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Development of the Energy Balance Statistics and Energy Systems Model for the Union of Comoros

Disclaimer

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List of Acronyms

DEA	Direction de l'Eau et de l'Assainissement
DEM	Direction de l'Energie et des Mines
DER	Direction des Energies Renouvelables
DG	Direction Générale
DGEME	Direction Générale de l'Energie, des Mines et des l'Eau
EDA	Electricité d'Anjouan
EPS	Service d'Etudes, Planification et Statistiques
GDP	Gross domestic product
HFO	Heavy fuel oil
IEA	International Energy Agency
LCOE	Levelized cost of energy
LDC	Least Developed Country
LEAP	Long-range Energy Alternatives Planning
MAMWE	Gestion de l'Eau et de l'Electricité aux Comores
OECD	Organisation for Economic Cooperation and Development
SA	Service de l'Assainissement
SAEMR	Service Accès, Efficacité et Maitrise des ressources
SCA2D	Strategy for Accelerated Growth and Sustainable Development
SCH	Société Comorienne des Hydrocarbures
SE	Service de l'Energie
SEI	Stockholm Environment Institute
SERVP	Service Etudes, Recherche et Valorisation du Potentiel
SM	Service des Mines
SRE	Service des Ressources en Eau
TPES	Total Primary Energy Supply
UNECA	United Nations Economic Commission for Africa

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Executive summary

This report is developed as part of an advisory service request made to UNECA by the Government of the Union of Comoros. The request was for the development of national energy balance statistics to bridge gaps in the energy information system, as well as for the development of a national energy systems model to support energy sector planning, the analysis of the National Energy Strategy and the delivery of capacity development in energy planning. This report focuses on the development of Comoros' first energy balance statistics (for 2017) and on a nationally and regionally disaggregated energy systems model. It also analyses model scenarios on the basis of targets specified in the Energy Strategy 2033.

The energy sector of Comoros is characterized by a reliance on firewood and petroleum products as the two main sources of final energy consumption in the country (which totals 6,487 terajoules (Tj) per year). The energy mix is 57% biomass, 2% electricity and 41% oil products. The role of renewable energy in generation is gradually increasing, but is still negligible compared to conventional energy sources. Considering the different sectors, household energy consumption accounts for 63% of total final energy consumption; the other main sources are the transport sector (32%) and the industrial and commercial sector (5%). Most of the biomass consumed is used for households and restaurants (93%) and ylang-ylang (essential oil) distilling (7%). The petroleum products consumed are all imported and are used for transport, electricity generation and household use. Comoros relies mainly on thermal generation of electricity from fossil fuels (219.11 million kilowatt hours (kWh)), while using some hydro (8.65 million kWh) and minimal solar energy. The high cost of electricity is mainly attributed to the dilapidated state of the distribution grid, which gives rise to over 40% losses in energy transmission. The management challenges of the state-owned utility (MAMWE) and high costs of imported fuel also increase the delivered cost of energy.

To develop the energy balance statistics, the International Energy Agency guidelines were used; energy data was thus gathered at the decentralized level of each island (Grande Comore, Anjouan and Mohéli) and combined for the national energy balance statistics. These statistics indicate that the country's total primary requirements stood at over 7.5 petajoules (PJ) in 2017, over half of which arose in Grande Comore. Nationally, this indicates an average annual requirement of 9.1 gigajoules (GJ) per capita. Among final energy demands, the average annual electricity consumption per person in Comoros was 66.1 kilowatt hours (kWh) per capita. Comparatively, the average electricity consumption across all Least Developed Countries was just over 200 kWh/capita in 2014. The energy intensity of the Comoros economy was USD 0.19 per megajoule (MJ) in 2017, similar to economic intensities observed in other Least Developed Countries. Energy requirements are dominated by wood and other biomass, satisfying nearly half of primary energy needs in 2017. This is followed by diesel consumption, which is also used for power generation. Gasoline and kerosene are important fuels for transportation, and households also rely on kerosene for cooking needs. All petroleum products are imported.

The Energy Strategy 2033 of the Union of Comoros specifies targets to be achieved. On the basis of the national and regional energy systems model developed in the Long-range Energy Alternatives Planning (LEAP) tool, five scenarios from the strategy are analysed to demonstrate a pathway for their achievement. The first is a Reference Scenario based on historic growth trends. The second is the National Energy Independence Scenario, which requires the share of renewable energy to increase to 10% by 2018 and 55% by 2033. To achieve the required dispatch mix, the national installed capacity of renewables on each of the islands was 9.4 MW, based on baseline electricity demand projection.

The third is the Accelerated Electricity Access Scenario, seeking to increase electrification to 60% by 2018 and 100% by 2033. To meet this goal, electricity demand would increase by 55% in 2033 to 135 GWh, requiring Comoros to generate an additional 23 MW power capacity to satisfy the demand. The fourth is the Biomass Energy Transition Scenario, seeking to reduce the contribution of wood fuels in the country's overall energy consumption to 65% by 2018 and 25% by 2033. In implementing this policy, Comoros would be able to save 20% of total final energy demand from the baseline and reduce total wood requirement for final energy delivery by 64%. The rise in LPG demand in this ambitious scenario requires concerted action and active private sector involvement.

A Combined Scenario analysis is also conducted for all these policy measures. On the supply side, the National Energy Independence scenario results in the decrease of electricity generation by 25% (from 145 GWh to 109 GWh) in 2033. This is attributed to grid stabilisation and reduced grid losses. The Biomass

Energy Transition (BIO) scenario has minimum effect on electricity supply. The Accelerated Electricity Access Scenario steeply increases electricity demand, increasing the generation requirement to 226 GWh – 56% higher than the Reference Scenario. But a combined implementation of the Accelerated Electricity Access and National Energy Independence scenarios keeps down the increase to 17%. This is attributed to the savings from an enhanced grid network and a more efficient renewable energy technologies mix.

In conclusion, the energy balance statistics for Comoros (2017) showed that 51% (or 3,820 TJ) of the total energy consumed is imported, while 49% (or 3,742 TJ) is generated within Comoros. Most of this generated energy is the firewood used in the residential sector for cooking. The total primary supply of energy on each of the three islands was 4,392 TJ for Grande Comore, 2,759 TJ for Anjouan and 411 TJ for Mohéli in 2017. However, an average of 13% of this energy is lost during transformation, transmission and distribution. Comoros has a great opportunity to reduce these losses through grid stabilisation.

The projections indicate that Comoros' energy demand up to the year 2033 will grow from 6,597 TJ in 2017 to 11,189 TJ in 2033 in the baseline (reference) scenario. This would be met by 9,383 TJ in total energy supply, made up of 72% oil products, 22% biomass and 6% renewable.

The following key recommendations are made to strengthen the country's energy planning capacity and relevant energy statistics:

1. Based on the 2017 Energy Balance Statistics developed at island and national levels, subsequent updates and reporting of energy balance statistics should be pursued by organizing national data in accordance with the baseline balance statistics established and the IEA guidelines.

2. Strengthen the Energy Planning Unit within the Directorate General of Energy, Mining and Water as a hub for collecting and organizing energy sector data and to implement the national energy systems model to respond to energy sector policy and planning requirements.

3. Support institutionalization of the annual production of the national Energy Balance Statistics report by the Directorate General of Energy, Mines and Water Resources.

4. Maintain a national biomass inventory to support evaluation of sustainable biomass use and improve on biomass energy planning.

5. Conduct additional data gathering to fill the gaps in the developed national and regional energy systems models to improve the accuracy of the model for policy and planning uses.

Finally, it is essential that Comoros continually build capacity in all energy sub-sectors and relevant government agencies if the country is to achieve the National Energy Strategy and Agenda 2030 Sustainable Development Goals, particularly goal #7 on energy.

Acknowledgements

This report was developed upon receiving an advisory service request of the Government of the Union of Comoros, following the Intergovernmental Committee of Experts annual meeting (in November 2017) of the UN Economic Commission for Africa (UNECA), Sub-Regional Office for Eastern Africa (SRO-EA). To meet the request, this report on the development of the Energy Balance Statistics of Comoros, and a separate national energy systems model using LEAP, were developed and delivered.

The implementation of the advisory service request was coordinated and guided on behalf of the Government of the Union of Comoros by Mr. Ali Ibrahim Maziada, the Director General of Energy, Mines and Water Resources, under the Vice-President, in charge of the Ministry of Economy, Planning, Energy, Industry, Craft, Tourism, Investment, Private Sector and Land Affairs. Mr. Yohannes Hailu, Energy Policy Expert at UNECA, SRO-EA, conceptualized (in tandem with Comorian experts), developed and led the implementation of the project, under the support and overall guidance of Mr. Andrew Mold, Acting Director of SRO-EA. The support initiative for Comoros was coordinated with Ms. Daya Bragante of SRO-EA, who undertook advisory service on the Blue Economy.

The implementation of the Energy Balance Statistics and the development of the Comoros energy system model in LEAP required partnership with the Stockholm Environment Institute's (SEI) Africa Centre. SEI's implementation effort was led by Dr. Rocio A. Diaz-Chavez, Deputy Director and Energy and Climate Change Programme Leader. Mr. Mbeo Ogeya from SEI's Africa Centre undertook the technical analyses and report development.

The development of Comoros' first Energy Balance Statistics required the gathering of extensive energy sector data from Grande Comore, Anjouan and Mohéli. The data gathering and extensive project coordination support were provided by Mr. Omar Mssoma and Ms. Mariama Chabane from the Directorate General of Energy, Mines and Water Resources. Data gathering support in Anjouan and Mohéli were supported by Mr. Abdoulmajid Youssouf and Mr. Abdoulatif Boina. Dr. Ali Moissi, from the Directorate General of Energy (in charge of Energy Planning), provided immensely useful support with the provision of valuable energy sector data and studies. Mr. Mbeo Ogeya developed a template for the gathering of relevant data for the development of the Energy Balance Statistics and undertook the extensive data gathering effort. Ms. Priscilla Lecomte of UNECA, SRO-EA, ably supported the energy data gathering effort, as well as provided valuable support in facilitating interpretation and stakeholder engagement.

Mr. Mbeo Ogeya and Mr. Taylor Binnington, from SEI's U.S. Center, co-conducted the national energy planning training, as part of this initiative, which is appreciated.

The full support of the Ministry of Foreign Affairs, Directorate General of Statistics, National Society of Hydrocarbons, the national utilities of MAMWE and EDA, power plants, Geological Bureau, Directorate of Environment and the General Commissariat of Planning are greatly appreciated.

1. Introduction

Country background

The Union of Comoros is a sovereign nation in the Indian Ocean off the coast of Africa, between Madagascar and Mozambique. It is the third smallest African country with an estimated population of 828,147 in 2017 and an annual average population growth rate of 2.7%. The population is distributed among the three islands; 51% reside in Grande Comore (Ngazidja in Swahili), 42% in Anjouan and 7% in Mohéli.[1] Moroni, on Grande Comore, is the national capital, with an estimated population of 55,000. The urban population stands at 28.5% of the total population, and the annual rate of urbanisation stands at 2.71%.[2]

The United Nations classifies Comoros as among the Least Developed Countries (LDCs). Comoros' economy is similar in structure to other developing countries. However, it has high diaspora remittances, which contribute to over 20% of the gross domestic product (GDP) (UNECA, 2017). Unemployment is a challenge, particularly among the youth; more than 50% of those between 15 and 24 years of age lack gainful employment. The country has a gross national income per capita of USD 1,467 in 2017 and an average annual GDP growth of 5% (Figure 1). A high growth to 10% was recorded in 2013 and then fell to 2% in the year 2015, followed by a slight rise to 4% in 2017 and 2018. The United Nations Economic Commission for Africa (UNECA 2017) reports that this recent growth is partly the result of a concentrated effort by the current government, which has set out to revive public investment. However, the country's economy has not managed to achieve structural transformation. In its economic growth blueprint – or the Strategy for Accelerated Growth and Sustainable Development (SCA2D) – the government articulates how it will revamp the national economy. The strategy is anchored on three main growth pillars: a) the acceleration of the structural transformation of the economy and sustainable management of the environment; b) the acceleration of the development of human capital and promotion of social welfare; and c) the consolidation of governance and promotion of the rule of law.

The country's total land area is 1,861 square kilometres. About 71.5% of the total land area is arable, and a further 20% of the land is forested (FAOSTAT, 2018). Agriculture is the primary driver of the economy with

Figure 1: Real annual growth rate in Comoros

Source: Country profile of the Union of Comoros (UNECA, 2017)

1 This population projection was provided by Directorate of Statistics during a data collection visit.
2 https://www.indexmundi.com/comoros/demographics_profile.html

about 80% of the population engaged in agricultural activities. It forms the primary economic sector, which also includes silviculture and fisheries. Exports of agricultural products accounted for 32% of GDP in 2017 – fully 90% of total national export income. Food crops such as banana, cassava, sweet potato, taro, potato, legumes, maize and coconut are grown for domestic purposes. Main agricultural exports include vanilla, clove and ylang-ylang essential oil. The country imports virtually all its animal products and vegetables. The sector has a high potential for economic transformation through agri-based industries and enhanced food security and nutrition. In the national strategic plan, agriculture, livestock farming and fishing are important levers in the fight against unemployment among young people. The SCA2D strategy includes goals to sustainably increase agricultural production by developing ecologically intensive agriculture.

Overall aims and specific objectives of this study

The Comoros Energy Strategy identifies energy information as a key challenge to achieving the country's development strategy (SCA2D). To bridge this challenge, the Comoros government seeks to develop energy balance statistics, to use as the evidentiary basis for long-term scenario analyses based on the country's energy strategy. This report summarizes the outcomes of a data collection process spanning all economic sectors in Comoros. The historical energy balance of Comoros, in an overview of the energy production, consumption, trade, and transportation across all sectors is then presented. This energy balance is then used to identify gaps or other inconsistencies in the collected data, in order to develop a complete picture of energy flows in the country.

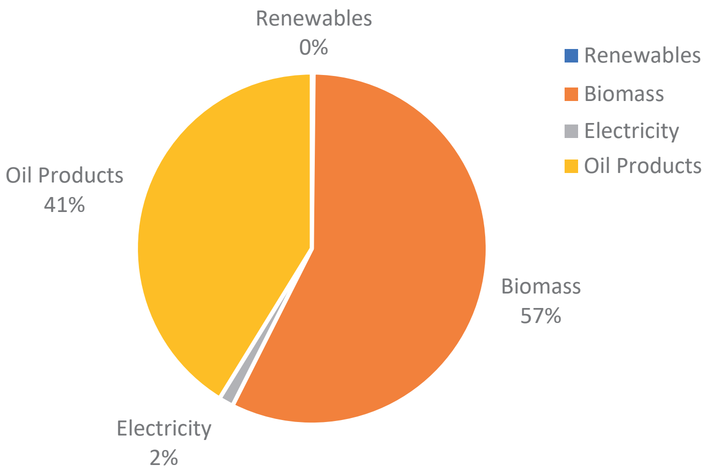
To generate a national energy balance, SEI's Long-range Energy Alternatives Planning system, or LEAP, is utilized to develop a historical representation of Comoros' energy system (Heaps, 2018). LEAP is a flexible, scenario-based planning tool for conducting energy demand and/or supply analyses, as well as for developing cost-benefit assessments and emissions projections. Specific objectives of the study included:

- Development of energy balance statistics, based on international standards;
- Development of a scenario analysis, on the basis of the energy strategy; and
- Capacity development to support energy balance developments.

Description of the energy system

Firewood and petroleum products are the two main sources of final energy consumption in the country (6487 terajoules (Tj) per year). The energy mix is 57% biomass, 2% electricity and 41% oil products. Solar photovoltaic (PV) for power generation is gradually entering the market but is still negligible compared to conventional energy sources. Considering the different sectors, household energy accounts for 63% of total final energy consumption; the rest is from the transport sector (32%) and the industrial and commercial sectors (5%). Most of the biomass consumed is used by households and restaurants (93%) and ylang-ylang distilling (7%), while other activities such as drying vanilla comprise a negligible share. The petroleum products consumed are all imported and are used for transport, electricity production and household use. The country mainly relies on electricity from using fossil fuels (219.11 million kilowatt hours (kWh)), while using some hydro (8.65 million kWh) and minimal solar energy. Fossil fuel use is very expensive due to its low economies of scale, and power generation becomes a challenge. The high cost of electricity is mainly attributed to the dilapidated state of the distribution grid, which gives rise to over 40% losses in energy transmission. The management challenges of the state-owned utility (MAMWE) and high costs of imported fuel also increase the delivered cost of energy (Climatetagger, 2012). Comoros has the highest rate of electricity loss and the lowest recovery rate amongst all African countries. In 2015, Comoros lost 48% of the electricity it generated and recovered fees for 33% of energy generated (IEA and OECD, 2014).

