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ENERGY TRANSITION: MICROGRIDS AND THE IMPACT OF SELF-CONSUMPTION IN MOZAMBIQUE

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Energy Transition: Microgrids and the Impact of Self-Consumption in Mozambique

This work project aims to describe and analyze the energy transition in Mozambique, specifically the impact that microgrids and self-consumption can have on the electrification system. In the latest years, energy transition and climate change are one of the most discussed and researched topics. Furthermore, we now find ourselves shifting our energy sources, from fossil fuels to renewable energy because of climate change, the negative impact of fossil fuels. Moreover, Mozambique has strong renewable potential that could help increase access to electricity through solar panels, as well as improve the quality of service delivery with the right policies and regulations.

Keywords: Renewable energy; Mozambique; Microgrids; Self-consumption;

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List of Abbreviations

PV solar panels – Photovoltaic solar panels

IPP – Independent Power Producer

IRENA – International Renewable Energy Agency

MW/MWh – Megawatt/Megawatt per hour

GW/GWh – Gigawatt/ Gigawatt-hour

TW/TWh –Terawatt/Terawatt per hour

CO2 – Carbon Dioxide

Off-grid – local energy grid that can operate autonomously while disconnect from the traditional grid system

Micro-grid – a subtype of an off-grid system, composed by a small-scale electricity generation, often between 10 kW and 10MW, that serves a limited number of consumers/households

EDM – *Electricidade de Moçambique* (Mozambique's power utility company)

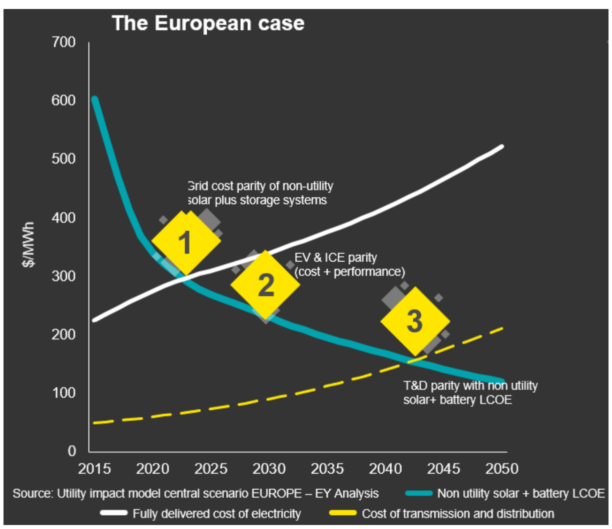
ARENE – *Autoridade Reguladora de Energia* (Energy Regulatory Authority)

Introduction

Energy has been very important to humankind ever since. But only recently it has become clear for everyone that the type of energy consumed in the past was unsustainable, making long and short-term energy security an important topic that rose to the top of every political agenda (Deng, Blok, and Leun, 2012)[1].

One can say that the past century was characterized by a centralized energy system, based on large-scale power plants that used fossil fuels, that are now being restructured by distributed energy systems (DES), especially because the share of renewable energy sources (RES) is continually increasing (Wang et al., 2018)[2].

The world is now witnessing in the **Energy Transition** phase, a transformation in the global energy sector, with energy sources shifting from fossil to sustainably based sources. Where the reduction of energy-related CO_2 emission is the main reason[3], this emergence of a new energy source will affect the current supply and demand structure as well as the current prices[4].



In a study conducted by EY, the way that electricity is generated and consumed is changing irreversibly towards a more distributed model. The future of our system is decarbonized, decentralized, and as of now, there will be 3 tipping points that depending on the region of the world, those changes can happen sooner or later[5].

Image 1*: Utility impact model central scenario Europe – EY analysis.*

The first tipping point will be signaled by the grid cost parity, where being connected to the grid will cost the same as generating one's electricity through Photovoltaic solar panels and storage systems.

Moreover, as time moves forward, the second tipping point marks the time where the price of battery electric vehicles reaches cost parity and performance parity with internal combustion engine vehicles. Finally, the third and final tipping point is marked by the cost parity of transporting electricity, as it exceeds the cost of generating and storing it locally.

The Energy Transition

Technology has proven to be the main driver of change in many sectors, and with its growth, a change in the energy sector was already expected. By introducing smart energy networks, along with several digital solutions that allow for a more efficient control for energy demand and its trade, renewable energy can transform the energy market in a way once seen as impossible.

Technology, however, cannot be the only instrument to achieve this transition, therefore, international energy policies are needed to align plans and increase the countries' emissions reduction[6].

The new geological age we live in, with climate change as its most critical indicator, the Anthropocene[7], has led countries to come together and elaborate on the COP21 Paris Agreement. In December 2015, 195 countries adopted the universal legal bind, concerning a global climate deal to reduce emissions and the increase of global average temperature bellow 2ºC and limiting it to 1.5ºC[8]. This shows that governments are becoming more concern with climate and changes and its consequences, thus are willing to invest in a clean-energy generation.

According to IRENA's Renewable Energy Roadmap (REmap) issued in 2018, around 65% of the total final energy use will be made up by renewables in 2050, where also 85% of the electricity generated will come from renewable sources, of which 72% will be supplied by solar and wind resources[9].

One can say that the main reason for it to happen is the need to reduce the energy-related global greenhouse gas (GHG) and CO_2 emissions, that have a direct effect on the climate change we are currently witnessing, and while decarbonization has turned to be an urgent matter in the energy sector, renewable energy and energy-efficient measures are so far the key way to achieve this[5].

During the Climate Action Summit 2019 that was held in New York in September 2019, global leaders joined together to announce the next steps to confront climate change. With noticeable rises in temperatures, carbon pollution, and climate destruction, it was expected that the 2019 Summit brought practical actions to control CO_2 emissions, as said by United Nations Secretary-General António Guterres, "This is not a climate talk summit. We have had enough talk… This is a climate action summit."[10]

One can say that the need for action is crucial. Despite many of the proposed goals not changing from the COP21 agreement, the results coming from the Paris agreement show a contradiction to what was agreed to. Furthermore, from the data gathered, one can observe a rapid increase in the global CO_2 emissions from fossil fuels by 2.7% in 2018, following a 1.6% increase in 2017, after remaining mostly flat for three years.[11]

This increase comes after an agreement that presented hope to some climate activists regarding a more stable global carbon emission. Government incentives towards the Chinese construction industry and a boost in energy demand were some of the drivers for the increase in emissions, and according to Zeke Hausfather, rising oil and gas use may continue emissions growth in 2019[12].

In the 2019 summit, over 50 countries and major sub-national economies committed to cut emissions by 2050, while 70 other nations aimed to boost their action plan in 2020[13]. These commitments should be seriously engaged since the lack of monitorization and sanctions associated might lead to another growth of emissions, thus having the same defined targets for the next Climate Change Summit.

The evolution of renewables – their contribution

Climate change is a big issue, and because it cannot be associated only with gas emission analysis, there are other ways to achieve the goals for energy efficiency. Child et al (2017)[14], in their publication, arose to the conclusion that only with a fully renewable energy (RE) system, countries will achieve their sustainability goals and a resilient future energy system.

This alternative energy resource has had a surprising growing path, surpassing what many expected to be, with a continuous increase in global installed capacity and production, with the support of new policies spreading to more countries and the development projects like *Akon Lighting Africa*[15]. This project has helped approximately 600 million Africans, including several villages and their members, community residences, as well as public health centers and schools located in rural areas, providing them first-time access to electricity.

The rapid growth was influenced by several factors, being some of them the various energy crisis the world faced, which began in the 1970s, and in the same time with countries like Germany, Denmark, Spain, and the United States. These pioneer countries created markets and enabled technology advances towards renewable energy production[16].

This accelerated growth was seen mostly in developed countries, those outside the OECD, where renewables were expanding at 7.4% per year, compared with the OECD member countries where this figure was 4.6%[17]. And according to the same article by *Mckinsey & Company*, renewables are expected to be responsible for 43% of new power plants in Africa, 48% of Asia's, and 63% of Latin America's in the next 25 years.

One can see renewable energy only as an evolution and not a revolution, and according to the paper on 50 Global Trends That Matter (Abouchakra, Mannaee, and Hijazi, 2016)[18], data and graphics analyzing topics from economics to energy suggest that despite strong growth in renewables such as geothermal, solar, and wind and more, by 2040 the majority of the planet's electricity will still depend on fossil fuels like coal and natural gas. This statement may be underestimating the growth and power that renewables will have in the future, since the IRENA reported in 2018[4], that the costs of renewable energy have been decreasing at higher rates, and additionally, the costs of solar photovoltaic (PV) projects since 2010 have had a global average cost decline of 73%.

