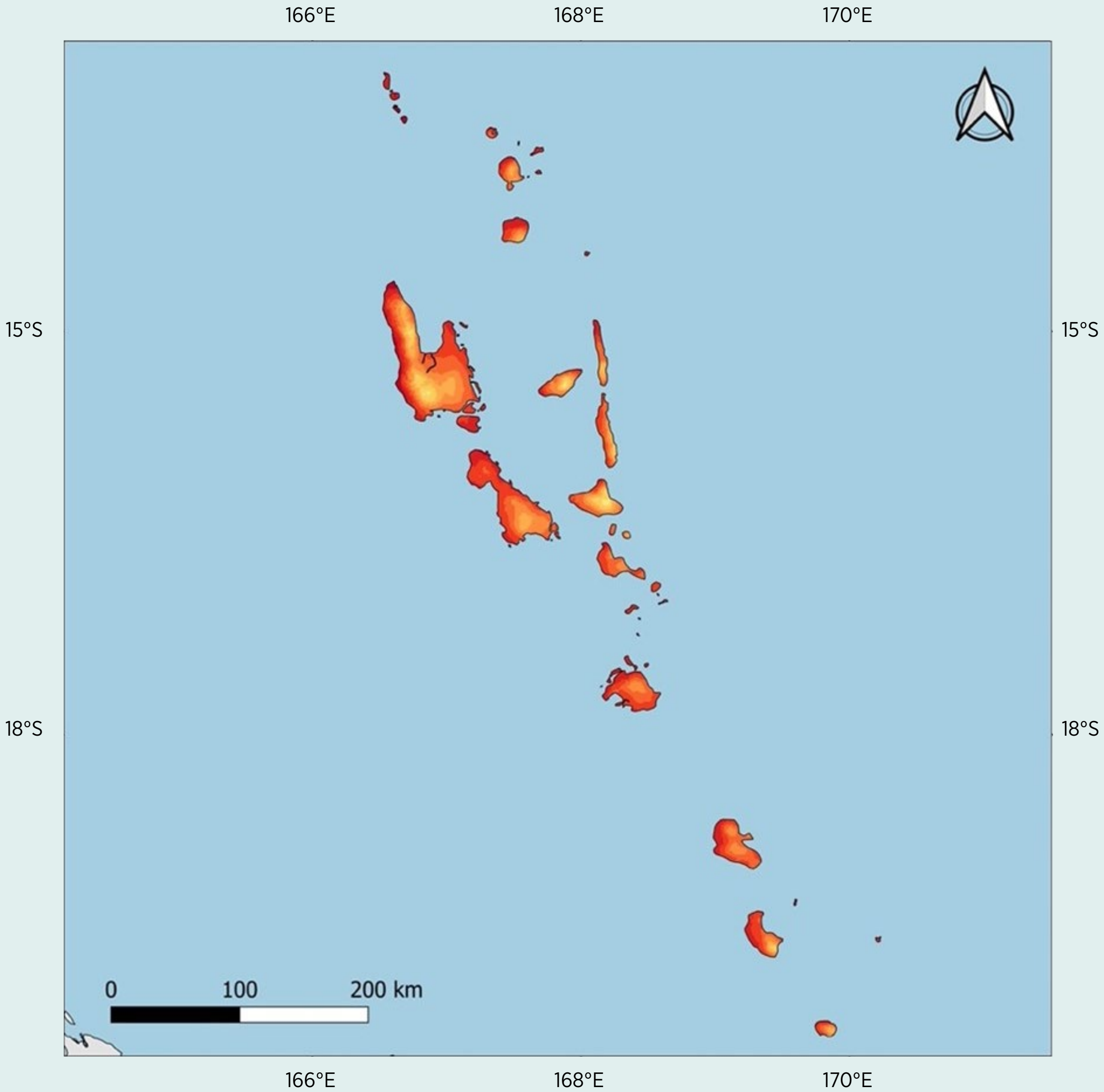
**Funding and unavailability of required data and technical know-how:** Development of grid-connected hydro projects in Vanuatu can easily eliminate large portions of diesel consumption for power generation but even though the resources are available, lack of funding, required rainfall and hydrology data, and technical (including environmental expertise) expertise hinders this development.