Figure 2: National energy mix in 2017



Source: Based on country data gathered

Power cuts and load shedding have been rampant. These challenges are worsened by the lack of a strategy and appropriate institutional framework, inadequate human resources, the small size of the market and high diesel cost (Economic Management Guidelines, 2009). This shows the magnitude of the energy crisis in the country and the need to look for short-, medium- and long-term strategies. The urgency is reflected in the African Development Bank's decision to focus solely on the energy sector in its 2011-2015 Comoros country strategy. To overcome this challenge, the government is promoting renewable energies such as geothermal, solar and wind. Solar energy is being targeted, in particular, as among the viable options because the country receives eight hours of sunshine daily (2,880 hours/year) and, on average, 5.0 kilowatt peak (kWp) (Climatetagger, 2012; United Nations Enviroment Programme, n.d.).

Electricity generation and distribution

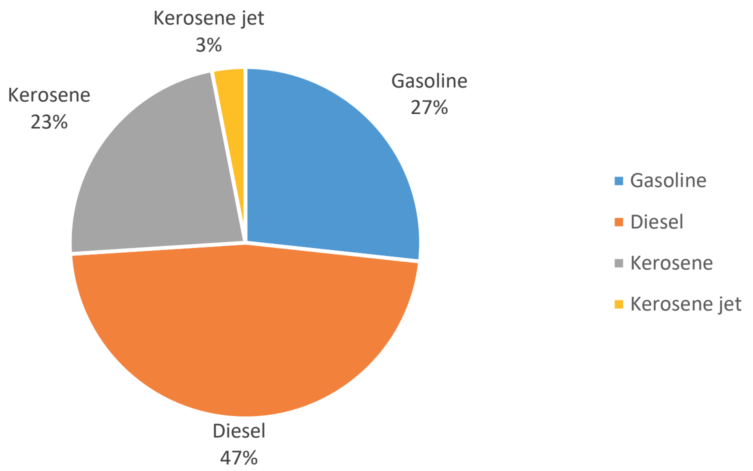
Two utilities generate electricity in Comoros. MAMWE covers Grande Comore and Mohéli, while Electricité d'Anjouan (EDA) covers Anjouan. The cost of electricity generation is currently estimated at about USD 1 per kWh compared with an average of USD 0.075 per kWh in the countries that make up the South Africa Development Community (SADC, 2016). The electricity tariff – or what consumers pay, on average – is USD 0.3 per kWh, indicating a high level of government subsidy.

Grid connectivity in Comoros is above 80% nationally, and about 63% of the total population had access to electricity in 2017 (EU, 2013; Nassurdine, 2018). At the regional level, electrification is 80.2% in Grande Comore, 43.7% in Anjouan and 52.9% in Mohéli. Although this is a high electrification level, real access – as defined by Sustainable Energy for All (2014) – remains a challenge due to various causes, both technical and cultural. Technically, the transmission and distribution networks on the three islands are weak. The medium voltage lines are thin, resulting in high transmission loses of over 40%. Gross losses are reported to be 51% in Grande Comore, 56% in Mohéli and 36% in Anjouan (Nassurdine, 2018). Human capacity to run and maintain the power plants is also a major hindrance, especially in Grande Comore and Mohéli. Generator failure is also a challenge as depicted by the plants grouping the generators without necessarily increasing the capacity (see Appendix 3). In 2016, there was power crisis in Mohéli and Grande Comore with major power failures that led to power rationing and blackouts. Cultural challenges mainly revolve around electricity billing. There are a high number of consumers – including most public institutions and mosques – who are not fully billed, either due to the metering method, illegal connections or social status. This constrains national revenue collection.

Biomass Energy

Biomass (wood and charcoal) is used to provide about 57% of energy use in the Comoros. Of this, 85% goes to household cooking needs and 15% is used in the ylang-ylang distilleries (Moissi, 2017). A survey conducted by the Initiative Developpement (ID) on household firewood consumption found that on average,

Figure 3: Petroleum product imports distribution in 2017



Source: Based on petroleum importation and stock flow data

5.1 kilograms (kg) of firewood are used per household per day, excluding charcoal (Initiative Developpement, 2017). Using national statistics, the ID report estimates that about 118 kilotons of wood are used for fuel in households in Anjouan. Forest degradation is rapid in the country.

Petroleum products

Comoros is a net importer of petroleum products. The country imports gasoline, diesel and kerosene to meet its overall energy demand. Gasoline is mainly used in the transport sector, while kerosene is used in households and fishing boats, as well as blended for aviation kerosene. Kerosene is also gradually being introduced in agro-processing for ylang-ylang distilleries. Diesel is the main fuel for electricity generation and is also used in the transport sector. The average annual growth rate for imported petroleum products is 7% for diesel and kerosene, and 14% for gasoline. In 2017, a total of 82 thousand tonnes of oil equivalent (ktoe) was imported; 47% of those imports were diesel (gasoil) (Figure 3). Of the total diesel imports, 53% was used for electricity generation and 47% was used in transport. Kerosene constitutes 23% of total petroleum product imports; a total of 3% is used as aviation kerosene and the remaining 27% is used for household, fishing and other uses. Due to high energy prices and overreliance on wood resources, the government has subsidised kerosene for use in households. This subsidy helps keep kerosene as the preferred option for household cooking and lighting. At KMF 215 per litre, kerosene is cheaper to consumers than a kilogram of charcoal (KMF 500), a litre of diesel (KMF 415) or a kilogram of liquefied petroleum gas (KMF 1,306). Moissi (2017) reported that 60% of Comorian homes rely on kerosene for lighting and cooking (49% on Grande Comore, 73% on Anjouan and 76% on Mohéli). Moreover, the low price per litre has made it cost-effective for fishermen to use it in their boat engines. According to the Swofish Association – a fishermen's association in Mohéli – the boat engines are designed to use either petrol or kerosene (Swofish Association, pers comm, 2018). There is however not a very clear data on the quantity of kerosene used per household and in boats. Based on our interview with the association, we came up with a rough estimate of 44.8 litres per day of kerosene used per boat. However, this information is not sufficient to estimate annual kerosene used for fishing. Data on the number of fishermen and effective annual fishing days will be required.

Liquefied Petroleum Gas (LPG)

Few companies import LPG – or butane gas – in Comoros, thanks to a history of government ownership of the sector. Today, Vitogaz dominates gas trading, though other companies are gradually emerging.The gas comes in 9kg and 36kg cylinders; the smaller cylinders are largely used for households, while the bigger cylinders are used by small businesses and the hotel industry. Vitogaz reports that it handles about 500 tons per year (Vitogaz, pers comm 2018), out of 1,133 tons in total imports in 2017 (DGEME, pers comm, 2018). According to Diallo (2017), LPG imports are growing an average of 11% annually, while Vitogaz estimates its growth at 3% estimated each year. In Anjouan, where demand is increasing about 5% per year, there are three main distributers of gas: two Vitogaz operators and EDA, which imports its gas directly from Dar es Salaam, Tanzania. In Mohéli, Vitogaz has had erratic deliveries, resulting in new competition, such as CAM-GAS. However, there are only two distributers of the gas cylinder. The transport of these cylinders from Grande Comore to Anjouan is challenging as it is not regular and the sea conditions during rainy season that makes transport difficult. These challenges would result to over one-month delay in gas supply. This is aggravated in rainy and stormy seasons between November and April.

The main challenges in the growth of LPG market include the government subsidy on kerosene for households, the initial purchase cost of a cylinder, and inadequate storage facilities. Furthermore, though LPG is supposed to be duty free in Comoros, in reality, the custom duty levied on LPG is high (14%) yet.

Renewable Energy

Although Comoros currently generates all its energy from diesel power plants, several studies point to the opportunity for energy independence through the use of renewable energy technologies. Solar has found success in private homes, standalone solar photovoltaics, and distributed micro solar lanterns. Community-managed hydropower – at the Lingoni and Marakani village micro hydro power plants – also show the country's national renewable energy capacity. In a spirited effort, the government – with the support of the European Union – is implementing a 125 kWp solar power plant in Mohéli as a demonstration project and to connect an under-served community in Ndrondroni. Furthermore, a recent assessment on the renewable energy options in Comoros highlighted the opportunity for a 10 megawatt (MW) geothermal power plant in Grande Comore and a 5 MW hydropower facility in Anjouan, as well as government-owned wind and solar farms (15 MW and 6 MW, respectively) (Apperley and Quinlivan, 2016). Based on the levelized cost of energy (LCOE) of each technology, the Comoros geology bureau has proposed a 5 MW solar farm and a 10 MW geothermal plant in Grande Comore (Bureau Géologique, 2018). This could provide a near-term energy solution for the island (Apperley and Quinlivan, 2016).

Comoros imports its gross energy needs, which has a negative impact on national energy security and economic development. The country thus aims to add renewable energy resources in its energy mix and has released a preliminary report on its master plan for the production, transportation and distribution of renewable energy. This plan lays out the development of the Comorian electricity system, both in the short- and long-term, in an attempt to forecast future demand and supply (CABIRA/NEPLAN, 2018).

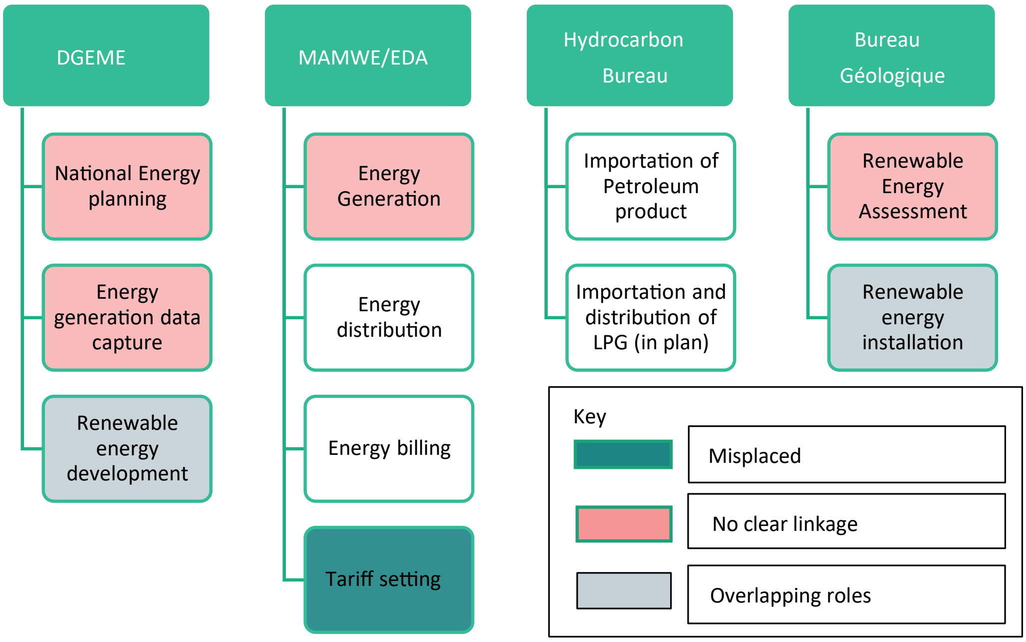
Several studies have highlighted renewable energy opportunities, which are summarised in Table 1. These potential projects are based on pre-feasibility surveys and cost-benefit analysis, not full potential assessments. This is an area that needs field assessment and evaluation.

Table 1: Renewable Energy potential in Comoros

	Comoros	Grande Comore	Anjouan	Mohéli	Source
Wind	15 MW				
Hydropower	1 MW		5 MW	27 KW	a, c
Solar	5 kWh/m²/day	5 MW			a, b
Geothermal		10 MW			a
Biomass		5 MW			a

a. CABIRA/NEPLAN, 2018
b. Apperley and Quinlivan, 2016
c. Bureau Géologique, 2018

Figure 4: Government agencies with energy-related mandates, and an assessment of overlap/ interlinkage among their respective roles



Source: Based on interviews with stakeholders

Legal and institutional framework

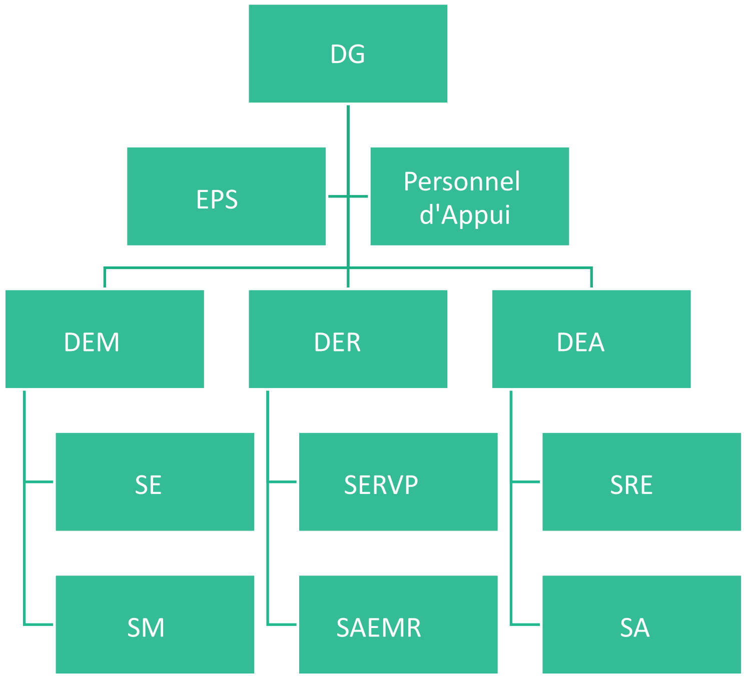
The Director General of Energy, Mines and Water Resources (DGEME) works to deliver to Comoros' energy needs. The director is responsible for the implementation of the country's energy policy. This work is supported by the regional directors in the islands, whose roles – though not clearly defined – are to propagate national energy policies within the islands. Key actors in the energy sector include DGEME, MAMWE/EDA (the main electricity providers), the Société Comorienne des Hydrocarbures (Hydrocarbon Bureau) and Bureau Géologique (Figure 4).

MAMWE is the national energy generation and distribution company in Grande Comore and Mohéli. It also distributes water in Anjouan, where EDA generates and distributes energy. The Société Comorienne de Hydrocarbures (Comoros Hydrocarbon Bureau) imports and distributes petroleum products on all the islands. The bureau operates two storage centres in Anjouan and in Grande Comore; it is in the early stages of building another storage facility in Mohéli. This is a move to ensure energy security on all the islands. In the past, the bureau also imported and distributed LPG gas. This role was later transferred to the private sector, but the government is considering setting up gas refilling stations to reduce the cost of importation and to spur its rapid adoption for household and institutional use. Bureau Géologique, meanwhile, performs renewable energy resource assessment and installation, among other responsibilities. It is currently engaged in the assessment of geothermal resources in Grande Comore. Geothermal is seen as an energy resource that could potentially help with baseload demand, as well as steer the country to energy sustainability pathways. Other renewable energies under assessment are wind, solar and biomass.

These entities operate in a semiautonomous way. MAMWE/EDA and the Hydrocarbon Bureau enjoy a monopoly in the delivery of energy services and goods to the country. Though their services are in the national interest of energy access and security, their operations are affected by roles that are misplaced and overlapping, as well as unclear institutional linkages. Solutions include: harmonising the renewable energy roles of the DGEME and the Bureau Géologique; establishing an independent energy regulator; setting an electricity tariff; and linking key public and private sector actors in the energy generation and supply value chain.

DGEME has set a roadmap to improving institutional communication, including a new organisational structure. This new structure is seen in Figure 5, although all the positions are not yet filled (Diallo, 2017).

Figure 5: Proposed Institutional arrangement in DGEME. Acronyms defined at the beginning of this report



Source: Diallo (2017)

The full names of the agencies are as follows: DG (Direction Générale); EPS (Service d'Etudes, Planification et Statistiques); DEM (Direction de l'Energie et des Mines); DER (Direction des Energies Renouvelables); DEA (Direction de l'Eau et de l'Assainissement); SE (Service de l'Energie); SM (Service des Mines); SERVP (Service Etudes, Recherche et Valorisation du potential); SAEMR (Service Accès, Efficacité et Maitrise des ressources); SRE (Service des Ressources en Eau); SA (Service de l'Assainissement).

Apart from the country's energy strategy – which is in the final stages of development – Comoros' energy sector has not been managed under any official policy. The energy strategy articulates the energy pathways to Vision 2033, but it does not concretely mention the envisioned structural and regulatory frameworks. Thus, sector regulation, information sharing and data management are major gaps in the sector.