Advancements in energy efficiency and generation from renewable sources have caused the smoothness in the global emissions of carbon dioxide (CO_2) from 2013 to 2016, rising only by an estimated 0.2% compared to the 2.2% average growth in the past decade[19]. Additionally, despite the growth of the renewable energy sector, especially for wind power and solar PV, due to the growth in overall energy demand, the share of renewable energy of the total energy consumption increased at a slower rate, offsetting the strong trends of the modern renewable energy technologies.

Along the years, renewable energy sources have helped many communities have access to electricity, reducing the percentage of share of people who lack access to modern energy services by 10 percentage points to almost 25%, and since 2004, the number of countries in favor of renewable energy with supporting policies and creating renewable targets to meet have tripled from 48 to 140[11], and as their policies become more ambitious, these countries intend to include renewables in heating, cooling, and transport.

Besides the common renewable energy sources, there is an additional source that can be generated both through fossil fuels and from renewable sources. Hydrogen has been a part of humankind for a long time, it contributed to the lift-off of airships and balloons in the 18th and 19th centuries, and was also an active factor that launched humankind to the moon in the 1960s[20]. Additionally, the demand for hydrogen, according to the International Energy Agency, has been growing ever since (*see Appendix 1*).

Currently, the production of hydrogen is not clean. However, the technologies to improve its production do exist, and when produced of clean energy, it can have more suitable applications rather than just fuel cars, since it can power trucks and ships while being a key raw material for industries that have few clean alternatives[21]. One can say that even though it can be the energy of the future, its production from renewable sources like wind and solar represent a challenge. This, nonetheless, can also be turned as an opportunity if the market for clean hydrogen is created.

Off-grid renewable energy solutions

The global energy demand grew by 2.3% in 2018, being the fastest growth observed during this decade. Whilst the world is witnessing a transition for more sustainable energy sources, electricity is considered to be the future oil, with a 4% increase in global demand for electricity in 2018 to more than 23 000TW/h[22]. This growth has been driving the share of electricity to 20% of the total final consumption of energy, as a consequence of the increase in renewable energy solutions.

Furthermore, despite the growth in electricity consumption, many regions still don't have access to it. By using a local energy grid that is autonomous and disconnected from the traditional grid, off-grid technology proves that it is possible to get access to electricity without being linked to the national electricity grid[23]. According to the World Bank, 840 million people yet have no access to electricity and 3 billion depend on polluting energy sources such as fertilizer and wood to warm their houses and for cooking.

Furthermore, Nick Butler, in his article for the *Financial Times*, stated that technology will help decrease the figures above. The progress that will be achieved through technology and off-grid electricity will also help decrease poverty, providing people clean drinking water, allow them to refrigerate their food and to participate in the trading economy. Between 2011 and 2016, off-grid renewable energy solutions beneficiaries increased, spanning to more than 133 million people, according to an IRENA report from 2018.

The off-grid energy system offers independency from the centralized national grid, which then translates into more reliable and sustainable energy to households. This renewable energy source has a significant attraction to families, due to its simplicity. It's an adaptable system that enables access to public services, it's cost-competitive and environment speaking, it has zero emissions and climate resilience (*See Appendix 2*)[24].

Micro-grid in Africa

The micro-grid energy system is a small network of energy producers (solar PV and wind) and users with a distributed system, different from a usual centralized power system. It is built independently of any larger grid, where supply and demand are balanced locally in real-time. Solar and wind power generate their energy and batteries keep surplus supply close to its final purpose, meaning that energy surpluses are stored and used afterward to give power in times of no wind or sun[25].

The contrary of what people may think, the Energy Transition is not being led by the US and Europe, since according to the Bloomberg New Energy Finance (BNEF), the majority of renewable energy projects were established in developing countries, shifting the observed trend of the last years[26].

When thinking about electricity in Africa, one can say it’s either based on small household solutions or large, grid-connected power plants, creating a gap. According to the International Energy Agency, micro-grids will give140 million people access to electricity in Africa by 2040, which will require rapid micro-grids expansion[27]. In 2015, a coalition of African governments and the African Union set a goal to deploy 300 gigawatts of renewable energy by 2030[28], and despite being an ambitious goal, from the developments made in technology, micro-grid can be a good tool to get Africa close to it.

Additionally, as stated by Adam Green, emerging markets and the fact that prices of wind and solar power technology are decreasing rapidly have moved investment towards green power, and therefore, even countries with no experience in renewable infrastructure are making good progress especially in solar projects.

With renewable energy and off-grid systems, developing countries can leverage the technology available to accelerate the accessibility of electricity, which will then motivate the development of many sectors driving the economy to a better state.

Energy in Mozambique

Mozambique is a large country, with over 800 000 km^2 of land and a long 2500 km coastline[29]. Located in the south of the African continent, it has more than 30 million people[30], and despite its abundant resources, it's acknowledged as one of the poorest nations worldwide. It shares its borders with several countries, Tanzania by the north, the Mozambique Channel and the island of Madagascar by the east, Swaziland and South Africa in the south and southwest, to the west with Zimbabwe, and the northwest with Zambia, Malawi, and Lake Nyasa[31].

Energy sector

According to Power Africa Fact Sheet, from all of the Southern African Nations, Mozambique is the one with the highest potential of power generation, as it could generate about 187 gigawatts of power from its hydro, wind, gas, coal resources, including solar[32]. Until now, most of the energy produced in the country comes from projects using hydro resources, where 83% of the installed capacity is consumed[33].

Mozambique has made significant efforts in recent years in improving access to electricity in the national territory. Nevertheless, according to the World Bank, until 2017, only 27.43% of the people in Mozambique have access to electricity.[34] (*See Appendix 3 - graph*)

Despite being a country in which more than half of the energy supply had come from renewable sources, and that fossil fuels gained value in its energy mix portfolio later, the Mozambican government is aware of the energy transition phase that the world is going to and the need to diversify energy sources.

The national electricity grid is inadequate to satisfy the energy demands of the population, and with the increase in energy consumption, the Government has set a goal to intensify the access to electricity for more households and companies by 2030[35]. Off-grid projects with smaller capacity are being directed by the Mozambique Energy Fund Institute (FUNAE) for the installation of electricity in rural areas, far from the national grid[36]. Moreover, Independent Power Producers (IPPs) that started in 2015 have also grown are helping electrify communities in that southern African country.

Furthermore, according to the Ministry of Energy and Mineral Resources, with its purpose to increase the access to electricity, as of 2019 the Government is amenable to open the production, distribution, and commercialization of electricity to foreign companies, as a way to provide more efficient services in the energy sector[37].

Moreover, new large-scale projects related to energy production have started as a way to meet the energy consumption of 14 billion kWh (2018)[38], such as a natural gas combined-cycle thermoelectric power plant with a capable of producing 106 megawatts and, according to deputy minister of mineral resources and energy, the plan to initiate the construction of a new hydro dam that is going to be controlled by both *Eletricidade de Moçambique* (EDM) and *Hidroelétrica de Cahora Bassa* (HCB)[39].

The national entity, *Electricidade de Moçambique* (EDM), is the one accountable for the national grid system, as well as the production and distribution of electricity and its one of the 3 production players in the energy sector in Mozambique (*See Appendix 4 - table*). In terms of production, the country’s largest power generation plant is *Cahora Bassa*, capable of producing 2,075 MW, which is located in the Zambezi river. It’s the largest hydro dam in southern Africa[40] and is operated by *Hidroelectrica de Cahora Bassa* (HCB).

Renewable energy

Since the discovery and incorporation of fossil fuels in the Mozambican energy mix, data from the World Bank show that the percentage of renewable energy in the total energy consumption has been shrinking in the last years, going from 94.3% in 1991 to 86.4% in 2015[41] (*See Appendix 5 - graph*). Nonetheless, renewable sources still represent a huge part of the country's energy mix[42].

The current portfolio of renewable energy in Mozambique is composed of hydropower, modern biomass and traditional biomass. Traditional and modern biomass resources account for 79.2% of the total energy consumption. Additionally, according to ALER's national status report, even though *Cahora Bassa* is the largest hydroelectric in the country, its production is mostly exported to South Africa and Zimbabwe, leaving it with a small contribution to the country's energy matrix of only 9.6% of total energy consumption.

As affirmed previously, the country has made significant efforts and according to the Government Portal, in 2017 the Mozambique Energy Fund Institute (FUNAE) decided to launch a US $ 500 million portfolio of renewable energy projects with the purpose to electrify 332 villages across the country. This is part of the goal to achieve an universal access to electricity, using hydropower through mini-grids technologies set to generate a total of 1,013.12MW, along with 343 projects using solar photovoltaic panels, of which 10 medium-sized mini-grids (1 to 3MW), 111 micro or mini small networks (1 to 100 kW) and the rest, automated with systems[43].