**Lack of local industry:** As most of the hydro resources are located in remote places, it is essential to Identify off-grid hydro projects where demand centres (often villages with small businesses and sometimes with anchor loads such as telecom towers, *etc.*) are located near enough. Donor support (such as World Bank funded pre-electrification projects in Sri Lanka and Nepal) can help in boosting this industry and supporting government and private institutions (ministries, private and local banks, environmental consultants, *etc.*). Leveraging or building local expertise where possible is vital. Otherwise, importing turbines and controls makes these projects unviable and affect the sustainability as the maintenance of these imported equipment will be beyond the expertise of village technicians.

### 3.3.2 Solar PV

Vanuatu has moderate solar potential characterised by an annual global horizontal irradiation ranging between 1108 kWh/m$^2$ and 1867 kWh/m$^2$ with an average value of 1565 kWh/m$^2$ (see Figure 14). The actual installed solar PV is 4.75 MW as of 2022 (IRENA, 2023c).

**Figure 14** Average annual global horizontal irradiation in Vanuatu




**Global horizontal irradiation kWH/m$^2$**

< = 1200 | 1200 - 1300 | 1300 - 1400 | 1400 - 1500 | 1500 - 1600 | 1600 - 1700 | 1700 - 1800 | > 1800

**Source:** Global Solar Atlas (ESMAP, 2019); Base map: UN boundaries. Maps available also on the IRENA Global Atlas for Renewable Energy.

**Note:** km = kilometre; kWh/m$^2$ = kilowatt hours per square metre.

**Disclaimer:** This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

*Socio-economic and environmental benefits: Opportunities and barriers*

Harnessing the sun's power promises Vanuatu a multitude of socio-economic and environmental benefits. Energy access rates will rise as the existing distribution grid is extended to unelectrified peri-urban households (ADB, 2017). Decentralised solar PV technologies can also greatly expand energy access in off-grid communities, reducing reliance on dangerous kerosene lamps and candles for light (World Bank, 2017), costly imported diesel fuel, and fuel wood and charcoal for cooking. **Household electricity expenditures** can thus be reduced while improving health outcomes and protecting the environment through reduced air pollution, emissions and deforestation.

For some time, the Utilities Regulatory Authority has had regulations in place for connecting private solar installations to the grid, presenting an opportunity for households and businesses to sell unused, excess electricity with additional socio-economic benefits (IRENA, 2015). However, the Department of Energy continues to navigate challenges regarding safety and grid stability, with respect to solar rooftop self-generation supplying power back to the grid (DOE Vanuatu, n.d.). Other challenges and potential barriers relate to high costs and maintenance, preventing the widespread roll-out of household solar power systems (ADB, 2017), especially amid low population densities (World Bank, 2017). Another barrier is the lack of national standards and guidelines for designing off-grid solar systems for public installations like schools and health centres (IRENA, 2015).

IRENA's earlier renewables readiness assessment of Vanuatu identified the importance of designing an institutional approach to sustaining off-grid electrification via SHSs, developing standard designs for SHSs and solar mini-grids, training and capacity building (*e.g.* including long-term training options via local educational institutions, specific to both grid-connected and off-grid solar). The assessment also highlighted opportunities to learn from prior experience in other Pacific islands, with respect to off-grid SHSs and mini-grid system policies and approaches (IRENA, 2015).

One success story is the Vanuatu Rural Electrification Project, launched in 2014 with assistance from the World Bank and the Government of New Zealand. To improve energy access in remote areas of the country, the project subsidised 50% of families' SHS costs. It made it possible for 17 000 households to turn on the lights and charge phones. Some systems were able to support radios, small televisions and other such end uses. Subsidies also allowed not-for-profit community centres and community-run health clinics to purchase solar kits, extending social and health benefits to larger numbers (World Bank, 2017).