Institutional capacity for maintaining energy statistics

Comoros has inadequate energy data on a national level, as well as at the sub-sectoral level by source and use. The energy flows are opaque, and national accountability of imported and national resources is a challenge. Furthermore, the limited available data is disaggregated and spread throughout various organisations, depending on which agency conducted and/or commissioned the survey. Energy systems planning is at the core of effective and efficient national development. Diallo (2017) recommends the analysis of national energy balance statistics to understand sector dynamics and produce good, statistically-based forecasts. Specifically, he recommends that DGEME build the capacity and tools to implement strategic national energy plans. Moreover, he calls for medium- to long-term forecasts based on reliable determinants and correlations, to build on the government's knowledge of the energy flows by source and end use. These recommendations are included in the national energy sector strategy (AETS, 2013).

Energy balance statistics supports an understanding of national energy flows, providing quantitative information on national production, imports and exports, as well as on transformation and demand. It allows for a country to generate future projections for the sake of national planning and for the testing of development targets against available national resources. Energy statistics can also help the country monitor, verify and report key development plans. This feeds into the national energy sector strategy (2013), specifically by helping enhance the level of energy dependence and implement three strategic actions: planning and implementing energy systems, enhancing the renewable energy mix on the three islands, and energy dispatch controls.

2. Study methods

This section gives a detailed description of our approach to developing national energy statistics and conducting scenario analysis of the 2033 energy strategy based on the developed national energy systems model in LEAP. It provides an overview of our data-gathering processes, including stakeholder engagement, as well as introduces the LEAP tool and explains our selection of the energy balance format based on guidelines from the International Energy Agency (IEA, 2004). We also introduce the methodology for a selection of scenarios.

Data gathering process and stakeholder involvement

To generate an accurate and current set of energy statistics for Comoros – one that covers energy production and consumption in all sectors of the economy – we used a participatory data collection approach, involving stakeholders from across the national energy landscape. We developed an energy balance for Comoros – as well as defined and grouped its energy commodities and the commodities flows to various sectors – using a methodology that follows the IEA's internationally established standards.

Energy data collection from stakeholders followed a two-stage process:

- Introductory visit to DGEME and other institutions that focus on energy and energy data gathering. This enabled us to explain the main focus of the initiative and to brief relevant stakeholders on the energy balance highlights.

- Data gathering across institutions and on the three islands relevant to the development of energy balance statistics, as per the IEA standard.

Data collection efforts engaged stakeholders from each of the major sectors in Comoros. These sectors included those with final energy demands, such as industrial (essential oil production), transport (including road transport, domestic navigation and domestic aviation) and others (households and commercial or public buildings). We also collected data from energy supply sectors, including transmission and distribution of electricity, electricity production (both on- and off-grid) and charcoal production. Furthermore, we sought cross-cutting data (data which may pertain to more than one sector, such as the country's GDP or population). Our historical data gathering focused on annually-resolved data from the past decade (2007 – 2017). Finally, wherever possible, data was collected separately for each of the three islands in the country. A list of stakeholders consulted is given in Figure 6.

Following the data collection phase, all information was prepared for entry into LEAP, the Long-range Energy Alternatives Planning system.

LEAP: a tool for energy system modelling

LEAP is a software tool developed by the Stockholm Environment Institute (SEI) for building integrated energy system models, spanning energy production and consumption in all sectors of an economy. The software can be used to perform analysis of different energy sector development scenarios, and to compare relevant results using a range of visualisations. LEAP was selected as the modelling tool of choice for this analysis for a range of reasons. First, LEAP is freely available for developing country governments to use, and can be installed on any modern PC. Second, it is highly flexible in its data requirements and modelling structure, allowing it to be useful in data-sparse environments. Finally, as an integrated modelling tool, LEAP can be used to generate a complete energy balance for any historical year (or future scenario year) natively within its interface (Figure 7).

Figure 6: List of stakeholders consulted for historical data, and the type of data sought from each

DGEME
- Energy and water sector policy and planning
- Renewable energy technologies

MAMWE (Grande Comore and Mohéli) and EDA (Anjouan)
- Electricity utility company (transmision and distribution)
- Electricity Generation

Statistics Bureau (Grande Comore, Mohéli)
- Demograhic and Economic survey

Geology Bureau (Grande Comore)
- Renewable energy assessment
- Implementation of renewable energy projects

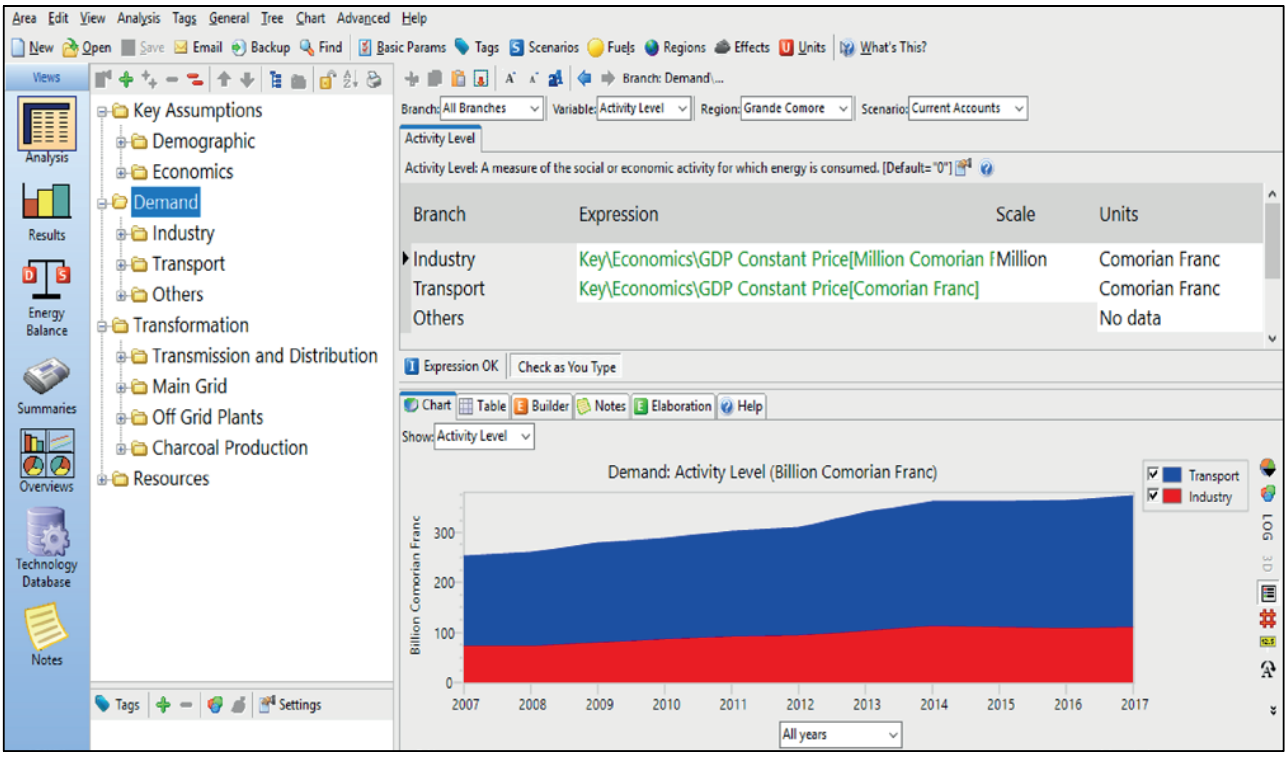
Hydrocarbon Bureau (Grande Comore and Mohéli)
- Importation and distribution of petroleum product

National Planning Comission (Grande Comore)
- Government strategies and development plans and targets

Vitogaz (Grande Comore) COMGAS (Mohéli) and EDA
- Importation and distribution of LPG

Private sector manufacturers (Initiative Development), Ylang ylang manufacturer
- Vanilla production and exportation
- Ylang ylang distilleries

Figure 7: The main LEAP interface



The energy balance format

An energy balance is an annual reporting format that shows the production, conversion and consumption of energy commodities in an economy, which obey physical accounting rules. An energy balance provides a complete representation of how energy flows through an economy from its point of entry (production or imports), through its transformation into other energy products, and eventually to its final consumption or export. To avoid uncertainty arising from differing fuel qualities or physical units that depend on temperature and pressure, energy balances are typically displayed in energetic units. Energy balances help to ensure consistency in records across sectors, years and geographic regions, as well as help draw boundaries, ensure completeness across sectors, consistently define and track energy-related indicators, and find errors and accounting anomalies. They are often represented in tabular format, with different energy commodities represented in columns, and commodity flows represented in rows. Figure 8 provides an example of energy balance statistics of Montenegro in 2012 – 2013 (MONSTAT, 2014).

Figure 8: An example of an energy balance table, showing different flows (in rows) and energy commodities (in columns)

Commodity

Commodity flow

	Total energy	Coal	Oil p		Electricity
Primary production	**22 885**	15 583	-	7 302	-
Recovered products	**2 196**	-	-	-	2 196
Import	**13 059**	28	12 265	32	734
Stock changes	**-**	-	-	-	-
Export	**- 3 476**	- 212	- 622	- 313	- 2 329
Gross inland energy consumption	**34 664**	**15 399**	**11 643**	**7 021**	**601**
Transformation - input	15 203	15 178	-	25	-
Transformation - output	4 732	-	-	12	4 720
Exchange and transfers	8 906	-	-	-	8 906
Own consumption in energy sector	490	-	-	-	490
Losses	2 239	-	-	-	2 239
Non-energy consumption	**1 246**	**-**	**1 246**	**-**	**-**
Final energy consumption	**29 124**	**221**	**10 397**	**7 008**	**11 498**
Industry	7 508	120	2 211	209	4 968
Transport	7 917	-	7 795	-	122
Households and other sectors	13 699	101	391	6 799	6 408
Statistical differences	**-**	-	-	-	-

Source: MONSTAT, 2014

There are a number of different formatting conventions in use, but one of the most common and well-established is that prescribed by the International Energy Agency (IEA). The IEA's canonical energy statistics handbook (IEA, 2004) describes a system of accounting rules to balance the following fundamental relationship.[3]

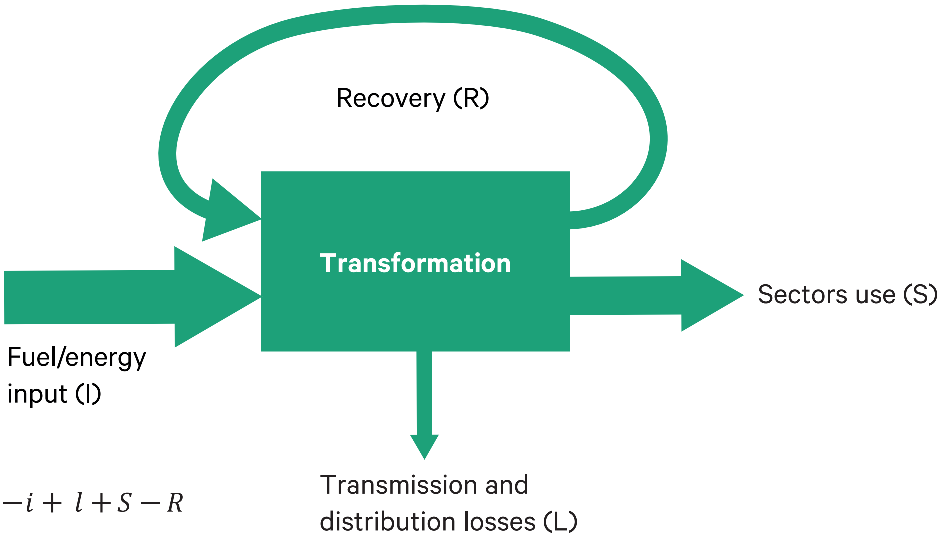
Total primary energy supply + transfers = Total demand

In principle, the equality above must hold for each energy commodity. However, due to accounting discrepancies, small mismatches between the left and right hand side may exist, and these are classified as statistical differences. Statistical differences are thus a representation of mismatch of demand and supply. They should be investigated and resolved by an energy analyst, or represented as a separate commodity flow in the final energy balance.

A simplistic black box, input-output diagram presents this relationship in Figure 9. The circular sum of all inputs and outputs equates to zero.

3 Total primary energy supply (TPES) is comprised of indigenous production of resources, manufacture of secondary fuels and other sources of fuels, to which imports and negative stock changes are added and exports positive stock changes are subtracted. Finally, international marine and aviation bunker fuels are then subtracted to obtain TPES. Transfers arise primarily as the result of reclassifying energy commodities from one year to the next. Total demand is comprised of inputs into energy conversion processes, energy sector own-use, distribution losses and final energy consumption. For further detail on each of these components, the reader is directed to consult the IEA's Energy Statistics Manual (IEA, 2004).

Figure 9: Simplified high level energy balance computation expression



$$0 = -i + l + S - R$$

The LEAP software natively enforces these energy accounting relationships, which means that it can be used to calculate and visualize each component of an energy balance, or to display a comprehensive all-sector energy balance for a given year.

Scenario selection and analysis

After building a complete representation of Comoros' historical energy system using LEAP, we prepared a number of development scenarios, each describing a different possible future for the national energy system. A scenario is a consistent way of describing something that could happen in the future – a change in the way that consumers use energy, the introduction of a new group of technologies, etc. These scenarios were self-consistent and abided by a clear set of rules that described, included and excluded changes.

In this report, a baseline scenario is adopted in which the energy system continues to evolve in the same manner as was observed in the past, as well as four scenarios informed by the country's National Energy Strategy:

1. National Energy Independence scenario
2. Accelerated Electricity Access scenario
3. Biomass Energy Transition scenario
4. Combined scenario

3. Data inputs and assumptions

Cross-cutting assumptions

Population and economic data are key inputs that drive the demand side and affect the energy balance long-term. Economic and population growth assumptions influence the pattern of energy demand and other energy relationships, such as measurements of energy intensity. These assumptions either need to be based on key economic and population forecasts from existing data or made with a good observation of trends.

Data pertaining to final energy demands

LEAP is a demand-driven model that can generate energy balances. In order to harmonise it with the International Energy Agency guidelines, the IEA final energy demand structure is adopted. The guidelines classify energy use in three broad categories:

***Industrial**:* This is energy used for generating heat for industrial processes. Other forms of energy used in the industrial sector are not included; for example, energy used for the industrial transportation of goods and cargo are considered in the transport category.

***Transport**:* This comprises fuel use for the transport activity itself. Any non-transport purposes should be reported in different categories. Four sub-categories are identified in this branch: road transport; air; pipeline and inland navigation.

***Others**:* The LEAP tool provides the user with the ability to organize work based on data availability. Where there are data gaps, assumptions are made based on reasonable assessment and supplementary interviews or inquiries, including with national experts. For example, if the data on energy intensity in household energy use is missing, LEAP users can either aggregate calculations or use existing bits of information to develop the relevant energy intensities based on the technology used. This offers flexibility to energy system modellers and improves usability, while also opening the door for future opportunities to establish values based on actual observed data.

Data entry in LEAP

LEAP provides users with the ability to organise their work based on the data availability of a specific country or region. The platform provides a friendly environment to input the data with key components. These components are shown in Figure 10.

The user can arrange the data in categories of demand and supply in the tree structure section. Mathematical expressions are entered in the expression field and the energy balance is viewed on the energy balance tab.

Data processing for energy statistics

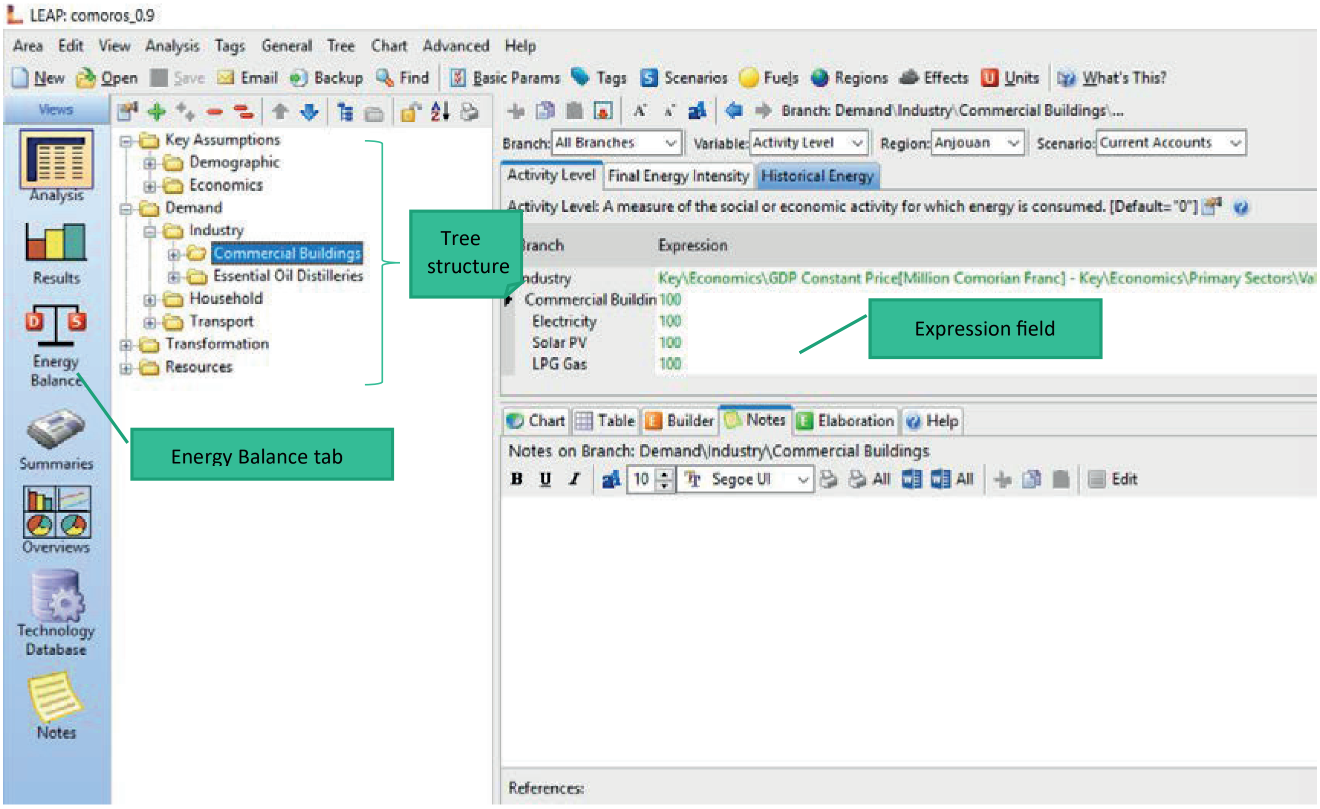
The data capture questionnaire was based on the LEAP model tree structure. The tree structure arranges the data in three levels (activity level, energy intensity and historic trends). In some instances, the data obtained did not fit into the three categories for the purpose of modelling. Therefore, the following approaches were developed to synthesise available information into data suitable to develop the Comoros energy model.