The Ministry of Mineral Resources and Energy created an integrated master plan for the Mozambican power system development. This program will be divided into two stages. The first stage will focus on meeting domestic energy demand in both systems, the Southern region, and the Central & Northern system. The second stage will have projects for an integrated system, and where 20 % of domestic peak demand will be exported with the help of gas-fired power plants installed to strengthen electricity export to the region (*See Appendix 6 - tables*)[44].

Furthermore, according to the integrated master plan, the government also has clear projects for renewable energy generation to implement. There are 5 development plans, including some theoretical plans, consisting of 2 solar power generation projects, 1 wind power generation project, and 2 biomass power generation projects. One of the solar power generation projects was already in construction at the time, with operations scheduled to start in 2019 (*See Appendix 7 - table*).

Renewable potential

Mozambique has a lot of potential in the value chain of energy production using renewable energy. Its area of over 800,000 sq. km and cost the 2,500 km long coastline[29] is where many renewable sources stand, from the most used hydro resource to waves resources.

According to the Renewable Energy Atlas of Mozambique, the country has a renewable production capacity of more than 23,000 GW, and from the potential 23,026 GW to be precise, it’s possible to see from the graph below, that solar energy potential being the most abundant resource in the country of it with 23,000 GW, followed by hydro, wind and biomass[45].

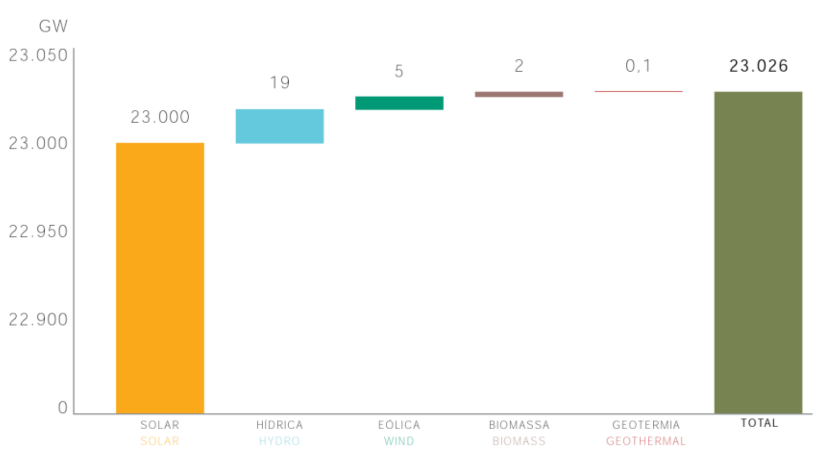


Image 2*: Identified Renewable Potential of Mozambique*

According to the Renewable Energy Atlas of Mozambique:

- Solar resources

The tropical climate of the country enables it to have an abundant solar resource across the territory and consistent during the year. Solar, with a total potential of 23 TW, is the primary renewable resource (*See Appendix 8*), that be generated in the large empty fields over the country. Furthermore, throughout the energy transition phase, and due to the decrease in installation costs on Solar PV technology, the solar resource is becoming an even more attractive option when thinking about electrification in Mozambique.

- The hydro resource

The northern region of the country has one of the highest energy potentials due to a better flow, land morphology, presenting sites with high head and for being rainier than other regions. The greatest potential for production is along the Zambezi River, and throughout the country, there have been identified more than 1,400 projects were identified and studied, corresponding to a total of 18.6 GW of hydroelectric potential, of which 351 projects, 5.6 GW, are economically viable without overlaps (*See Appendix 9*).

- Wind resource

In the south of the country and the uplands of the Center and North, winds can reach a high speed, giving those regions more potential for Wind energy. Over a year of measurements, 16 sites with a total of 4.5 GW of wind potential were confirmed in the Center and South of the country. Of these, about 1.1 GW have feasibility for grid connection and equivalent production hours between 2,300 and 3,900 hours (*See Appendix 10*).

- Biomass Resource

The vast hectares of forest in the country provides a variety of 6 biomass resources, where the forest biomass and the sugar cane industry, utilization of the residual bagasse resulting from the sugarcane crushing process, are considered the principal ones. This resource has a higher potential in the north of the country as a result of higher rainfall levels and favorable climate conditions and with a total territory potential of 2 GW (*See Appendix 11*).

- Wave resource

Despite the country's extensive coastline, its wave resources for power generation are limited, mostly due to a dissipating effect of Madagascar and the Mozambique canal. The only potential is located on the coast of Inhambane, with indicators of about 10 kW/m (*See Appendix 12*).

- Geothermal resource

The country has a complex geological history, and the provinces with geothermal occurrences are Tete, Manica, Sofala, Zambézia, Nampula e Niassa. Throughout this structure, geothermal discharges occur in the form of thermal springs and reach temperatures that in some areas exceed 600C, existing even a historical record temperature of 950ºC (*See Appendix 13*).

With this said, one can see that Mozambique has a tremendous potential to develop electricity through renewable resources. Furthermore, the country's energy sector is expected to grow further with the introduction of a US $ 500 million portfolio fund for renewable energy projects, along with good energy policies and regulations. As a consequence, this renewable development process can bring new players in the market, consumers who will start producing part of their electricity, the prosumers.

Microgrids and self-consumption in Mozambique

In countries where the grid distribution is inefficient, micro-grids play an important role in providing access to electricity, as a result of an increase in micro-grid projects[46].

One can say that with the features of a rapid energy transition[47] and the constant decrease in the price of Solar PV panels[48], self-consumption, the use of PV electricity aimed at reducing the electricity bill and increase energy efficiency, is a scenario bound to be seen with more intensity.

Furthermore, as these technologies develop, one can only assume that developing countries may engage in leapfrogging[49], having the advantage to leverage existing technologies and jump to a new and better consumption era. The accessibility of clean energy has a positive effect on people's lives.

With a self-consumption photovoltaic system, owners can decrease their electricity bills by using the energy produced by the solar PV's, and if needed, consume additional power from the grid. A small version of a PV system with micro-inverters is very practical that can also be installed on smaller places like garden sheds, garage roofs, facades, balconies as well as on areas with partial shading, allowing owners to reducing their electricity consumption[50].

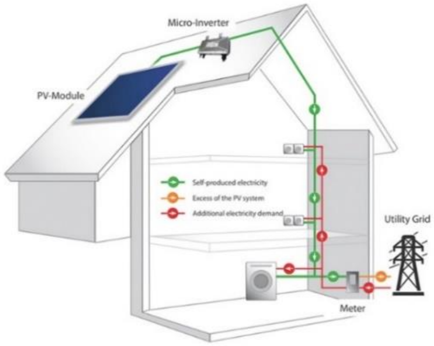


Image 3: *Example of self-consumption energy flows*

As we move forward, consumers will become prosumers, electricity consumers producing electricity for their consumption (Lettner et al., 2018)[51], and with an increase in retail electricity prices, the grid parity will soon be achieved (Goy and Sancho-Tomás, 2019)[52]. The figure below illustrates the ration named self-consumption relative to the production of energy and daily consumption[53].

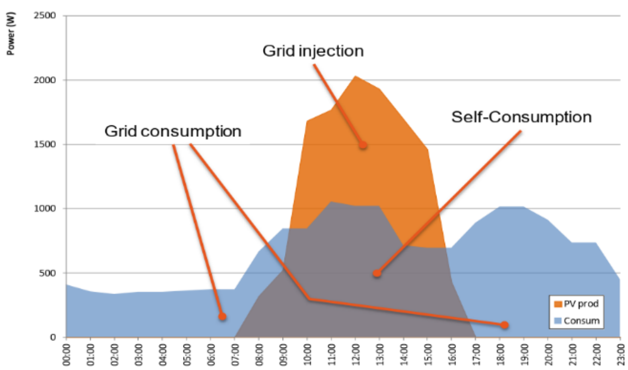


***Image 4**: Comparison of production and consumption profiles*

Off-grid electrification in Mozambique and its impact

In Mozambique, approximately 30% out of 30 million people have access to electricity[34]. One can say that this is due to a lack of infrastructure by the national energy company EDM (*Electricidade de Moçambique*), and it's true.

However, additionally, the majority of rural areas in the country cannot be reached because they are too far away and are inhabited by very poor people that may not be able to pay the retail price for electricity access. To overcome these conditions, other ways of electrification should be considered.

Off-grid systems can be an efficient and cost-effective option for easy electrification of many rural areas. With it, small hydropower plants can be built, leading to a decentralized power generation for specific communities (Mulder and Tembe, 2008)[54]. One can only hope that now that renewables are gaining ground in the energy mix of many countries, more people will get access to electricity.