In Loltong, North Pentecost, a pico-hydropower hybrid mini-grid system (5.3 kW + 8.8 kW) (IRENA, 2023f) connects two neighbouring villages with 3.4 kilometres of distribution lines. Since the system's commissioning in October 2021, more than 60 households have connected to the grid. The system has thus enabled clean electric cooking and refrigeration. By reducing demand for fuelwood collection for cooking, the project has reduced deforestation and erosion. The project is estimated to reduce 160 tonnes of $CO_2$ equivalent annually. The Wintua and Lorlow solar micro-grid project in Vanuatu is another promising community-driven renewable energy initiative, reducing $CO_2$ emissions and generating 9.3 megawatt hours of electricity within its first six months of operation (PCS, 2021).

Solar PV can contribute to the well-being of remote communities. A transformative project in Loltong showcases a unique hybrid decentralised solution, combining solar PV and pico-hydro, that can be replicated by other remote island communities. Thanks to the project, students can now do their homework at night. Beyond households, the mini-grid provides power to local businesses, two schools, churches and a medical clinic which is now able to refrigerate medical supplies. Electrical tools have improved the productivity of carpentry and automobile and boat repair workshops, which once relied on diesel generators. To ensure financial viability, additional means of earning revenue from productive uses have been introduced, including a block-making machine for bricks, operated by the mini-grid technician or leased to other users. The project and associated economic transformation is drawing interest. Loltong is increasingly playing host to meetings, workshops and training events for governmental, non-governmental and private entities (Vanuatu Daily Post, 2023).

PV mini-grid projects in Vanuatu include grid-connected projects in Tagabe (81 kWp), Kawene (1 094 MWp) and Undin Bay (510 kWp) that are benefiting once-unelectrified enterprises and communities. The Wintua and Lorlow solar micro-grid project is operated as a co-operative by the local community, with operations and maintenance managed by a local company. The project empowers residents, promotes local job creation and drives economic benefits. It offers access to clean energy to more than 2 800 people, supports educational and health facilities, and saves substantial fuel costs (UNDP, 2020). It enabled Wintua Secondary School, for instance, to save up to VUV 2 million (about USD 16 700) on fuel costs yearly (Vanuatu Daily Post, 2020).

Solar drying technology has played a crucial role in climate resilience, food security and **women's empowerment**. The initiative described in Box 11 utilises solar-powered food dryers. The training provided to Epi kava and cacao farmers in solar drying technology is geared towards improving the quality of products for export. The introduction of solar dryers has generated considerable interest across the island, indicating a growing recognition of sustainable agricultural practices and their potential to elevate product quality and bolster economic prospects.

### **Box 11** Women-led fruit drying enterprises using solar solutions: A climate adaptation innovation in Vanuatu

The use of solar-powered food dryers, each costing around USD 300, is part of a broader initiative in Vanuatu focusing on agricultural sustainability and food security. Approximately 500 women have been trained to use the dryers to preserve various crops such as fruits, vegetables and nuts. After a surplus harvest, solar drying offers a practical food storage solution. Leveraging renewable energy for agricultural practices reduces reliance on traditional methods that may be less sustainable and more vulnerable to climate-induced disruptions.

The solar dryers not only offer an eco-friendly way to preserve food but also empower local women economically and socially. This empowerment is crucial in Vanuatu's patriarchal society, helping to reduce injustices, discrimination and abuse against women. The project's success has sparked global interest in its healthy, natural food products. The technology's simplicity and cost-effectiveness make it replicable in other communities, across Vanuatu and beyond (UNFCCC, 2023).

Further building on this concept, the Vanuatu Primary Producers Authority and Pacific Horticulture and Agricultural Market Access (PHAMA Plus) have initiated training for Epi kava and cacao farmers in solar drying technology. This training aims to improve product quality, aligning with efforts to meet export standards. Growing interest from farmers on the island underscores the potential of renewable energy solutions in enhancing agricultural productivity and quality, contributing to the region's sustainable development (Vanuatu Daily Post, 2022).