Direct data application: Directly obtained data that could be inputted as-is were fed to the model with no further processing. Such data included macro-economic and demographic information, as well as household fuel shares for lighting and cooking.

Extrapolation: Historical energy consumption was extrapolated based on international data sets provided through UN data.

Triangulation: In cases of inadequate data, the triangulation method was used to generate logically appropriate data for the model. For instance, data on the daily kerosene use by fishing boats was inadequate to establish the final annual kerosene demand without knowing the number of boats and the number of

Figure 10: LEAP tool work space



trips made per boat annually. In this case, the annual kerosene used in homes annually was subtracted from the overall import values. This produced the annual kerosene fuel demand for boats. Because the total kilometres boats have travelled is known, the number of litres of kerosene per "boat kilometre" could be generated.

Relation: The data collected on one island was used to represent all islands in Comoros, assuming a commonality in practices. For instance, a household firewood survey in Anjouan demonstrated that each household uses 5.1 kg of firewood per day for cooking. This assumption was applied to Mohéli and Grande Comore.

For further details on the data entered into the LEAP, see Appendix 1.

4. Historical energy statistics

This section describes the energy statistics based on model results and data captured from various stakeholders. The information is correlated with secondary literature, reports and past studies in Comoros. In some instances, Comoros' energy system was compared with that of developing countries.

A key objective of this study is to synthesize, for the first time, energy consumption and production data from a wide variety of stakeholders into a comprehensive set of energy balance statistics. A significant part of the study comprised data collection. This enabled the development of a clear picture of the Comorian energy system and to identify gaps and inconsistencies in the available data, before taking steps to remedy them.

Historical data was sought for as many years as were available from 2007 to 2017. Since annual surveys or centralized reporting is not widely practiced in all sectors, data items during this historical period have been filled using a point estimate from a single year. This practice often results in large statistical differences, defined earlier in this report, which are observed when reconciling sources of energy supply to annual demands. Statistical differences indicate an inconsistency between energy production and final demands – the result of missing data, different accounting practices among data holders, and other data quality challenges. To present a complete overview of the country's energy system, statistical differences are investigated (and largely resolved) for only the most recent historical year at the time of publication, 2017. A national energy balance table for Comoros is provided in Table 2.

The energy system model constructed for this study contains regionally disaggregated energy statistics for each of the three regions in Comoros – Grande Comore, Anjouan and Mohéli. Historical energy balance tables may be viewed for all regions combined, as in Table 2, or they may be displayed separately for each region. Table 3 summarizes the energy flows for each island. Fuel-specific details for each island is provided later in Table 4, Table 5 and Table 6.

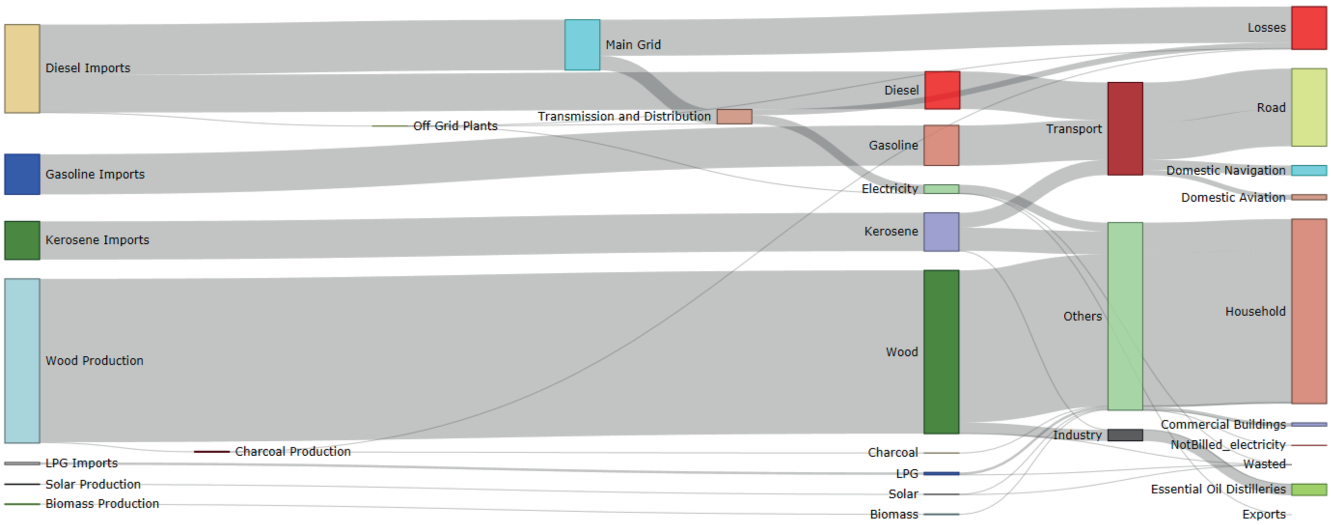
Figures 11, 14, 17 and 20 are Sankey flow diagrams for the entire energy systems of Comoros, Grande Comore, Anjouan and Mohéli, respectively.

Table 2: National energy balance for Comoros in 2017, all islands combined (in terajoules)

	Gasoline	Kerosene	Diesel	LPG	Wood	Charcoal	Biomass	Solar	Electricity	Total
Production	-	-	-	-	3714.7	-	17.1	10.6	-	**3742.3**
Imports	906.6	864.6	1995.7	53.6	-	-	-	-	-	**3820.5**
Exports	-	-	-	-	-	-	-	-	-	**-**
Total Primary Supply	906.6	864.6	1995.7	53.6	3714.7	-	17.1	10.6	-	**7562.8**
Charcoal Production	-	-	-	-	-20.4	4.6	-	-	-	**-15.9**
Off Grid Plants	-	-	-7.4	-	-	-	-	-	1.8	**-5.5**
Main Grid	-	-	-1140.1	-	-	-	-	-	325.3	**-814.8**
Transmission and Distribution	-	-	-	-	-	-	-	-	-129.9	**-129.9**
Total Transformation	-	-	-1147.5	-	-20.4	4.6	-	-	197.2	**-966.2**
Industry	-	4.7	-	-	251.5	-	-	-	-	**256.2**
Essential Oil Distilleries	-	4.7	-	-	251.5	-	-	-	-	**256.2**
Transport	906.6	338.3	848.2	-	-	-	-	-	-	**2093.1**
Road	906.6	-	848.2	-	-	-	-	-	-	**1754.8**
Domestic Navigation	-	224.7	-	-	-	-	-	-	-	**224.7**
Domestic Aviation	-	113.7	-	-	-	-	-	-	-	**113.7**
Others	-	521.5	-	53.6	3442.8	4.6	17.1	10.6	197.2	**4247.2**
Household	-	521.5	-	34.4	3442.8	4.6	17.1	9.0	146.0	**4175.3**
Commercial Buildings	-	-	-	19.2	-	-	-	1.6	50.1	**70.8**
Unbilled Electricity	-	-	-	-	-	-	-	-	1.1	**1.1**
Total Demand	**906.6**	**864.6**	**848.2**	**53.6**	**3694.2**	**4.6**	**17.1**	**10.6**	**197.2**	**6596.6**

Source: Produced based on national data collection and modelling

Figure 11: Sankey diagram energy flow of Comoros



Source: Generated from the developed Comoros energy system model

Table 3: Energy balance summary by region for Comoros in 2017, all fuels combined (in terajoules)

	Grande Comore	Anjouan	Mohéli	Total
Production	1831.6	1705.0	205.7	**3742.3**
Imports	2560.7	1054.1	205.7	**3820.5**
Exports	-	-	-	**-**
Total Primary Supply	4392.3	2759.0	411.4	**7562.8**
Charcoal Production	-7.9	-6.8	-1.3	**-15.9**
Off Grid Plants	-	-	-5.5	**-5.5**
Main Grid	-594.9	-178.8	-41.2	**-814.8**
Transmission and Distribution	-87.2	-33.8	-9.0	**-129.9**
Total Transformation	-689.9	-219.3	-57.0	**-966.2**
Industry	16.1	233.7	6.5	**256.2**
Essential Oil Distilleries	16.1	233.7	6.5	**256.2**
Transport	1403.2	569.0	120.9	**2093.1**
Road	1253.0	419.3	82.5	**1754.8**
Domestic Navigation	92.3	101.5	30.8	**224.7**
Domestic Aviation	57.9	48.2	7.6	**113.7**
Others	2283.1	1737.0	227.1	**4247.2**
Household	2233.1	1719.7	222.5	**4175.3**
Commercial Buildings	50.0	16.9	3.9	**70.8**
Unbilled Electricity	0.0	0.4	0.7	**1.1**
Total Demand	**3702.4**	**2539.7**	**354.4**	**6596.6**

Source: Produced based on national data collection and modelling

Across the country, total primary requirements stood at over 7.5 petajoules (PJ) in 2017, over half of which arose in Grande Comore. Nationally, this indicates an average annual requirement of 9.1 gigajoules (GJ) per capita. This ranks Comoros among the lowest-consuming countries in the world. For reference, the average consumption across all UN-classified Least Developed Countries was 15.2 GJ/capita in 2014, according to the most recently available statistics (IEA and OECD, 2014). Among final energy demands, the average annual electricity consumption per person in Comoros was 66.1 kilowatt hours (kWh) per capita (electricity production less transmission and distribution losses), which is also among the lowest in the world.

Comparatively, the average electricity consumption across all Least Developed Countries was just over 200 kWh/capita in 2014 (IEA and OECD, 2014). The energy intensity of the Comoros economy was USD 0.19 per megajoule (MJ)4 in 2017, similar to economic intensities observed in other Least Developed Countries.

Energy requirements are dominated by wood and other biomass, satisfying nearly half of primary energy needs in 2017. Wood and biomass are used primarily in households and for essential oil production. This is followed by diesel consumption, which is used also for power generation. Gasoline and kerosene are important fuels for transportation, and many households also rely on kerosene for cooking needs. All petroleum products are imported.

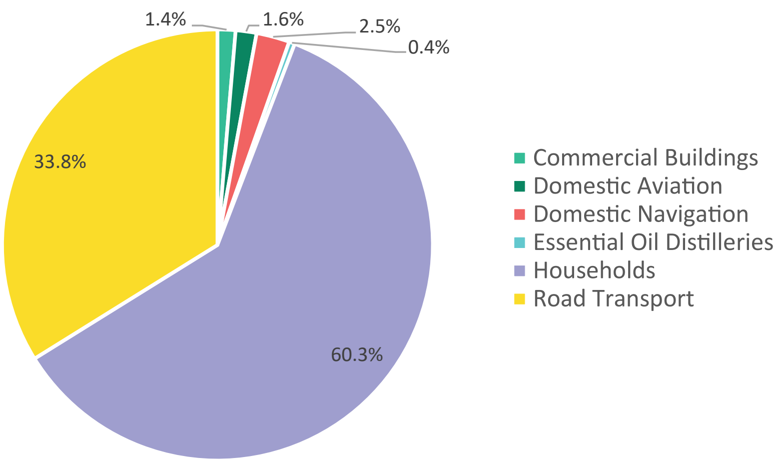
Grande Comore energy statistics

Historical Final Energy Demands

The largest and most populous of the Comoros archipelago, Grande Comore (Ngazidja) is also the economic centre of the nation. Final energy demands are distributed across a range of sectors, the largest of which is household consumption. Like each of the islands, household energy consumption is dominated by primary biomass in the form of fuelwood. Final electricity consumption is the highest in the country, with 95.2 kWh/capita consumed annually.

Figure 12 shows the total final energy demand in Grande Comore (3,702.4 TJ) by sector, for the 2017 historical year. For display purposes, the chart excludes unbilled electricity, which comprises less than a 0.1% of final energy demands.

Figure 12: Share of total final energy demand by sector in Grande Comore

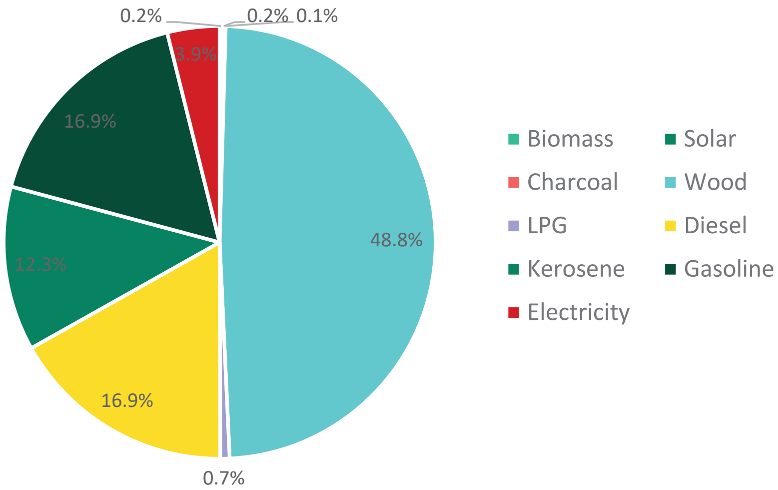


Source: Based on computed energy demand by sector

Figure 13 shows the total final energy demand in Grande Comore (3,702.4 TJ) by fuel, for the 2017 historical year. For display purposes, the chart excludes unbilled electricity, which comprises less than 0.1% of final energy demands. Biomass, solar and charcoal make up only 0.2%, 0.2% and 0.1% of final energy demands, respectively, and their visibility on the chart is poor.

4 Measured in 2007 USD, assuming the 2007 average exchange rate of 354.87 Comorian francs (KMF) per USD 1 (XE Corporation, 2018).

Figure 13: Share of total final energy demand by fuel in Grande Comore



Source: Based on computed energy demand by fuel

Energy flows in Grande Comore

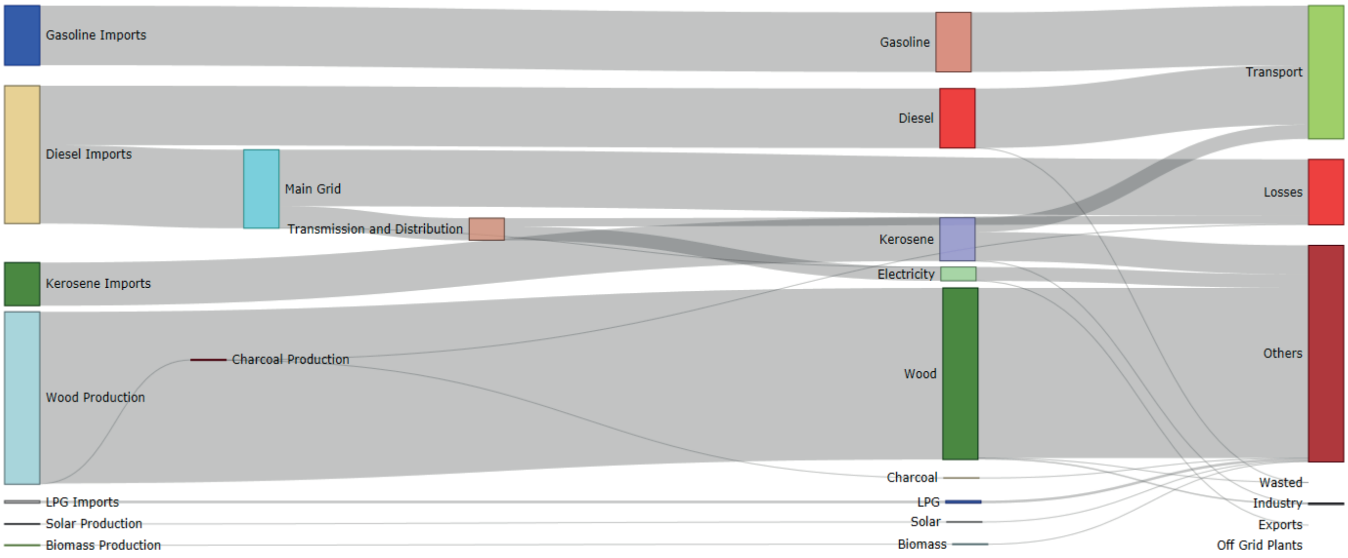
Grande Comore's inhabitants and economic activities give rise to the largest energy requirements among the three islands, with average primary energy requirements of 10.4 GJ/capita. Table 4 provides an energy balance for Grande Comore, for 2017.