With the government's attempt to give access to electricity to all Mozambicans by 2030[35], many projects have been undertaken since 2017. According to the Renewable Energy Atlas of Mozambique[46], approximately 10,000 villages were identified and studied to have a renewable solution for their electrification, solutions like:

- 100% renewable: jatropha oil engine, wind turbines with batteries, pico-hydro and solar PV with batteries;
- hybrids: diesel with solar panels or wind generator;
- diesel engine (fossil fuel option).

The cheapest and 100% renewable solution is the micro-hydro; however, the different condition of the villages only favors 300 localities that have favorable characteristics, head and flow, and fair distances from villages. Nonetheless, in the rest villages, the least expensive 100% renewable solution is solar photovoltaic using batteries for energy storage.

In their paper about Mini-Grid Hydropower for Rural Electrification in Mozambique, Uamusse et al. (2019)[55] suggested an approach to improve water, energy, and food security at a local level first. They investigated the possibility of installing off-grid small hydropower energy to be sustainable. For it, they decided to do a case study with approximately 200 households of the Chua Village, along the Chua River, in Mozambique.

With a successful implementation of hydropower energy, they concluded that to increase the mini-grid hydropower's profitability, a small-scale business needed to be installed. In this case, a small-scale facility for milling of corn and other cereals was the right fit.

The electricity produced was enough to process the food and to pump water supply to families for their private use and to use it as a small-scale irrigating system for their farm lots. This increased their purchasing capacity of approximately 8 and 19 USD per household and MWh.

These results showed to be an economic local driver and business model for new small-scale hydropower plants, that could be replicated to other rural areas with similar characteristics. Moreover, Uamusse et al. believed that for efficient rural electrification, scale and institutional strengthening are pillars to be considered, since there's a lack in national framework to support small and independent power producers.

With the climate impact risks surrounding the hydropower generation, solar power is an increasingly attractive off-grid electrification option for Mozambique (Baruah and Coleman, 2019)[56]. One can say that the solar photovoltaic (PV) system is considered to be an efficient and cost-effective renewable energy solution for off-grid electrification.

In their paper on off-grid solar power in Mozambique, Baruah and Coleman (2019), outlined the countries' advantages and opportunities for off-grid solar power in the table below:

***Table 1**: Advantages and opportunities for off-grid solar power in Mozambique*

Advantages	Opportunities
• High-quality solar resources endowment across the country • Decrease of solar power costs • Strong government interest in off-grid solar power • Role of off-grid solar power is recognized in major national strategies/plans	• Rapidly falling costs of solar and battery technologies • Increasing retail prices of conventional fuels • Successful regional experiences to emulate from • High penetration of mobile phones and the increasing availability of mobile money

• Rural energy agency FUNAE has considerable experience with off-grid solar power installations • Success stories in Africa to learn from	• Increasing interest from development donors and the private sector • Potential many-fold increase in state revenues from expanding extractive industries that could support the sector's development

Furthermore, the installation of an off-grid solar system for a household costs approximately less than $200 in Mozambique – nearly 6% compared to the ~$3,500 required for a grid connection. Overall, an off-grid connection is becoming cheaper than the retail price paid in some countries, making self-consumption a more profitable choice and a strong incentive for PV system growth (Luthander et al., 2015)[57].

Moreover, according to Luthander et al. (2015), battery storage and demand-side management are two essential techniques to improve the solar PV systems usage. Results show that energy storage increases self-consumption by between 10 and 24 percentage points.

The intensification of solar PV projects and their combination with small storage technologies is a technique that can be used to electrify the communities living in rural areas of Mozambique, far away from grid connection. It's a growing technology that can be acquired to give access to thousands of people

Self-consumption and impact on local energy retailers

The rise in renewable alternatives for electrification is based on the ideas of decentralization, decarbonization. It's a new era that is bringing challenges to traditional energy retailers and disrupting the energy market.

The Mozambican government opened the production, distribution, and commercialization of electricity to foreign companies[37]. In a country where the national energy distribution is insufficient to give more households access to electricity and with, consumers can have a more active role in the energy market as they will be able to choose from different energy suppliers (Fontana, 2016)[58]. Later, consumers will have the power to decide their role in the market, if they only want to buy and consume grid electricity or be part of the network and produce part of the electricity they consume.

One can say that many governments across the globe are opening their energy markets to competition, driving energy reforms. Traditional energy retailers will encounter more challenges with the liberalization for **new entrants**, as they will provide better solar solutions including PV panels, storage devices, and maintenance. This will cause consumers to reduce their grid consumption or even switching to an off-grid system[59], leaving the national energy retailer with fewer revenues and a growing **pressure to reduce margins**.

In the first quarter of 2019, the national utility EDM (*Eletricidade de Moçambique*) introduced an electricity retail price increase[60], to allow the utility company to invest in the expansion of the network and the continuity of quality and secure energy supply. This and the non-ending infrastructural difficulties that the company has will give enough reasons to drive a portion of the population to consider alternative and cheaper energy suppliers.

Overall, the existence of a solution that is based on renewable energy and is proven to be cost-effective compared to tradition energy retail prices will **change customer expectations**.

Recommendation for the government and the companies

One can only assume, based on the impacts of microgrids and future self-consumption, that the national energy utility company is bound to face some challenges, a result of their inefficient grid infrastructure and the liberalization of the market[37].

The increase in electricity prices is also an important factor that will affect customer expectations. However, there are clear opportunities that the utility EDM can leverage and create value for themselves and the community.

Traditionally, self-consumption states that PV electricity is consumed instantaneously or within a 15 minutes time frame, but with net-meters, consumers who generate their electricity partially or totally can use it anytime, instead of when it is generated (Luthander et al, 2015).

The excess electricity is "stored" in the grid and when consumed, the meter then considers only net consumption. Net metering is a policy designed to foster private investment in renewable energy.

Given the impacts mentioned in the previous chapter, the following recommendations are presented:

- **EDM** should leverage the decrease in prices and **invest in solar PV panels**
- The Mozambican government should **determine** specific **members** from the Ministry of Mineral Resources and Energy to **guide** and **supervise** the work of the **new independent energy regulator**, the Energy Regulatory Authority (ARENE)[61]. This will enforce transparent and better decision making, as well as ensure that the new regulatory body is successful in its pursuit.
- Foster **competition**, which forces companies to cut costs to maintain market share and thus preventing price increases, transferring benefits to consumers.

The solar PV system is a proven technology that, with a decline in installation costs[62], is gaining pace and will soon achieve grid parity. EDM could be the pioneer for solar PV daily usage, not only selling it to households in rural areas but also foster self-consumption by providing the equipment and maintenance support.

Leveraging new technology to give access to electricity not only brings a new revenue stream but with the proper adjustments and investments, the equipment sold to households who live in grid reaching areas, will allow EDM to purchase the excess electricity produced, at a lower price or even as a credit in the electric bill, that can be injected into the grid[63], providing more stability to other grid customers.

This re-purchase of energy can be through means of compensation in the electricity bill, and the process of electricity injection from solar PV to the grid is based on inverters. As illustrated below, DC electricity produced by the solar panels is converted into the AC electricity for household consumption, using inverters. The output power is synchronized with the grid voltage and frequency to avoid stability issues and mismatch[64].

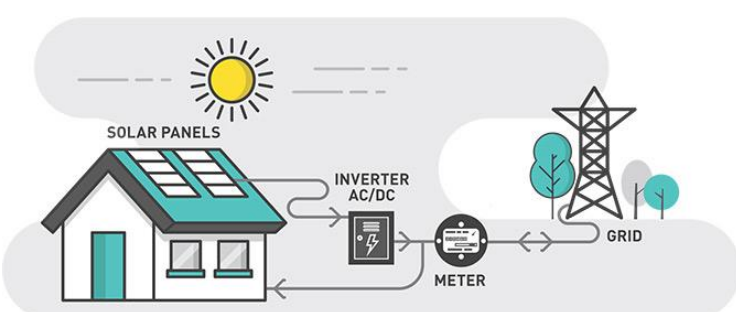


***Image 5**: Energy production and grid injection process*

One can say that in developing countries like Mozambique, good solutions should come with good governmental **policies**.

Moreover, when opening the doors and liberalizing the energy market to address the matter of electrification, it's crucial to take into account the importance of **competition**. It is a measure that forces companies to cut back their costs to compete in the market and maintain market share, thus prioritizing consumer needs, delivering good services and increasing welfare.

Furthermore, in light of the changes happening in the market sector, the Mozambican parliament jointly with the Assembly of the Republic collectively passed the first reading of a government bill to set up the ARENE[65], an **independent entity** to replace the current regulatory body.

ARENE (*Autoridade Reguladora de Energia*), will be a good step towards bringing private investment in energy services and electricity production and consumption to Mozambique. It will be responsible for approving electricity retail prices and tariffs, process applications and issue permits. This and all, since it's still an early phase, needs supervision to ensure the success of the new regulatory body and market effectiveness[66].