# 4. OUTLOOK

The challenges posed by climate change are monumental in scope, far surpassing the capacity of any single country to address, let alone small island nations with comparatively limited means and much greater exposure to climate impacts. Mitigating rising sea levels and averting the catastrophic impacts of climate-induced weather events requires global cooperation and concerted efforts. Nonetheless, renewable energy solutions offer a pathway to SIDS, not only by making a contribution to the global fight against climate change, but also by improving their socio-economic conditions.

By embracing solutions such as solar, wind and ocean energy, SIDS can diversify their energy mix, reduce reliance on fossil fuels, reduce costs and enhance energy security. By harnessing their abundant natural resources, SIDS can thus also make electricity more affordable for households and businesses. Renewable energy also holds substantial promise to reduce air, maritime and noise pollution across economic sectors, from residential electricity to agriculture, fisheries and maritime transport. An important end result is to cut the deleterious environmental and health impacts of burning fossil fuels.

The transition to a renewables-based energy mix not only mitigates carbon emissions and counters local air pollution but also creates new opportunities for economic growth and development. SIDS that are already renowned global climate champions within organisations like the Alliance of Small Island States can extend their leadership by embracing a renewable energy-based development model, setting a precedent for others worldwide. Collaborative frameworks such as the SIDS Lighthouses Initiative coordinated by IRENA (see Box 12) are crucial to translating discussions into action, supporting SIDS' energy transitions, and strengthening their climate resilience and sustainable development.

**Box 12** About IRENA's SIDS Lighthouses Initiative

The SIDS Lighthouses Initiative is a collaborative framework for action to support SIDS in their efforts to transition from fossil fuels to renewables, in the process strengthening climate resilience and sustainable development. Co-ordinated by IRENA, the initiative brings together 40 SIDS and 44 partners from public, private, intergovernmental and non-governmental sectors, promoting dialogue, collaboration and knowledge exchange.

Through the initiative, IRENA facilitates multi-stakeholder events, capacity building efforts, technical analyses (*e.g.* to facilitate grid integration of renewables), and site appraisals to assess financial viability. Key tools include renewable readiness assessments, Quickscans, renewable energy roadmaps and grid integration studies.

The SIDS Lighthouses Initiative has generated numerous publications, including regional and country-level profiles tracking progress on the deployment of renewable energy technologies in SIDS.

In July 2022, IRENA received the inaugural United Nations SIDS Partnerships Award in the environmental category in recognition of its promotion of sustainable development through the SIDS Lighthouses Initiative.

Integrating renewable energy solutions can lead to the establishment of clean energy firms and industries, which in turn stimulate local economies. The implantation of renewable energy infrastructure, such as solar farms and wind turbines, requires both skilled and unskilled labour for installation, operation and maintenance, thereby creating jobs. Although SIDS are less likely to develop industries that manufacture renewable energy equipment, given the dominance of countries with large-scale supply chains, it may become possible in the future to develop some limited component manufacturing or small-scale assembly operations. But this may be more feasible if carried out jointly with neighbouring countries, bundling resources and fostering capacities in regional clusters.

The socio-economic impacts of integrating renewable energy solutions extend beyond providing energy. Access to reliable and affordable electricity stimulates economic activity, supports education and health care, and enhances the overall quality of life for island communities. Furthermore, renewable energy projects can attract foreign investment and promote technological innovation. Collaborative partnerships with international organisations and private investors can facilitate the transfer of knowledge, expertise, and funding for the development of sustainable energy infrastructure. Collaboration among SIDS could support the deployment of renewables (and other economic activity) by pooling experience and resources, including in areas such as education, training and regulation.

In conclusion, while SIDS will not single-handedly alter the trajectory of climate change, the pursuit of renewable energy solutions allows them to be international role models, contributing significantly to mitigating climate impacts while fostering positive socio-economic outcomes. Through strategic investments in renewable energy infrastructure and supportive policies, these states can build resilience, promote sustainable development and create a brighter future for generations to come.

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