Table 4: 2017 energy balance for Grande Comore (in terajoules)

	Gasoline	Kerosene	Diesel	LPG	Wood	Charcoal	Biomass	Solar	Electricity	Total
Production	-	-	-	-	1817.1	-	8.4	6.1	-	**1831.6**
Imports	626.9	455.1	1452.8	25.9	-	-	-	-	-	**2560.7**
Exports	-	-	-	-	-	-	-	-	-	**-**
Total Primary Supply	626.9	455.1	1452.8	25.9	1817.1	-	8.4	6.1	-	**4392.3**
Charcoal Production	-	-	-	-	-10.1	2.3	-	-	-	**-7.9**
Off Grid Plants	-	-	-	-	-	-	-	-	-	**-**
Main Grid	-	-	-826.7	-	-	-	-	-	231.8	**-594.9**
Transmission and Distribution	-	-	-	-	-	-	-	-	-87.2	**-87.2**
Total Transformation	-	-	-826.7	-	-10.1	2.3	-	-	144.7	**-689.9**
Industry	-	0.4	-	-	15.6	-	-	-	-	**16.1**
Essential Oil Distilleries	-	0.4	-	-	15.6	-	-	-	-	**16.1**
Transport	626.9	150.2	626.1	-	-	-	-	-	-	**1403.2**
Road	626.9	-	626.1	-	-	-	-	-	-	**1253.0**
Domestic Navigation	-	92.3	-	-	-	-	-	-	-	**92.3**
Domestic Aviation	-	57.9	-	-	-	-	-	-	-	**57.9**
Others	-	304.5	-	25.9	1791.4	2.3	8.4	6.1	144.7	**2283.1**
Household	-	304.5	-	16.1	1791.4	2.3	8.4	5.2	105.2	**2233.1**
Commercial Buildings	-	-	-	9.8	-	-	-	0.8	39.5	**50.0**
Unbilled Electricity	-	-	-	-	-	-	-	-	0.0	**0.0**
Total Demand	**626.9**	**455.1**	**626.1**	**25.9**	**1807.0**	**2.3**	**8.4**	**6.1**	**144.7**	**3702.4**

Source: Produced based on national data collection and modelling

Figure 14: Energy flow Sankey diagram of Grande Comore



Source: Generated from the developed Comoros energy system model

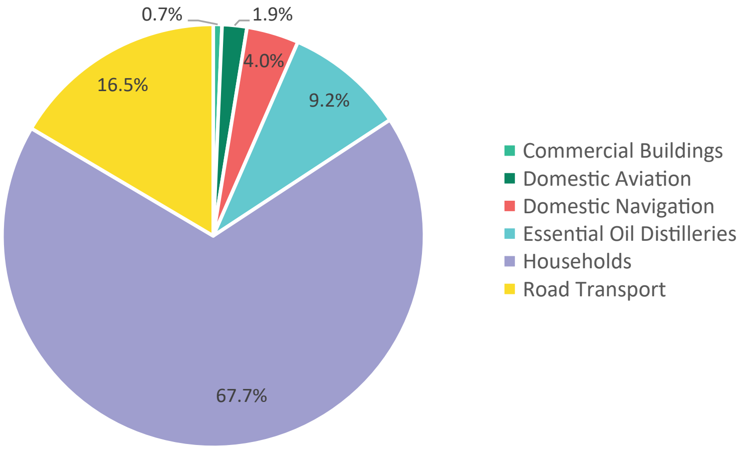
Anjouan energy statistics

Historical Final Energy Demand

The second largest island of the Comoros archipelago, Anjouan (Ndzuwani) is responsible for much of the country's production of ylang-ylang oil. Despite the importance of essential oil production to the economy, household consumption is still the largest contributor to final energy demands. Final electricity consumption is the lowest in the country, with 33.9 kWh/capita consumed annually.

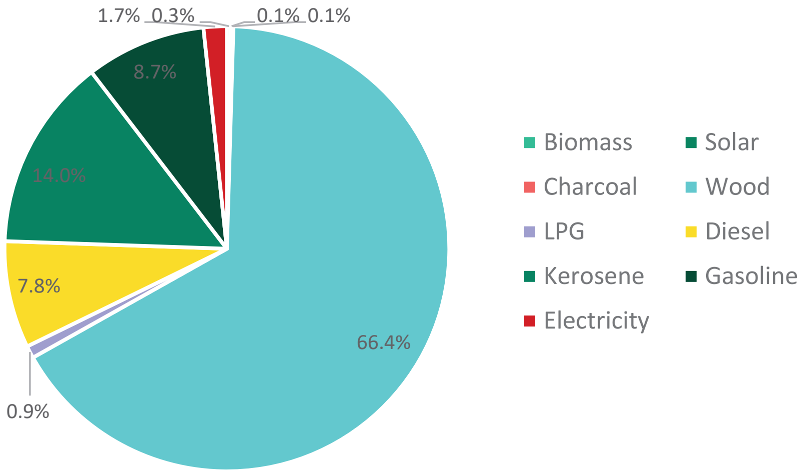
Figure 15 shows the share of total final energy demand in Anjouan (2,539.7 TJ) by sector, for the 2017 historical year. For display purposes, the chart excludes unbilled electricity, which comprises less than a 0.1% of final energy demands.

Figure 15: Share of total energy demand by sector in Anjouan



Source: Based on computed energy demand by sector

Figure 16: Share of energy demand by fuel in Anjouan



Source: Based on computed energy demand by fuel

Figure 16 shows the share of total final energy demand in Anjouan (2,539.7 TJ) by fuel, for the 2017 historical year. For display purposes, the chart excludes unbilled electricity, which comprises less than 0.1% of final energy demands. Biomass, solar and charcoal make up only 0.3%, 0.1% and 0.1% of final energy demands, respectively.

Energy balance for Anjouan

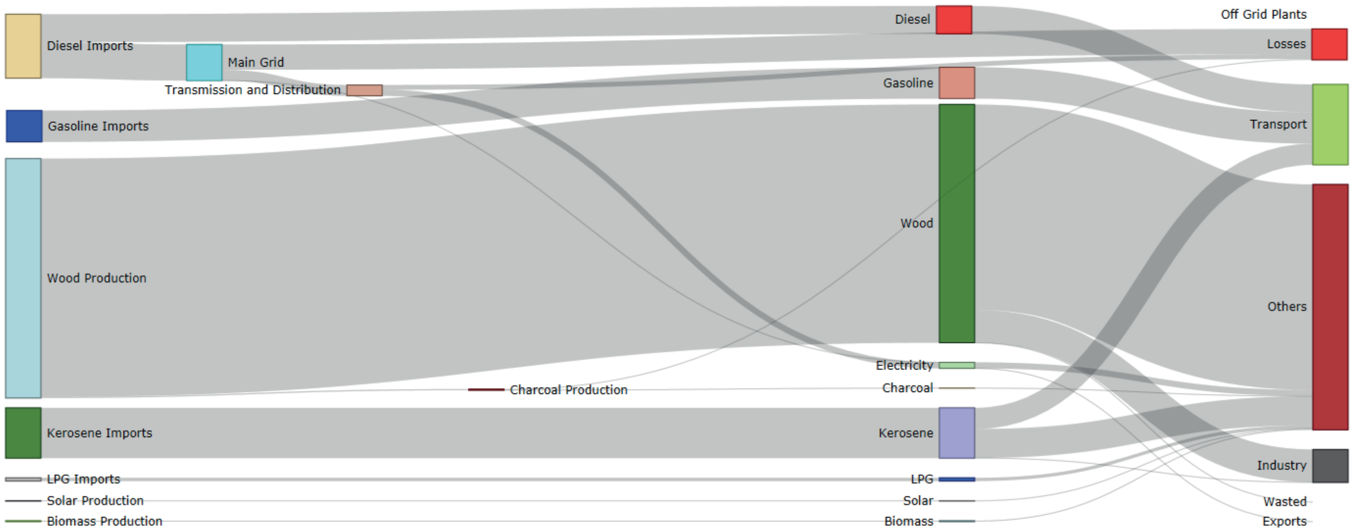
The island's average primary energy requirements are 7.9 GJ/capita, nearly one quarter less than neighbouring Grande Comore. Table 5 provides an overview of energy commodity flows for Anjouan, for 2017.

Table 5: 2017 energy balance for Anjouan (in terajoules)

	Gasoline	Kerosene	Diesel	LPG	Wood	Charcoal	Biomass	Solar	Electricity	Total
Production	-	-	-	-	1695.0	-	7.3	2.7	-	**1705.0**
Imports	221.7	356.5	452.9	22.9	-	-	-	-	-	**1054.1**
Exports	-	-	-	-	-	-	-	-	-	**-**
Total Primary Supply	221.7	356.5	452.9	22.9	1695.0	-	7.3	2.7	-	**2759.0**
Charcoal Production	-	-	-	-	-8.7	1.9	-	-	-	**-6.8**
Off Grid Plants	-	-	-	-	-	-	-	-	-	**-**
Main Grid	-	-	-255.4	-	-	-	-	-	76.6	**-178.8**
Transmission and Distribution	-	-	-	-	-	-	-	-	-33.8	**-33.8**
Total Transformation	-	-	-255.4	-	-8.7	1.9	-	-	42.8	**-219.3**
Industry	-	2.0	-	-	231.7	-	-	-	-	**233.7**
Essential Oil Distilleries	-	2.0	-	-	231.7	-	-	-	-	**233.7**
Transport	221.7	149.7	197.6	-	-	-	-	-	-	**569.0**
Road	221.7	-	197.6	-	-	-	-	-	-	**419.3**
Domestic Navigation	-	101.5	-	-	-	-	-	-	-	**101.5**
Domestic Aviation	-	48.2	-	-	-	-	-	-	-	**48.2**
Others	-	204.8	-	22.9	1454.7	1.9	7.3	2.7	42.8	**1737.0**
Household	-	204.8	-	14.7	1454.7	1.9	7.3	2.0	34.3	**1719.7**
Commercial Buildings	-	-	-	8.1	-	-	-	0.7	8.1	**16.9**
Unbilled Electricity	-	-	-	-	-	-	-	-	0.4	**0.4**
Total Demand	**221.7**	**356.5**	**197.6**	**22.9**	**1686.3**	**1.9**	**7.3**	**2.7**	**42.8**	**2539.7**

Source: Produced based on national data collection and modelling

Figure 17: Energy flow Sankey diagram of Anjouan



Source: Generated from the developed Comoros energy system model

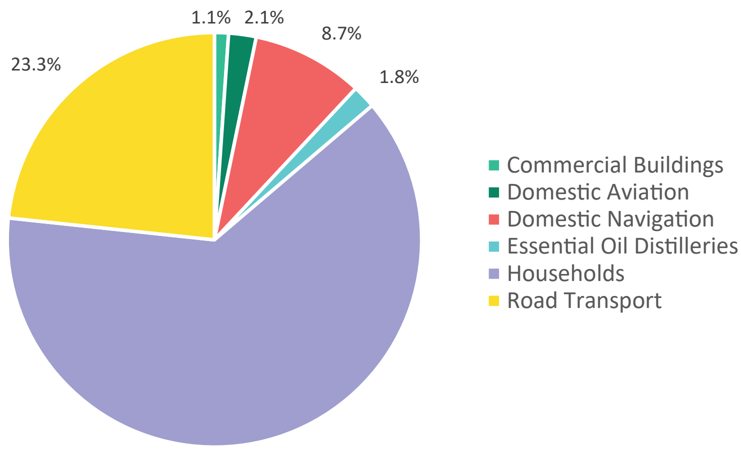
Mohéli energy statistics

Historical energy demand

Mohéli (Mwali) is the smallest of the three Comorian islands. Its inhabitants consume slightly more electricity annually than in neighbouring Anjouan, with final electricity consumption at 48.7 kWh/capita annually.

Figure 18 shows the share of total final energy demand in Mohéli (354.4 TJ) by sector, for the 2017 historical year. For display purposes, the chart excludes unbilled electricity, which comprises less than a 0.1% of final energy demands.

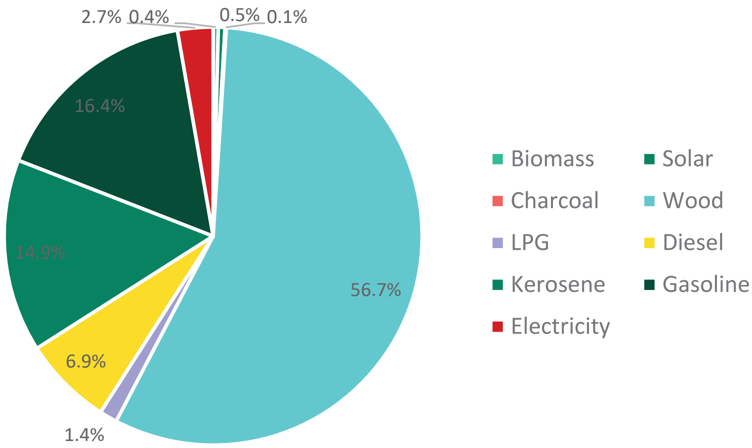
Figure 18: Share of total energy demand by sector in Mohéli



Source: Based on computed energy demand by sector

Figure 19 shows the share of total final energy demand on Mohéli (354.4 TJ) by fuel, for the 2017 historical year. For display purposes, the chart excludes unbilled electricity, which comprises less than 0.1% of final energy demands. Biomass, solar and charcoal make up only 0.4%, 0.5% and 0.1% of final energy demands, respectively.

Figure 19: Share of total final energy demand by fuel in Mohéli



Source: Based on computed energy demand by fuel

Energy balance for Mohéli

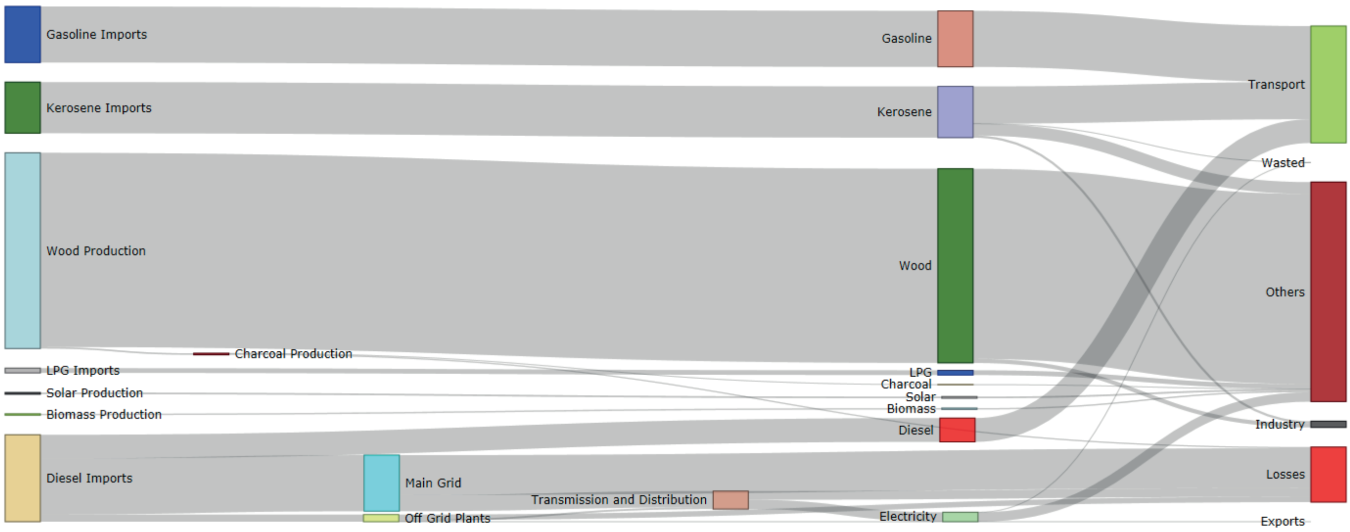
Mohéli's inhabitants consume the least energy on a per capita basis (7.4 GJ/capita) among the three islands. Table 6 provides an overview of the energy commodity flows for Mohéli, for 2017.