Moreover, although regulation is a major success factor, in a country where most of the rural areas are very isolated and difficult to access, it should be light-handed, therefore facilitating investments in rural electrification projects (Aitken, 2014)[67].

Conclusion

The energy transition one can witness is gaining pace to a mature state, where renewable solutions are growing at a faster rate and thus, will soon achieve the grid cost parity, the first tipping point presented by EY's study, where being connected to the grid will cost the same as generating one's electricity through photovoltaic solar panels and storage systems.

Climate change is an issue all countries should address and act accordingly, ensuring ecosystem growth for future generations. Where this transition may be difficult to integrate into one's country's policies and regulations, other countries may benefit from a rapid transition to cost-effective and stable access to electricity.

Hence, one can conclude that Mozambique can leverage the knowledge and expertise of foreign companies to deliver better services with the right policies and regulations. Additionally, it can also allow EDM (*Eletricidade de Moçambique*) to be a first-mover in bringing structured solar PV solutions with maintenance services to the market, giving them the position to grow their business while achieving total access to electricity, one solar panel at a time.

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ENERGY TRANSITION: MICROGRIDS AND THE IMPACT OF SELF-CONSUMPTION IN MOZAMBIQUE

APPENDIX

Valter Enoque Fumo | 24521

A Project carried out on the Master's in Management Program, under the supervision of Professor Luís Manuel da Silva Rodrigues

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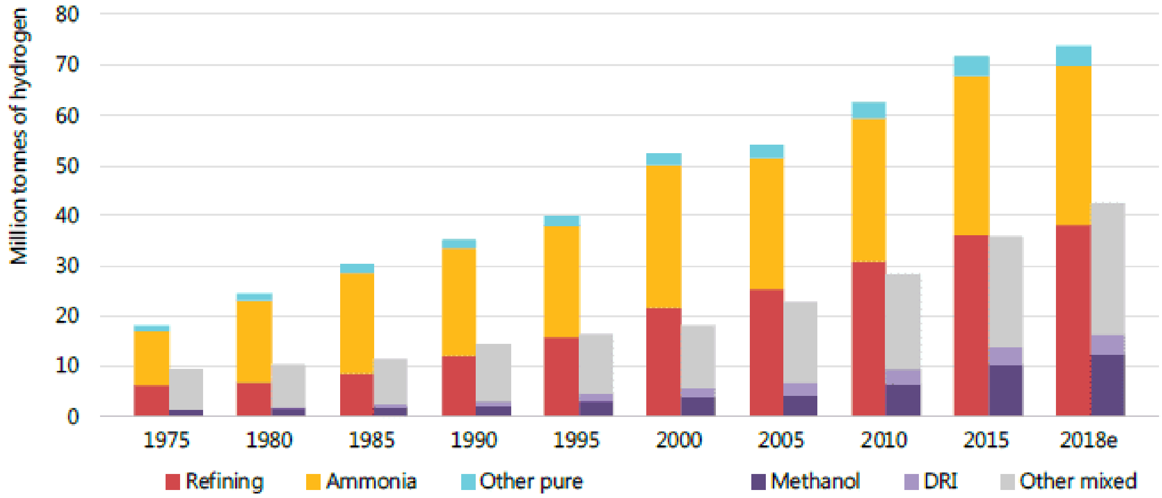
Appendix 1 – Global annual demand for hydrogen

Figure 1. Global annual demand for hydrogen since 1975

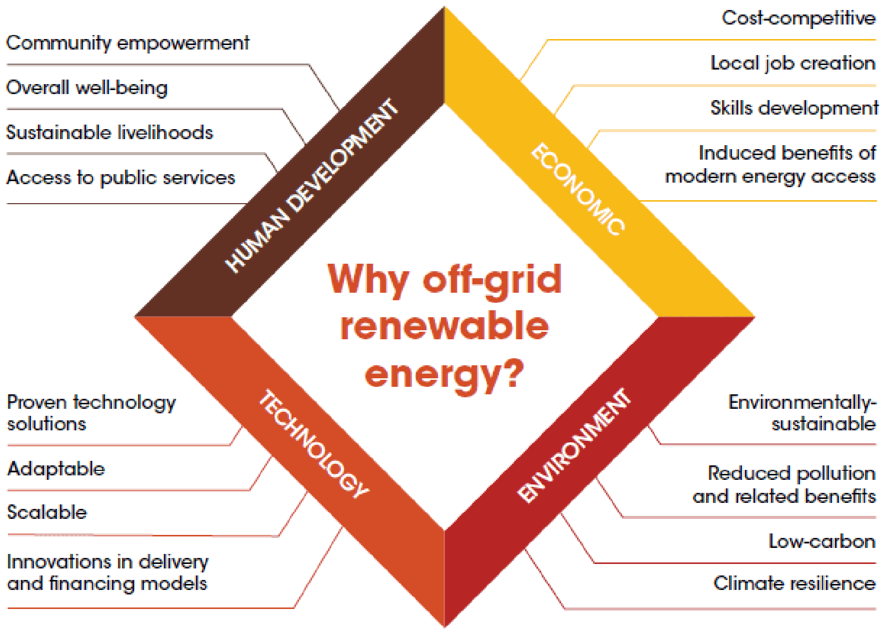


Notes: DRI = direct reduced iron steel production. Refining, ammonia and "other pure" represent demand for specific applications that require hydrogen with only small levels of additives or contaminants tolerated. Methanol, DRI and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

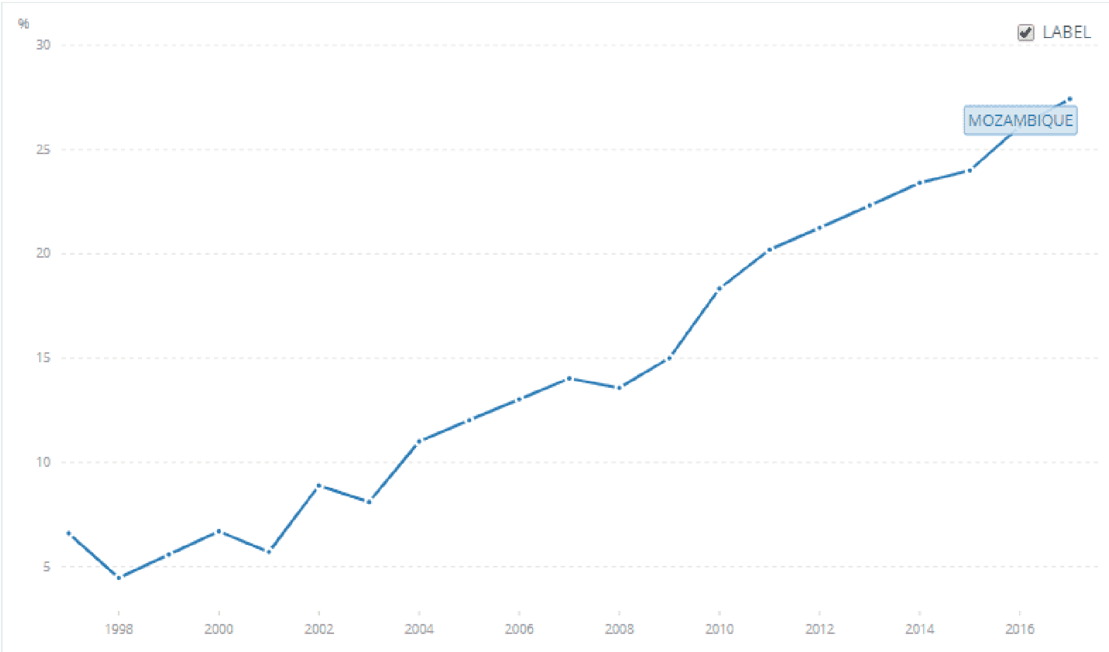
Source: IEA 2019.