Table 6: 2017 energy balance for Mohéli (in terajoules)

	Gasoline	Kerosene	Diesel	LPG	Wood	Charcoal	Biomass	Solar	Electricity	Total
Production	-	-	-	-	202.5	-	1.4	1.8	-	**205.7**
Imports	58.0	52.9	89.9	4.9	-	-	-	-	-	**205.7**
Exports	-	-	-	-	-	-	-	-	-	**-**
Total Primary Supply	58.0	52.9	89.9	4.9	202.5	-	1.4	1.8	-	**411.4**
Charcoal Production	-	-	-	-	-1.6	0.4	-	-	-	**-1.3**
Off Grid Plants	-	-	-7.4	-	-	-	-	-	1.8	**-5.5**
Main Grid	-	-	-58.0	-	-	-	-	-	16.8	**-41.2**
Transmission and Distribution	-	-	-	-	-	-	-	-	-9.0	**-9.0**
Total Transformation	-	-	-65.4	-	-1.6	0.4	-	-	9.7	**-57.0**
Industry	-	2.3	-	-	4.2	-	-	-	-	**6.5**
Essential Oil Distilleries	-	2.3	-	-	4.2	-	-	-	-	**6.5**
Transport	58.0	38.4	24.5	-	-	-	-	-	-	**120.9**
Road	58.0	-	24.5	-	-	-	-	-	-	**82.5**
Domestic Navigation	-	30.8	-	-	-	-	-	-	-	**30.8**
Domestic Aviation	-	7.6	-	-	-	-	-	-	-	**7.6**
Others	-	12.2	-	4.9	196.7	0.4	1.4	1.8	9.7	**227.1**
Household	-	12.2	-	3.6	196.7	0.4	1.4	1.7	6.6	**222.5**
Commercial Buildings	-	-	-	1.3	-	-	-	0.1	2.5	**3.9**
Unbilled Electricity	-	-	-	-	-	-	-	-	0.7	**0.7**
Total Demand	**58.0**	**52.9**	**24.5**	**4.9**	**200.9**	**0.4**	**1.4**	**1.8**	**9.7**	**354.4**

Source: Produced based on national data collection and modelling

Figure 20: Energy flow Sankey diagram of Mohéli



Source: Generated from the developed Comoros energy system model

5. Building energy scenarios

In LEAP, a scenario is defined as: a *self-consistent storyline of how a future energy system might evolve over time in a socio-economic setting and under a set of policy conditions*. While policy and action plans guide the general formulation of scenarios, energy demand projections are affected by four main parameters: population growth, economic growth, human behaviour and end-use devices.

Comoros LEAP scenarios were modelled based on two main national development strategies: 1) the Strategy for Accelerated Growth and Sustainable Development (SCA2D) 2018 – 2021; and 2) the national energy sector strategy. Whereas the former is an umbrella strategy articulating the national development agenda, it lays the foundation for the development of a National Energy Strategy.

By 2030, Comoros aims to be an emerging country with sustained economic and social development and a strong diversified and competitive economy. Sustainable energy is principal to this transition. The revised SCA2D aligns the national planning framework with the Sustainable Development Goals and the 2030 Agenda for Sustainable Development, compelling the country to embrace low-carbon pathways. Moreover, this encourages Comoros to move from an importer of energy to a country with secure and resilient energy systems.

Energy sector development pathways are articulated in Axis I and Axis II in the SCA2D document including goals to:

- Accelerate the structural transformation of the economy and sustainable management of the environment; and
- Accelerate human capital development and promote social well-being.

The sustainable energy-centred targets discussed in Axis I and Axis II are:

- Add 18 MW of electricity capacity through a new Heavy Fuel Oil (HFO) power station by 2019;
- Raise the electrification rate from 60% in 2017 to 70% in 2021; and
- Increase the share of renewable energies in total electricity production (in installed capacity) from less than 1% in 2013 to 30% in 2021.

The medium-term energy strategy of 2013, however, identifies Comoros as an importer of fossil fuel for power and conventional energy use and would allow the continued overreliance on firewood for household, cottage industry and commercial uses, leading to excessive deforestation. This undermines sustainable economic development, energy security and environmental conservation. The Comoros energy system leads to energy insecurity, high environmental degradation and loss of biodiversity, and does not provide much access to modern energy solutions for households, according to the strategy.

As such, the strategy has identified four main work pillars to ensure energy sustainability and environmental conservation within the SDG framework. These are energy security, enhanced access to clean energy, ensuring sustainable economic development and entering a sustainable development path. Selected targets articulated in the strategy for modelling purposes include:

- Promote a broad use of renewable energy technologies (RET) by increasing the share of renewable energy in national installed power from less than 1% in 2013 to 10% in 2018 and 55% in 2033;

- Increase the rate of electrification from 46% in 2013 to 60% in 2018 and 100% in 2033; and

- Reduce the contribution of wood fuels in the overall energy consumption of the country from 78% to 65% in 2018 and 25% in 2033;

With the above targeted actions and stakeholder dialogues, four strategic scenarios are developed in the short term (2021) and medium term (2033) projections, including a reference scenario as listed below. An additional scenario was added to combine the scenarios.

1. **Reference Scenario**
2. **National Energy Independence Scenario**
3. **Accelerated Electricity Access Scenario**
4. **Biomass Energy Transition Scenario**
5. **Combined Scenario**

5.1 Reference scenario (REF)

The reference scenario has been built based on historic growth trends. It assumes no change or negligible change in development patterns and population growth, and assumes that the energy sector will remain in a similar state. It considers that population and economic growth trends are the main drivers for change. In this case, the population growth rate remains at an average 2.6% and GDP growth rates are 5.8%, 6.0% and 3.2% in the primary, secondary and tertiary GDP contributor sectors, respectively.

There would be no major change in energy consumption patterns in the industrial, transport and residential sectors (Figure 22). People would continue to use fuels for cooking and lighting in the current proportions, and transport modes would remain the same (with road, air and domestic navigation, and mainly small motor boats for fishing). The government would continue to provide electricity by increasing the number of thermal diesel generator groups as demand increases. Ongoing major national projects – such as the 18 MW HFO plants in Grande Comore and the 125 KW solar power plant in Ndrondroni – would be commissioned by 2020.

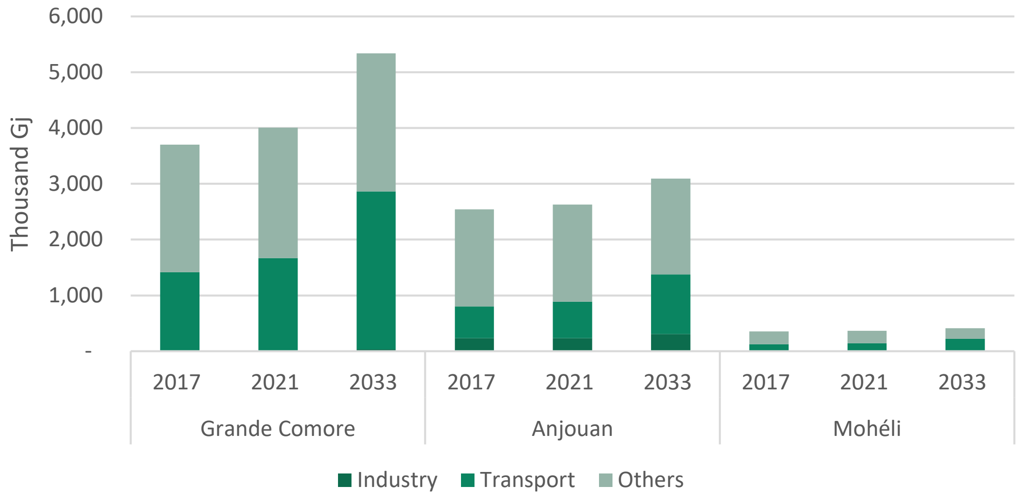
The below sections elaborate on the energy supply and demand in this reference scenario.

Energy demand and supply projections in the reference scenario

The final energy demand in Comoros was 6,597 gigajoules (GJ) in 2017. In the reference scenario, this would grow by 34% to 8,849 GJ in 2033. Of that, 56% of the demand would come from Grande Comore, 39% from Anjouan and 5% from Mohéli. The household and residential (labelled others) sectors would be the main consumers of energy in all regions (Figure 21).

Firewood would remain the highest contributor to final energy demand, accounting for 56% in 2017 and 52% in 2033. Also in 2033, petroleum products would account for 45% and electricity for 3% of final energy demand.

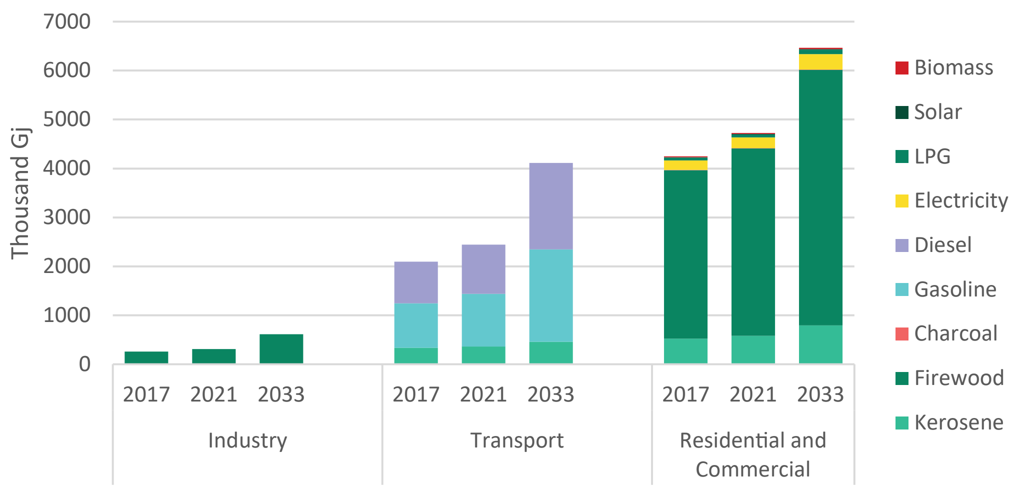
Figure 21: Energy demand by sector in medium-term projection



Source: Based on analysis in the LEAP Comoros energy systems model

Firewood would contribute to 81% of total residential energy demand, while kerosene would account for 12.3%, electricity for 4.9%, and others for 1.8%. Firewood is mainly used for cooking, and the annual demand of 222 kilotons is required to meet household use in the base year. This would grow to 247 kilotons in 2021 and to 336.9 kilotons in 2033. The distilleries for ylang-ylang essential oil – major income earners in the country – use mainly firewood, with a negligible number of distilleries adopting the use of kerosene (about 1%). An estimated annual consumption demand of 16 kilotons in 2017 is realised; this would more than double to 39 kilotons in 2033. Total wood demand thus would be 376 kilotons, excluding firewood use in hotels, restaurants and bakeries. With a limited supply of wood resources and a high deforestation rate, dependency on wood fuel is at a critical limit as demand exceeds supply. In interviews, stakeholders reported that forest resources are nearly depleted in Anjouan and Mohéli; forest resources have declined to less than 50% of what it was in 1990 (Forestry Department, pers comm, 2018). Charcoal use, meanwhile, is still low in Comoros. In 2017, the estimated total demand was 0.16 kilotons; this could double in 2033, meaning about 2 kilotons of wood would be required for charcoal production.

Figure 22: Fuel contribution to final energy demand by sector



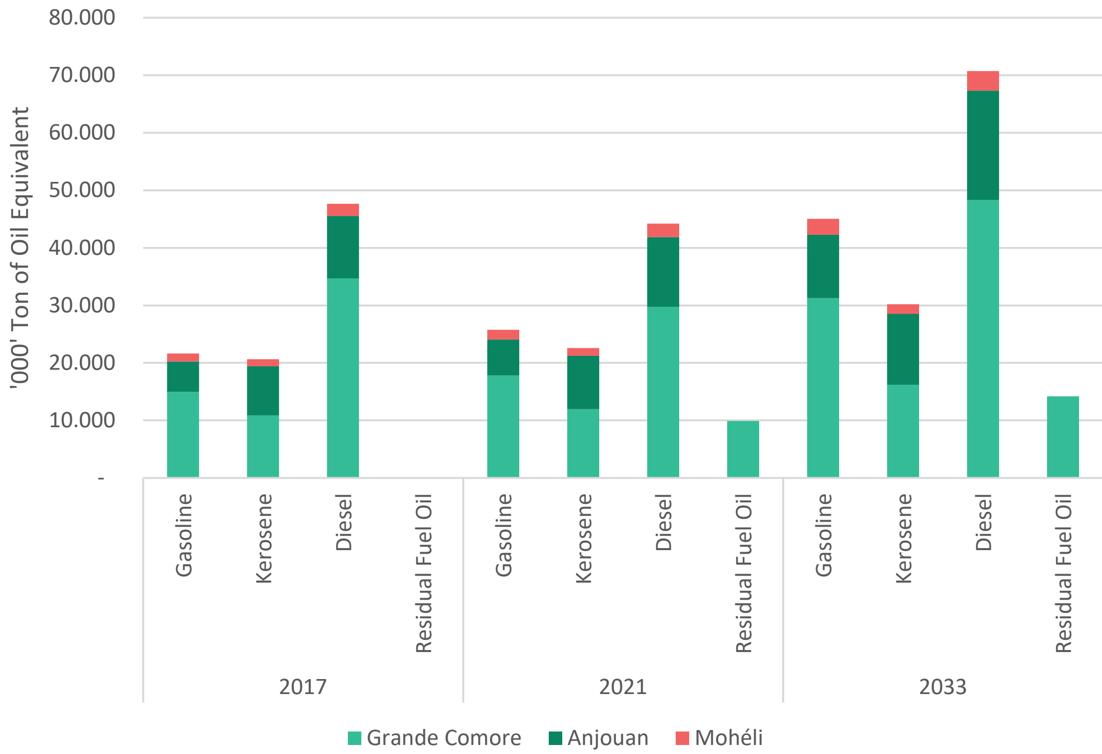
Source: Based on analysis in the LEAP Comoros energy systems model

Comoros is an importer of oil products (kerosene, diesel and gasoline). These products are directly used in the transport and household sectors, and part of the diesel is transformed for electricity production. The demand and supply of oil products is illustrated in Figure 23. There would be consistent growth in the oil products required to meet an energy demand that is estimated to double by 2033. Gasoline is projected to grow by 19% and kerosene by 9%. Diesel imports would decline by 7% between 2017 and 2021. This reduction in diesel imports would result from the introduction of the HFO electricity generation plant in Grande Comore. Between 2021 and 2033, gasoline requirements would increase by 75%, kerosene by 34% and diesel by 60%, increasing the national expenditure by similar proportions.

Electricity generation in all three of the islands is dominated by diesel power plants. Comoros' total electricity demand in the base year is 54.8 GWh, with 74% from Grande Comore, 21.2% from Anjouan and 4.5% from Mohéli. This is due to Grande Comore's high share of electricity access (89%) and electricity consumption intensity (446 kWh per household). Anjouan, in comparison, has an electricity access rate of 65%, with an annual electricity intensity of 222 kWh/household. Mohéli's electricity access rate is 62%, with an annual electricity intensity of 277 kWh/household.

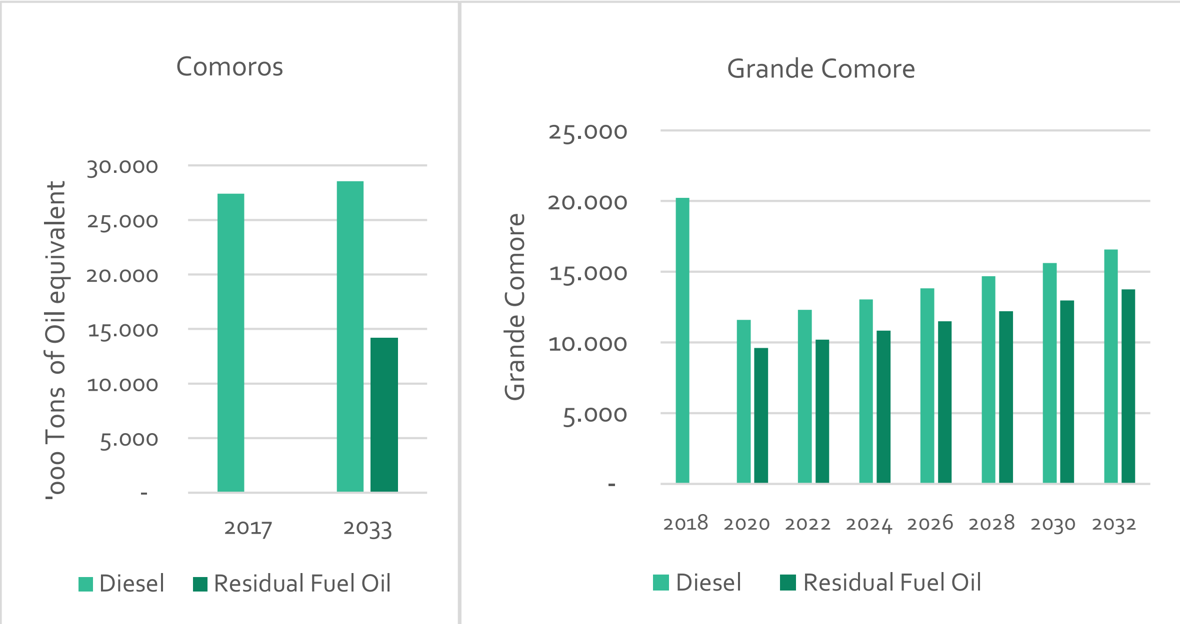
Electricity demand is in the rise and expected to increase 60% between 2017 and 2033, from 54.7 GWh/year to 87.4 GWh/year. The national plan to install a heavy fuel oil (HFO) power plant – and thus gain 18 MW of additional capacity – would reduce overall importation of diesel by 20%. In Grande Comore, diesel imports would decrease by 43% (Figure 24). About 33% of electricity generation would be from heavy fuel oil in 2033 (Figure 25).

Figure 23: National petroleum products required to meet final energy demand



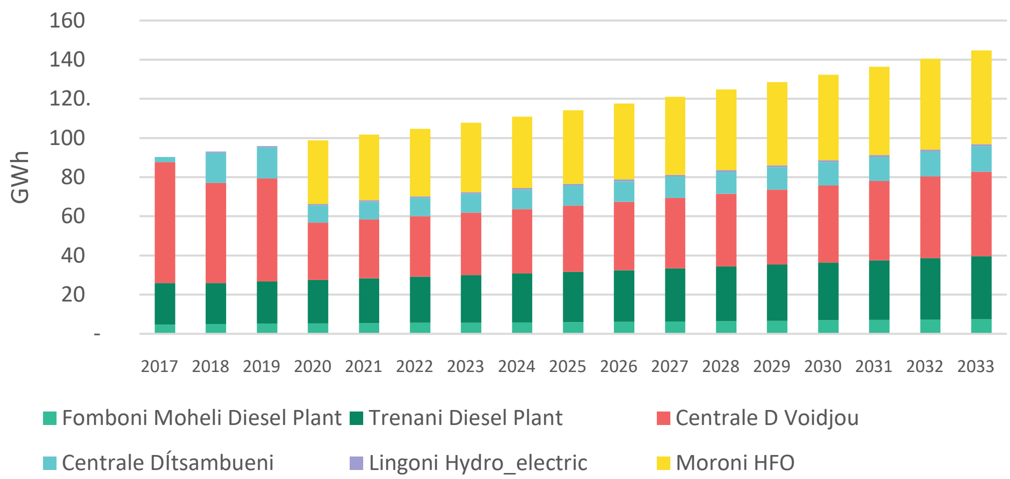
Source: Based on analysis in the LEAP Comoros energy systems model

Figure 24: Fuel requirement for electricity generation



Source: Based on analysis in the LEAP Comoros energy systems model

Figure 25: Electricity generation by plant



Source: Based on analysis in the LEAP Comoros energy systems model

5.2 National Energy Independence (ENE1)

In this scenario, Comoros would seek to develop and diversify its energy supply on the three islands by the utilization of local energy resources. It would set targets to promote a broad use of renewable energy technologies. The country's energy diversification would come from hydropower, geothermal, wind, solar photovoltaics and tidal.

Strategic Objective: Increase the share of renewable energy in national electricity installed capacity from less than 1% in base year to 10% in 2018 and 55% in 2033.

The expected 55% of renewable energy share would be distributed in the following proportions: 25% geothermal, 15% solar, 7% wind and 8% hydropower. In reality, these resources would be distributed unequally around the country depending on the local energy resource base. However, to ensure Comoros' overall achievement of the 55% renewable energy mix, a 55% renewable energy mix is modelled on every island, though this is made up of a different energy mix on each island. The following renewable energies were modelled based on the percentage share requirement by 2033 (Table 7).

Table 7: National Energy Independence scenario assumptions

	Renewable energy share in 2033				
	Wind	**Solar**	**Geothermal**	**Hydro power**	**Total Renewable Energy Mix percent share**
Mohéli	40%	15%			55%
Anjouan		25%		30%	55%
Grande Comore		15%	40%		55%

Source: Based on analysis in the LEAP Comoros energy systems model

This model independently implements additional renewable energy sources in a business-as-usual scenario consumption pattern, with a stabilised grid network; this reduces transmission and distribution losses to a 20% maximum. The dispatch of electricity is by merit order and intermittent sources, such as solar and wind energy, are dispatched on full available capacity. Table 8 shows the renewable energy capacities that have to be installed to meet the 55% mix in the national grid.

Table 8: Installed and additional capacity to achieve 55% renewable energy options (in MW)

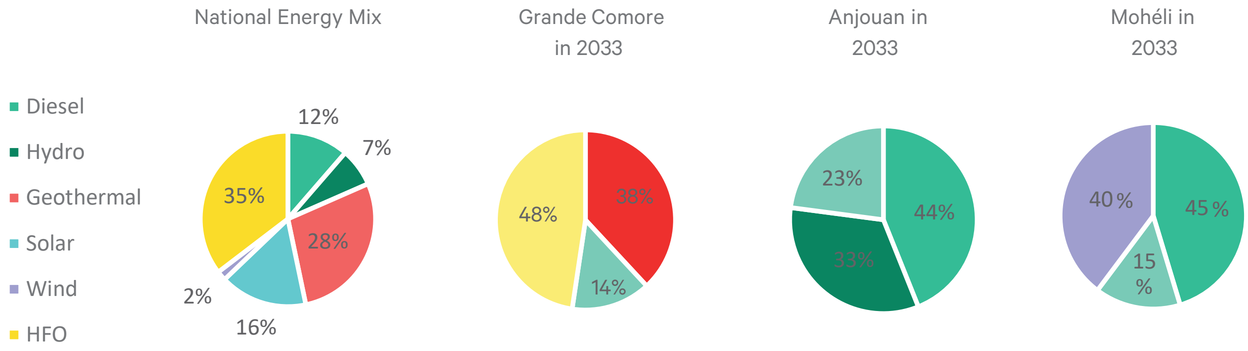
	Grande Comore		Anjouan		Mohéli	
Branches	2017	2033	2017	2033	2017	2033
Fomboni Mohéli Diesel Plant	-	-	-	-	3.6	3.6
Trenani Diesel Plant	-	-	5.7	5.7	-	-
Centrale D Voidjou	16.2	16.2	-	-	-	-
Centrale DÍtsambueni	8.4	8.4	-	-	-	-
Lingoni Hydro electric	-	-	0.3	0.3	-	-
Moroni HFO	-	18.0	-	-	-	-
Generic Diesel Technology	-	-	-	-	-	-
Hydro New	-	-	-	0.8	-	-
Solar New	-	4.6	-	2.2	-	0.3
Wind New	-	-	-	-	-	0.7
Geothermal New	-	3.8	-	-	-	-
Total	**24.600**	**50.988**	**6.000**	**9.021**	**3.600**	**4.613**

Source: Based on analysis in the LEAP Comoros energy systems model

In this Energy Independence Scenario, a total of 109 GWh of electricity generation in 2033 would dispatched in the following proportions (Figure 26).

Based on Comoros' renewable energy options – as presented in the assessment report (Apperley and Quinlivan, 2016) – it is more cost effective in Grande Comore to have a solar and geothermal mix. A 5 MW solar plant and a 10 MW geothermal plant would potentially reduce the base load generation diesel mix by 95%. In Anjouan, there is the potential to generate 5 MW in hydropower at the Lingoni and Marahani power

Figure 26: Renewable energy proportions in the Energy Independence scenario



Source: Based on analysis in the LEAP Comoros energy systems model

stations upon rehabilitation (Bureau Géologique, 2018). The report from Bureau Géologique (2018) also estimates that Comoros has the potential for 10.6 MWp in solar photovoltaic. This potential may enhance the achievement of the country's vision 2030 and the "Sustainable Energy for All"[5] objective of universal energy for all.

5.3 Accelerated Electricity Access (ENE)

In this scenario, the overall objective of the Comoros Energy Strategy would be in tandem with the 2030 Agenda and the Sustainable Development Goal of "access to clean and affordable energy for all". Thus the strategy seeks to contribute to the country's sustainable development, through the provision of energy services that are low-cost and accessible to as many people as possible. This is implemented in four main strategic thematic areas.

One of the thematic areas focuses on finding sustainable and low-cost solutions for the development of energy services (production, transport, distribution, management and maintenance). This thematic area defines the following strategic objectives:

Strategic objective 1: ***Secure and increase the country's electricity coverage from 84% in 2013 to 95% in 2018 and to 100% in 2033 (coverage is defined as electrical supply, by a medium voltage network, to the sector concerned);***

Strategic objective 2: ***Increase the electrification rate from 46% in 2013 to 60% in 2018 and to 100% in 2033.***

Anjouan and Grande Comore have achieved close to 100% electricity coverage, but electrification rates are at 65% and 88%, respectively. Mohéli Island has one main grid network and three isolated off-grid networks. The government has commissioned a project funded by the African Development Bank to extend the main grid to connect with the isolated networks. The result would be one main grid network that can be accessed in all the island's 26 villages. This advancement has the potential to spur further grid connectivity. The project also aims at strengthening the transmission lines in all the villages.

The Accelerated Electricity Access scenario therefore models universal electrification by 2033. All households would use electricity for lighting, eliminating kerosene for this use. Electric cooking, however, would only marginally increase, due to high electricity tariffs. Installation of renewable energy options would enhance reduced tariff rates, but this situation is not envisaged in the short- to medium-term. The electricity cost in Comoros is USD 0.37 per kilowatt hour (kWh); in comparison, that rate is USD 0.057 USD/kWh in South Africa.

5 https://www.seforall.org/

Therefore, despite electricity being available in every household, usage would be curtailed by cost. We implemented a conservative estimate of electricity use growth, from the current 0.3% annually in rural areas to 5% and from 1% in urban areas to 10%. Moreover, with a rising human development index, increased diaspora remittances and reduced unemployment, households would tend to have more electric appliances and thus overall energy intensity per household would increase. A conservative 30% rise in per capita electricity demand was assumed in the scenario. An independent implementation of this scenario, however, assumes additional power plants from renewable energy technologies.

Results

Implementing this scenario would increase electricity demand in 2033 by 55% from the baseline scenario, or from 87 GWh in a business-as-usual scenario to 135 GWh in an accelerated electricity access scenario in 2033 (Figure 27).

More generation would thus be required above existing power plants. The model depicts an additional 21 GWh of generation and overall capacity of 23 MW. This breaks down to 6 MW of additional capacity in Grande Comore, 13 MW of additional capacity in Anjouan, and 4 MW additional capacity in Mohéli.

Figure 28 shows that there would be sufficient generation for demand in a baseline scenario. In 2033, the new Heavy Fuel Oil (HFO) power plant would supply about 30% of the electricity required. But in the Electricity Access scenario, more electricity would be demanded, and an additional 23 MW plant would be required to generate an extra 21 GWh to meet the demand. This is represented by the additional power plant labelled as generic diesel technology. The model suggests more capacity would be needed to meet demand in this scenario.

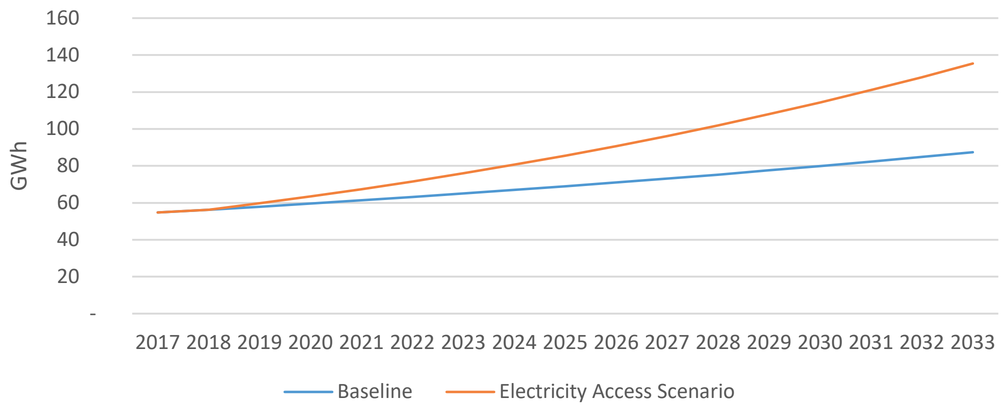
5.4 Biomass Energy Transition (BIO)

Firewood remains the main energy source in Comoros, accounting for 57% of the national energy mix amid a strained national biomass stock. Rural areas are the most affected, with 91% of this population cooking with firewood. Ylang-ylang distilleries are a growing concern for firewood use, as they use it for essential processing. About 98% of the distilleries rely on firewood, using 366 kilograms of wood per kilogram of essential oil. The National Energy Strategy seeks to reduce the contribution of wood fuels in the overall energy consumption of the country from 78% in 2013 to 65% in 2018 and to 25% in 2033. Achieving this requires a rapid transition to alternative energy options.

The assessment shows LPG is the leading alternative option in a transition to cleaner fuel. Kerosene use would increase in the short- to medium-term plan and eventually reduce as Comoros heads towards cleaner solutions. The achievement would not be uniform for both urban and rural areas. Considering the transition is from wood to LPG, the adoption of LPG is likely to spread more rapidly in urban areas than rural. Promotion efforts and media campaigns would be more effective in urban areas in helping reduce firewood and charcoal use to the minimum. In this scenario, the government would strive to eliminate charcoal use by 2033. The model thus reduces firewood dependency in urban areas to only 14% of households by 2033. Rural wood dependency, meanwhile, would fall from 91% of households to 30% in 2033. Kerosene use and LPG, however, would still dominate energy supply for cooking. LPG use on all islands would increase to 40% of rural households and 70% of urban households.

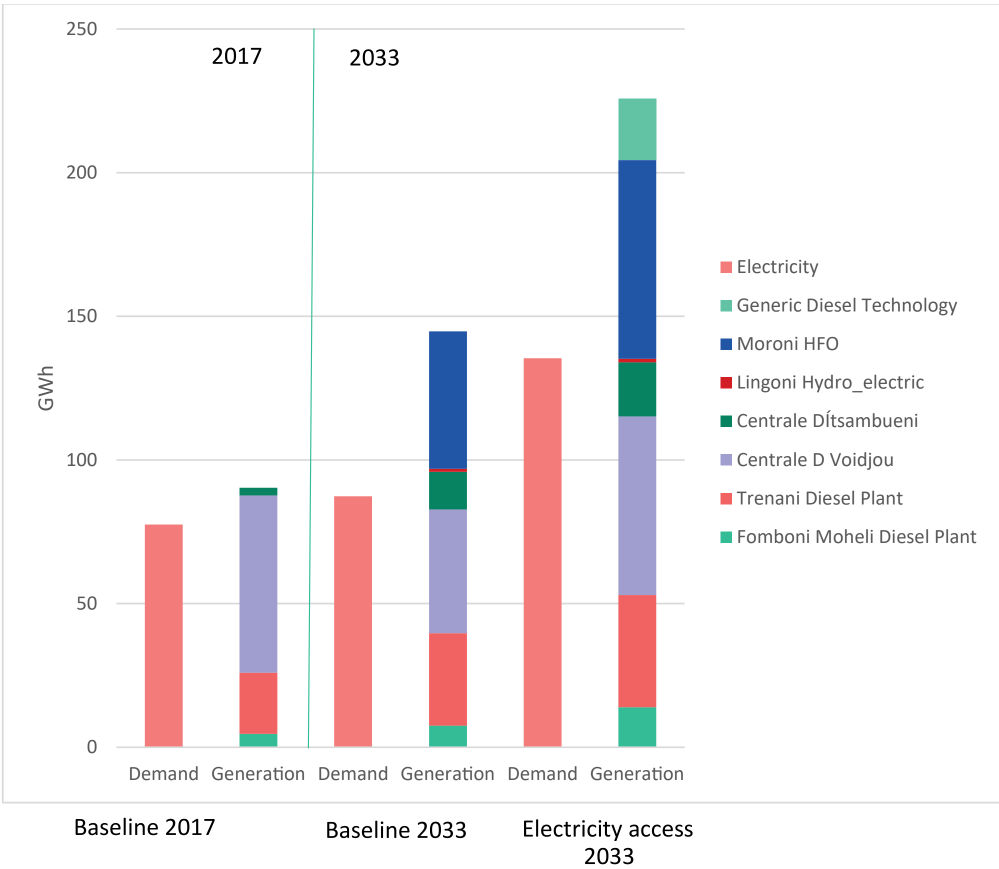
More ylang-ylang distilleries would also use kerosene as a substitute for wood in this scenario, in which the government would campaign to reduce firewood dependency. The Department of Renewable Energy in the Directorate General of Energy, Mines and Water Resources – along with non-governmental organisations – would promote the use of improved cooking stoves and improved biomass burners for the distilleries to reduce the use of fuelwood. In 2025, Grande Comore and Anjouan would achieve a 30% reduction in the use of traditional firewood burners; use in the ylang-ylang stills would be reduced by 45% in 2033. Kerosene use would substantially increase in Anjouan, where wood is critically cleared and there are more essential oil producers. Constraints in biomass in this region would induce a substantial 30% growth in the use of kerosene. On Mohéli, the ylang-ylang association is in the process of researching a solar-wood hybrid technology to reduce wood use to 75% of current use. This technology aims to pre-heat water for distilleries in a solar water heater to above 70°C, then use wood to heat the water to boiling point.