Appendix 2 – Off-grid renewable energy solutions

Figure 2: Case for off-grid renewable energy solutions



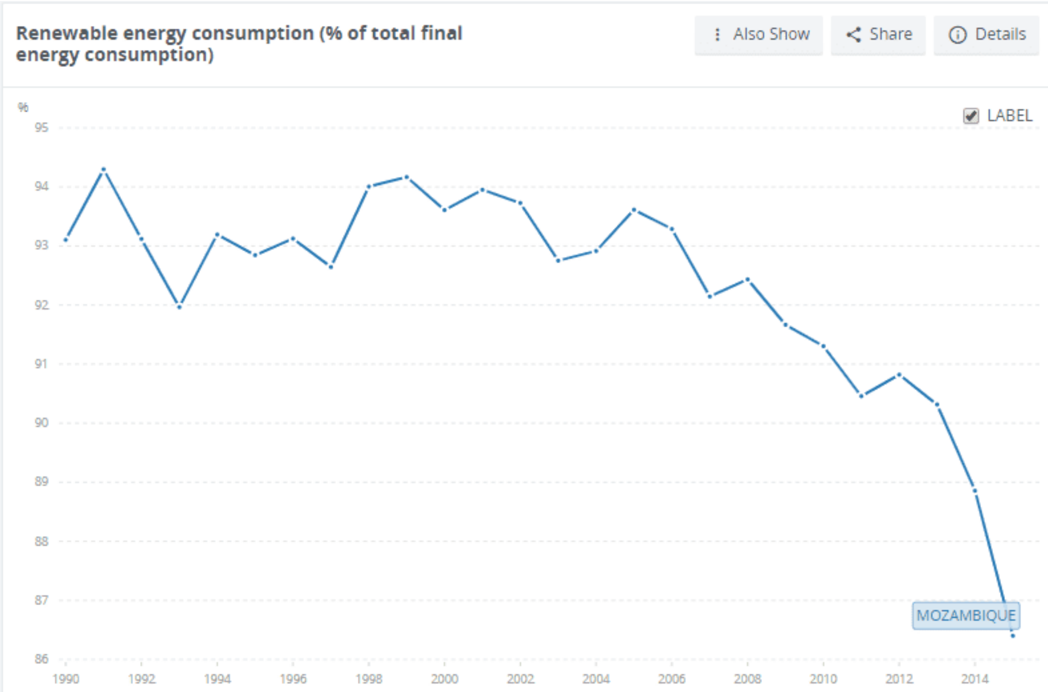
Appendix 3 – Access to Electricity (% of the total population).
Source: Data.worldbank.org



Appendix 4 – Map of the energy players in Mozambique

	Map of the energy players in Moçambique					
Players	Technology	Projects	Value chain	Instaled capacity (MW)	Available capacity for EDM (MW)	Market share (2015)
HCB	Hydro	HCB	Production	2075	500[*2017]	88%
EDM	Hydro	Mavuzi	Production	52	52	6%
	Hydro	Chicamba	Production	44	44	
	Hydro	Corumana	Production	16,6	16,6	
	Hydro	Cuamba	Production	1,09	1,09	
	Hydro	Lichinga	Production	0,76	0,76	
	Gas	Maputo	Production	24	24	
	Oil	Beira	Production	14	14	
	Gas	Temane	Production	11,6	11,6	
IPP	Hydro	Pequenos Lebombos	Production	1,5	1,5	2%
	Gas	Aggreko - phase 1	Production	107	15	
	Gas	Aggreko - phase 2	Production	122	32	
	Resíduos de açucareira (bagaço)	Maranga	Production	1,5	1,5	
	Gas	Ressano Garca Termic Station (CTRG)	Production	171	150	
	Gas	Gigawatt Ressano Garcia	Production	120,9	100	
	Gas	Kuvaninga	Production	40	40	
	Oil	Central Térmica de Nacala	Production	102,5	40	

Appendix 5 – Renewable energy consumption (% of the total energy consumption)



Appendix 6 – Mozambique's Energy master plan

Table 3.1 Generation Development Plan (southern system. 2018-2028)

Southern System										
Year	Peak Demand [MW]	Total Installed capacity [MW]	Hydro [MW]	Diesel [MW]	Gas [MW]	Coal [MW]	Required Additional Capacity [MW]	Solar [MW]	Wind [MW]	Retire [MW]
2017	622	548			40		80			-40
2018	680	628			110		40			-112
2019	800	666					140			
2020	872	806					70			
2021	951	876					250			
2022	1,031	1,126			400		-400			
2023	1,115	1,126			210		-180		30	
2024	1,201	1,186			100					
2025	1,289	1,286			1000			30		
2026	2,239	2,316			100					
2027	2,334	2,416			100				30	
2028	2,431	2,546			100					
Developed Capacity (MW)					2160		0	30	60	-152
			2,098							

Year	Operation Start	Retire
2017	Kuvaninga (40MW)	Aggreko Beluluane (40MW)
2018	JICA CTM (110MW)	Aggreko Ressano (112MW)
2019		
2020		
2021		
2022	Temane (MGTP) (400MW)	
2023	Temane (CCGT - 100MW) CTM Phase 2 - 110MW Tofo (Wind - 30MW)	
2024		
2025		
2026		
2027		
2028		

Table 3.2 Generation Development Plan (central & northern system. 2018-2028)

Central-Northern System											
Year	Peak Demand [MW]	Export [MW]	Total Instaled capacity [MW]	Hydro [MW]	Diesel [MW]	Gas [MW]	Coal [MW]	Necessary additional capacity [MW]	Solar [MW]	Wind [MW]	Retire [MW]
2017	498	1,500	2,308								
2018	725	1,500	2,308					260	40		-102.5
2019	823	1,500	2,506					100	40		
2020	878	1,500	2,646					50			
2021	981	1,500	2,696					110			
2022	1,087	1,540	2,806					110			
2023	1,194	1,540	2,916				650	-370			
2024	1,303	1,540	3,196						30		
2025	1,414	1,540	3,226	50							
2026	1,528	1,540	3,276				300	-100	30		
2027	1,646	1,540	3,506			80					
2028	1,768	1,540	3,586						30		
Developed capacity (MW)				50	0	80	950	160	170	0	-102.5
				1,308							

Ano	Operation Start	Retire
2017		
2018	Mocuba (Solar - 40MW)	Nacala Barcassa (102.5MW) for Mozambique
2019	Metoro (Solar - 40MW)	
2020		
2021		
2022		
2023	Jindal (Coal - 150MW) Nacala (Coal - 200MW) Tete (1unit - 300MW)	
2024		
2025	Tsate (Hydro - 50MW)	
2026	Tete (1unit - 300MW)	
2027	Shell (Gas - 80MW)	
2028		

Sistema Integrado de 2029 até 2042 (Com a Mozal)												
Year	Peak Demand (Domestic)	Peak Demand Export	Installed Capacity	Mphanda Nkuwa	Cahora Bassa	Lupata Boroma	Tete	Hídrica	CCGT	Coal	PV	Wind
				Hydro	Hydro	Hydro	Coal	Hydro	Gas	Coal	Solar	Wind
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
2029	4,283	857	6,132	1,500			300				30	
2030	4,499	900	7,962				300	100			30	
2031	4,722	944	8,392					100				30
2032	4,953	991	8,522			650					30	
2033	5,192	1,038	9,202					100			30	
2034	5,439	1,088	9,332		1,245						30	
2035	5,695	1,139	10,607					100	1,500			30
2036	5,961	1,192	12,237					100			30	
2037	6,237	1,247	12,367					200			30	
2038	6,523	1,305	12,597					100	2,000		30	
2039	6,821	1,364	14,727						400			30
2040	7,131	1,426	15,157						2,000		30	
2041	7,442	1,488	17,187						400		30	
2042	7,770	1,554	17,617					50		400	30	
2043												
Developed Capacity (MW)				1,500	1,245	650	600	850	6,300	400	330	90
				11,965								

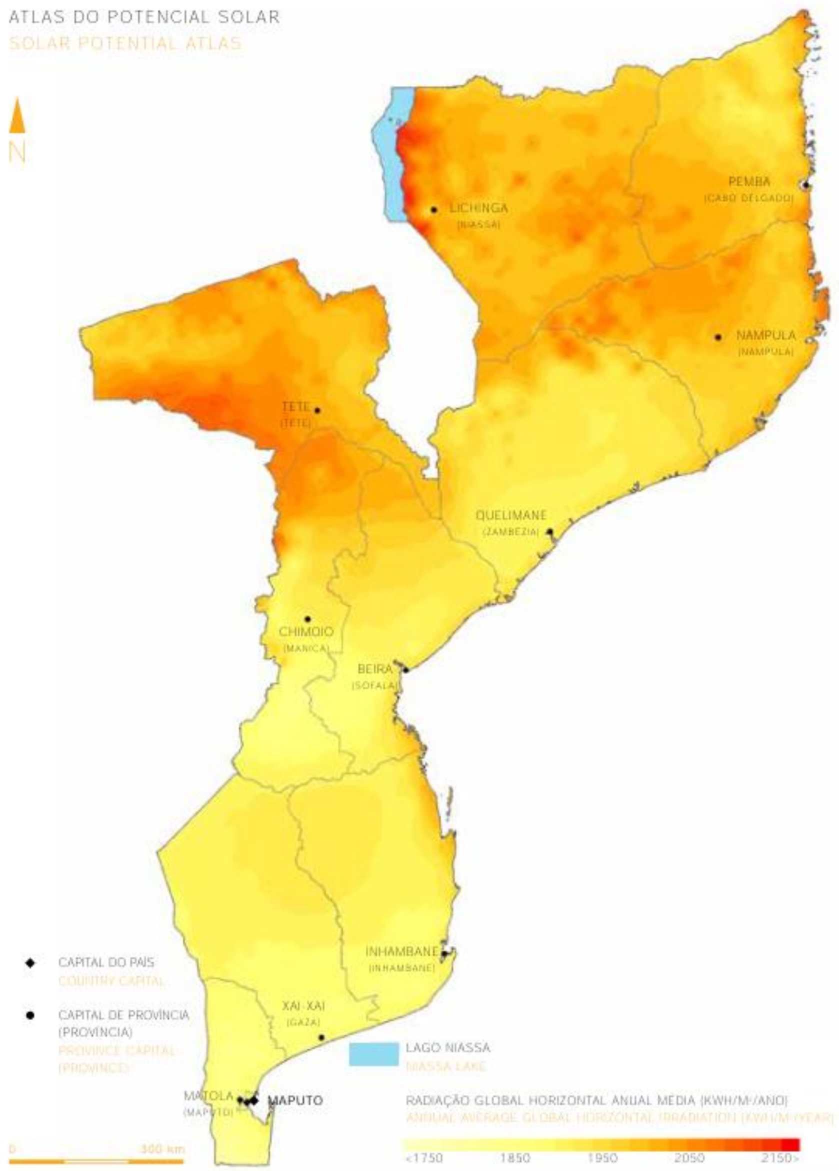
Considered 950MW of Mozal

Appendix 7 – Renewable energy development plans

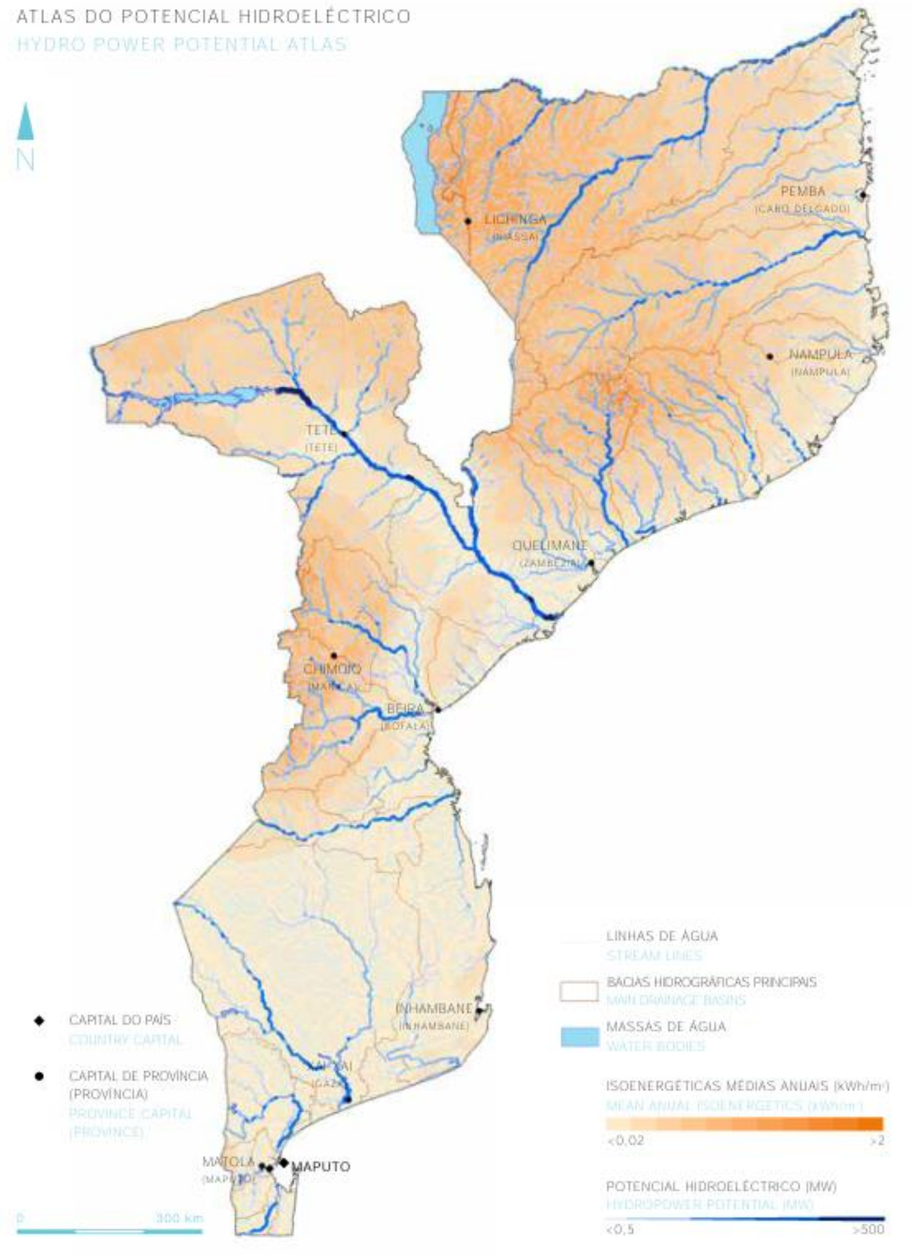
Table 5.4-5 Renewable energy development plans

No	Plant Name	Type	Installed Capacity (MW)	Supply Power to EDM Grid (MW)	Operation Start (COD)	Operation Type	Project Status
1	Mocuba-(PPP)	Solar	40MW	40MW	2018	Day time only	Under Construction
2	Metoro-(IPP)	Solar	30MW	30MW	2019	Day time only	Conceptual
3	Tofo	Wind	30MW	30MW	2023		Conceptual
4	Salamanga-(IPP)	Biomass	30MW	30MW			Conceptual
5	Moamba-(IPP)	Biomass	30MW	30MW			Conceptual

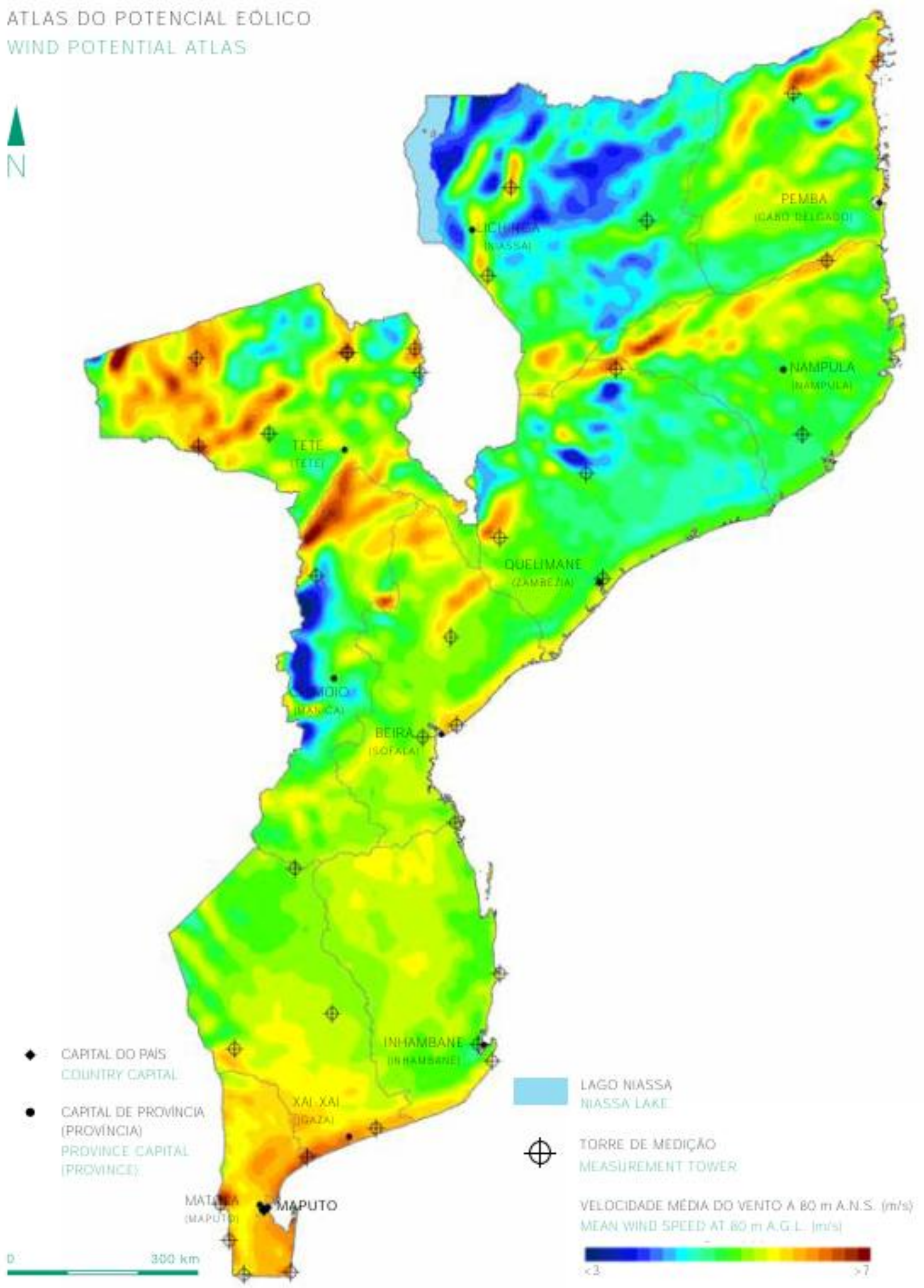
Appendix 8 – Mozambique's solar potential atlas



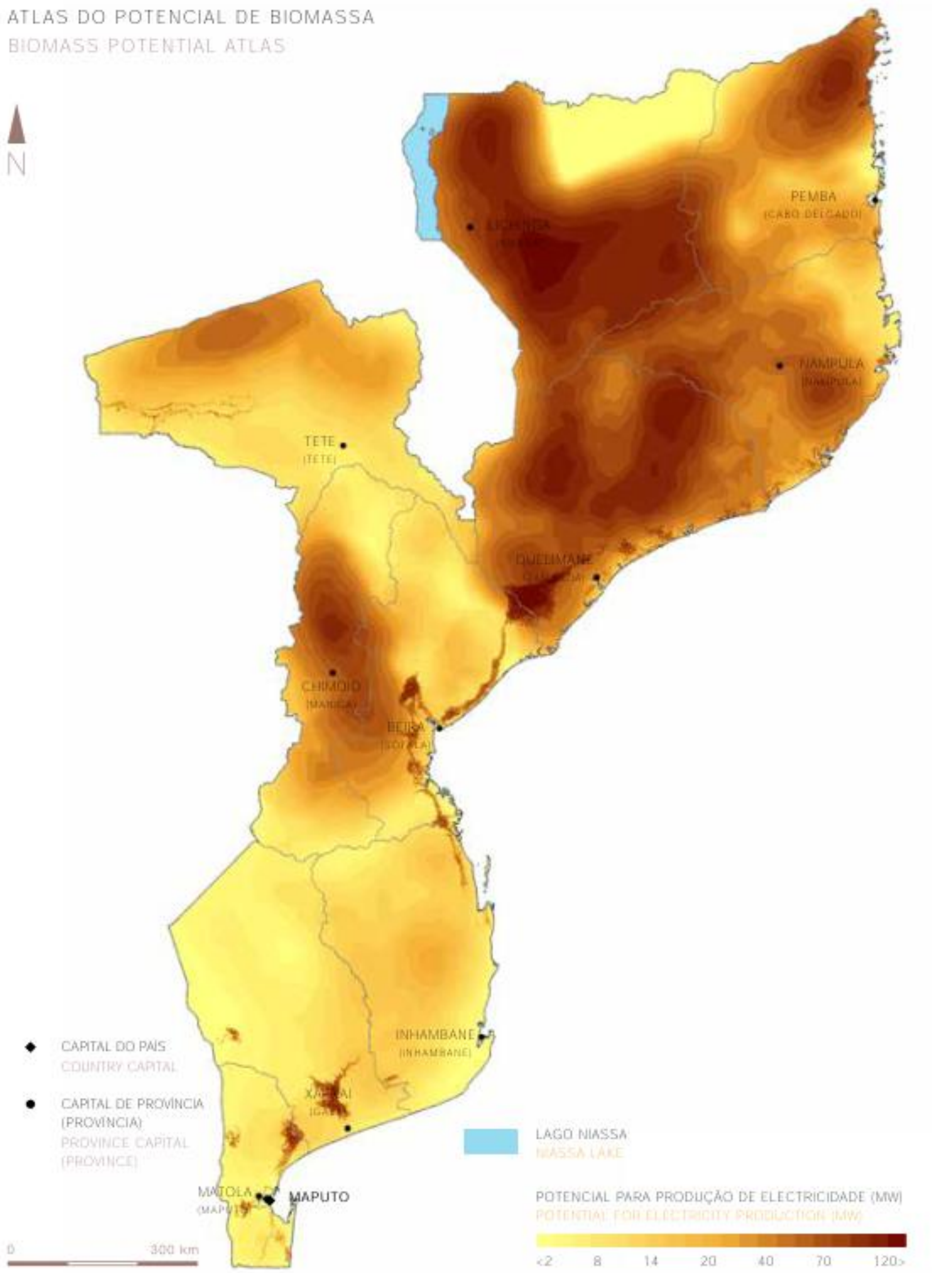
Appendix 9 – Mozambique's hydro power potential atlas



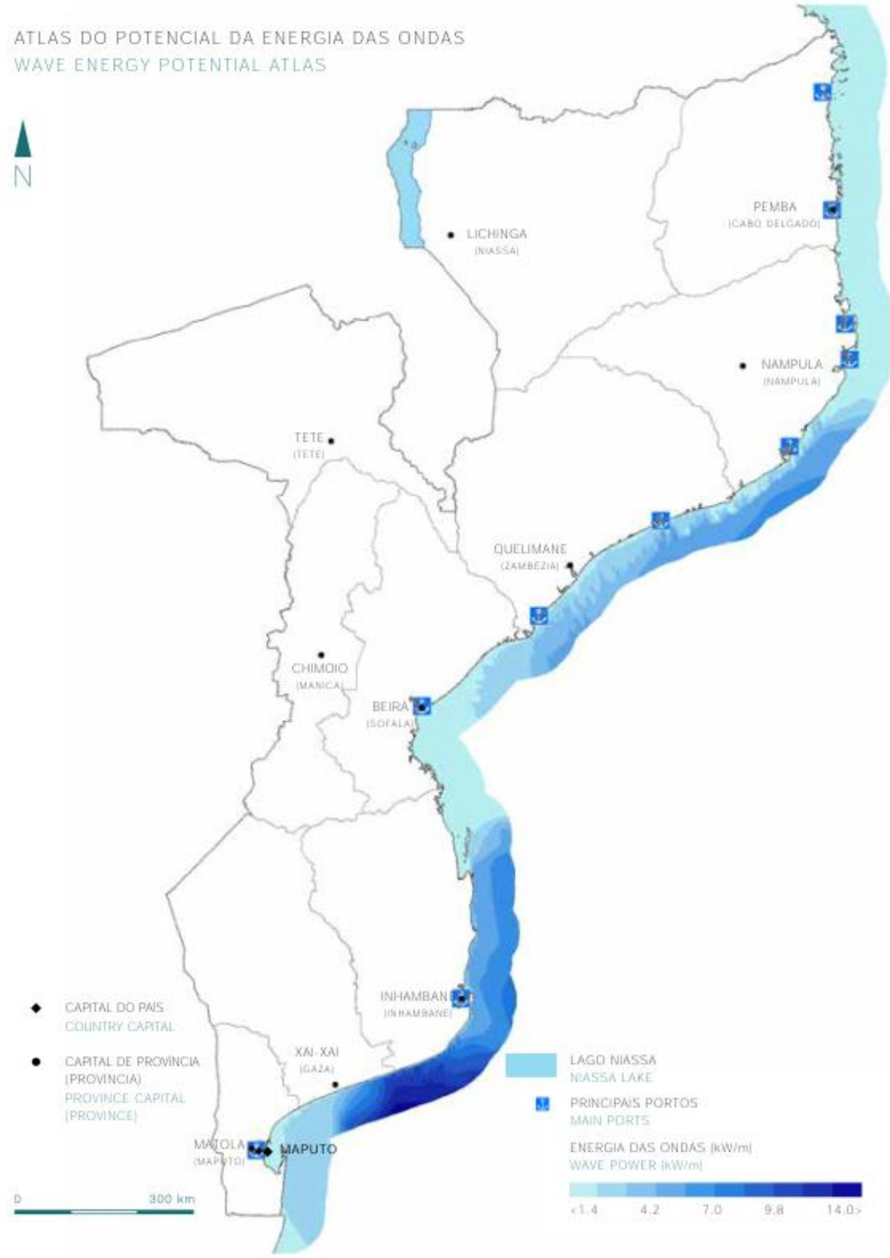
Appendix 10 – Mozambique's wind potential atlas



Appendix 11 – Mozambique’s biomass potential atlas



Appendix 12 – Mozambique' wave energy potential atlas



Appendix 13 – Mozambique's Geothermal potential atlas