Figure 27: Accelerated Electricity Access scenario compared to Baseline scenario



Source: Based on analysis in the LEAP Comoros energy systems model

Figure 28: Energy demand and generation in Accelerated Electricity Access scenario

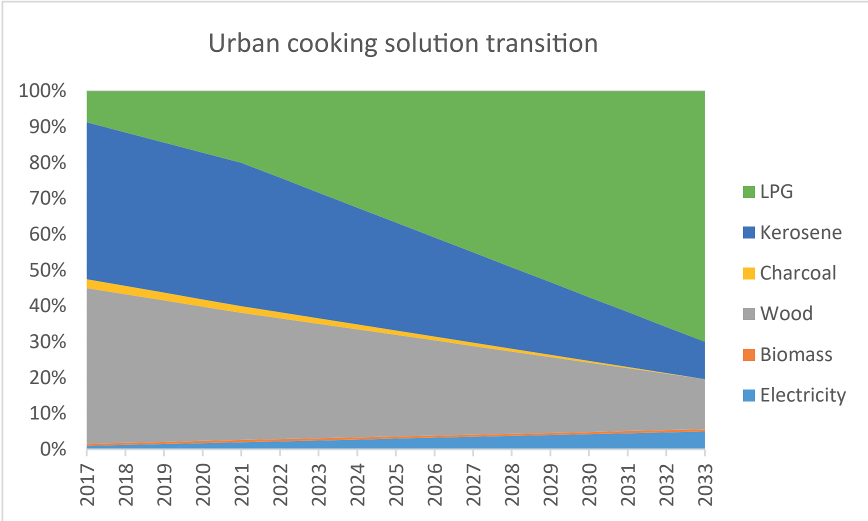


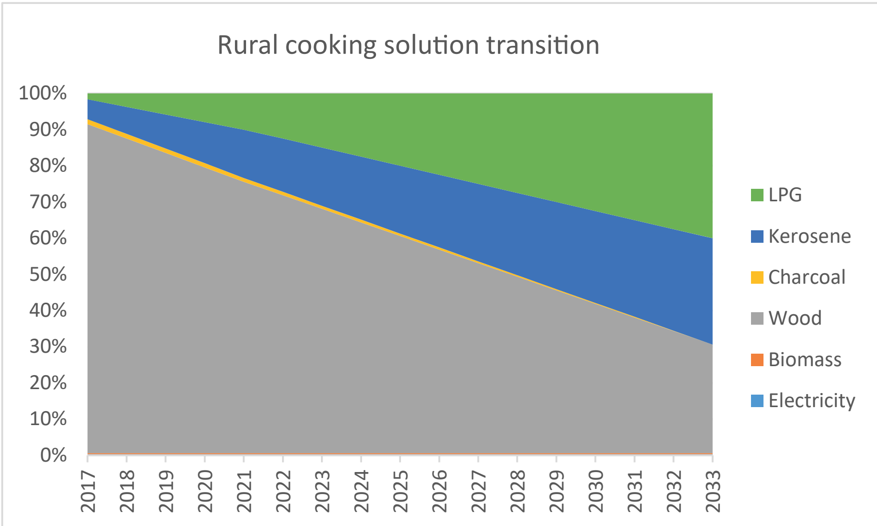
Source: Based on analysis in the LEAP Comoros energy systems model

The technology is expected to be in the pilot stages in 2030. This scenario assumes a minimum of 3 plants using this technology on a pilot basis in 2030.

The transition of households in urban and rural areas to alternative fuels sources for cooking is shown in Figure 29.

Figure 29: Share of households adopting alternative cooking fuels





Source: Based on analysis in the LEAP Comoros energy systems model

Results

In implementing this scenario, the country would be able to save 20% of total final energy demand from the baseline and reduce its total wood requirement for final energy delivery by 64% (Figure 30).

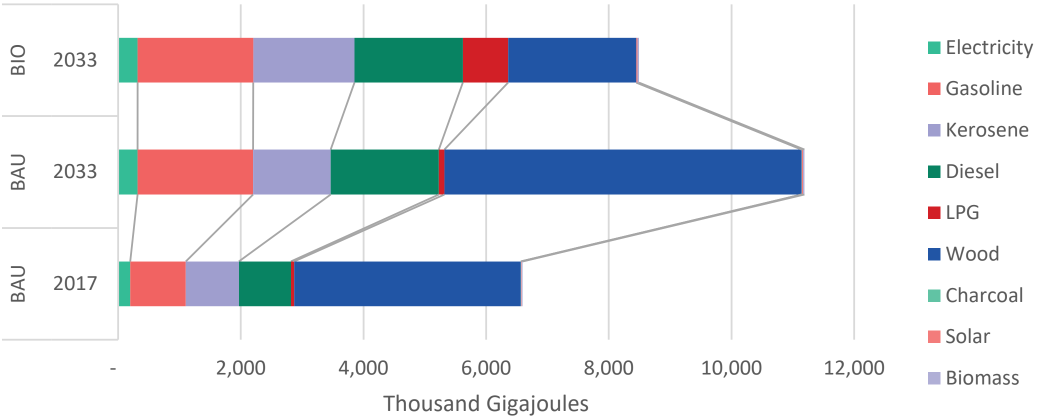
The rise in LPG demand in this ambitious scenario would require concerted action and active private sector involvement. LPG demand would triple in 2021 in this scenario, meaning about 8 times more LPG would be required to meet the demand (Table 9). Active promotion and awareness campaigns would also be required.

5.5 Combined scenarios (COM)

If Comoros opted to be very proactive, its government could do all these strategies in parallel. We thus introduce a final scenario that combines the Energy Independence (ENE1), Accelerated Electricity Access (ENE) and Biomass Energy Transitions (BIO) scenarios.

This scenario would introduce a mix of switching fuels, additional consumption and additional electricity generation capacity. The Energy Independence scenario (ENE1) seeks to increase renewable energy technology shares to 55% of total generation capacity. This scenario also enhances grid stability to achieve

Figure 30: Transition from wood to LPG



Source: Based on analysis in the LEAP Comoros energy systems model

Table 9: LPG requirements for household and commercial sectors in the reference and BIO scenario

	2017	2021	2033
BIO scenario	1,133	3,355	15,602
Reference scenario	1,133	1,282	1,851
Difference	-	2,073	13,750

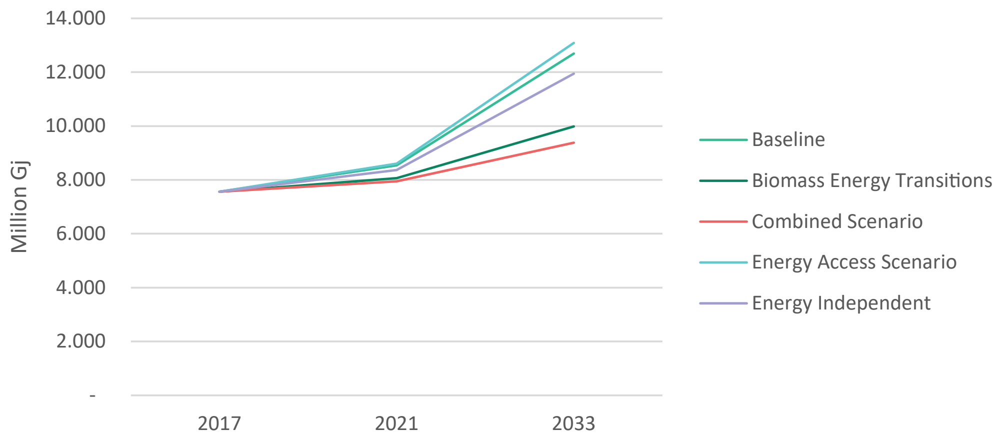
Source: Based on analysis in the LEAP Comoros energy systems model

a maximum of 20% transmission and distribution losses. The Accelerated Electricity Access (ENE) scenario seeks 100% electrification of Comoros. More people with electricity access would tend to acquire new electric appliances; however, thanks to cost, energy intensity per household would increase marginally. Finally, the Biomass Energy Transition (BIO) scenario seeks to accelerate a fuel switch from traditional firewood to LPG. The transition is expected to be experienced partially in the manufacture of ylang-ylang, which would switch from wood to kerosene. Overall, under this scenario, the country would achieve sustainability and reduce its final energy consumption by 26% in 2033 (Figure 31).

Firewood dominates demand in the Reference scenario, as shown in Figure 32. However, the implementation of a strategy to reduce firewood use would ensure that it only makes up 25% of final energy demand in 2033, as represented in both the BIO and Combined (COM) scenarios. LPG would rise from less than 1% of demand to 9% in 2033, while the use of kerosene would not change appreciably. Electricity contribution would double from 3% of demand to 6% in the COM and accelerated electricity access scenarios.

On the supply side, the Energy Independence (ENE1) scenario would result in the decrease of electricity generation by 25% (from 145 GWh to 109 GWh) in 2033. This is attributed to grid stabilisation and reduced grid losses. In this scenario, geothermal would make a significant contribution to total energy generation, which is 55% renewable energy. The Biomass Energy Transition (BIO) scenario would have minimum effect on electricity supply. The marginal increase is attributed to the small number of households who would be adopting electricity for cooking in 2033. The Accelerated Electricity Access Scenario (ENE) would steeply increase electricity demand, as reflected in the high generation output. Implemented independently, this

Figure 31: Energy demand in all scenarios

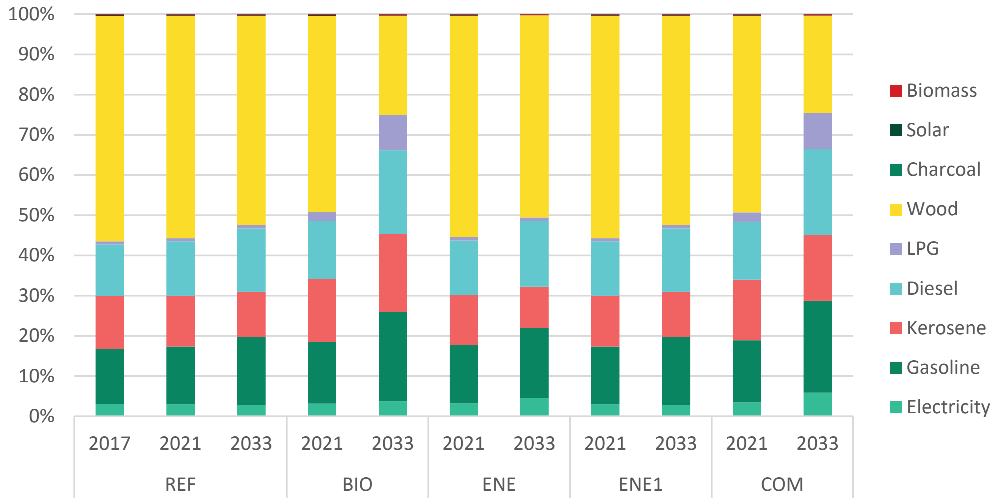


Source: Based on analysis in the LEAP Comoros energy systems model

scenario would increase the generation requirement to 226 GWh – 56% higher than the Reference scenario. But a combined implementation of the Accelerated Electricity Access and Energy Independence scenarios would keep down the increase to 17%. This is attributed to the savings from an enhanced grid network and a more efficient renewable energy technologies mix (Figure 33).

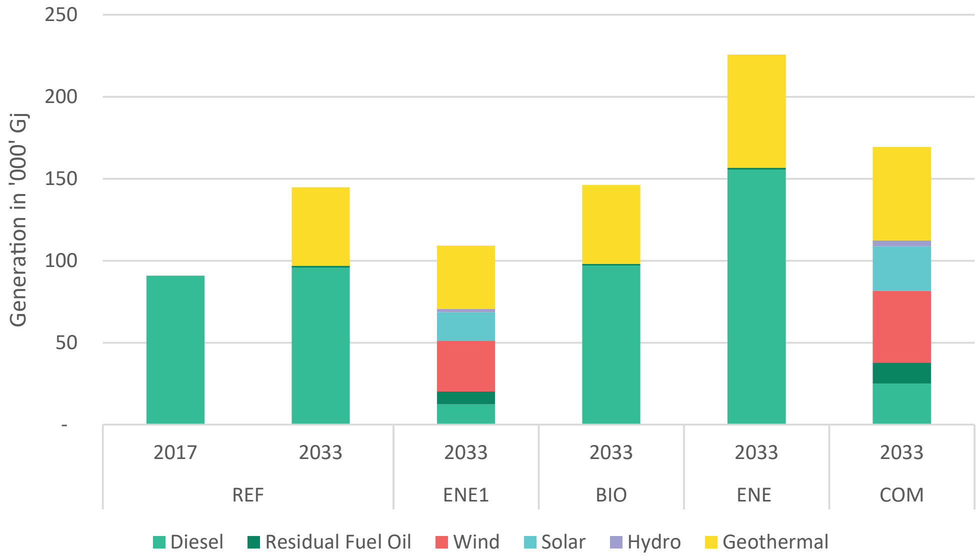
For the combined scenario, Table 10 shows that a total of 73 MW of installed capacity would be required. This would be made up of 27% renewable energy and 63% fossil fuel. In 2033, 1 MW of additional emergency power would also be required to meet the high demand.

Figure 32: Percent share for fuel for final energy demand



Source: Based on analysis in the LEAP Comoros energy systems model

Figure 33: Electricity supply in all scenarios



Source: Based on analysis in the LEAP Comoros energy systems model

Table 10: Plant capacity for the combined scenarios

	Grande Comore		Anjouan		Mohéli	
Power Plants	2017	2033	2017	2033	2017	2033
Centrale D Voidjou	16.2	16.2	-	-	-	-
Centrale DÍtsambueni	8.4	8.4	-	-	-	-
Fomboni Mohéli Diesel Plant	-	-	-	-	3.6	3.6
Generic Diesel Technology	-	-	-	-	-	1.0
Geothermal New	-	5.4	-	-	-	-
Hydro New	-	-	-	1.5	-	-
Lingoni Hydroelectric	-	-	0.3	0.3	-	-
Marakani village Hydroelectric	-	-	0.3	0.3	-	-
Moroni HFO	-	18.0	-	-	-	-
Ndrondroni Solar	-	-	-	-	-	0.1
Niamachoi_Ndrondroni_Miringoni	-	-	-	-	0.4	0.4
Solar New	-	6.4	-	3.9	-	0.5
Trenani Diesel Plant	-	-	5.7	5.7	-	-
Wind New	-	-	-	-	-	1.3
Total	24.6	54.4	6.3	11.7	4.0	6.9

Source: Based on analysis in the LEAP Comoros energy systems model

6. Conclusions and recommendations

This report focuses on the development of Comoros' first energy balance statistics (for 2017) and the development of the nationally and regionally disaggregated energy systems models. It also describes an analysis of scenarios based on targets the Energy Strategy 2033, in order to demonstrate the utility of the model for policy analysis and planning.

On the basis of baseline data from the developed 2017 energy balance statistics, the average national annual energy requirement is 9.1 gigajoules (GJ) per capita, with average annual electricity consumption of 66 kilowatt hours (kWh). Comparatively, the average electricity consumption across all Least Developed Countries was just over 200 kWh/capita in 2014. The energy intensity of the Comoros economy was USD 0.19 per megajoule (MJ) in 2017, similar to economic intensities observed in other Least Developed Countries. Wood and other biomass satisfy nearly half of primary energy needs in 2017, followed by diesel consumption. All petroleum products are imported.

The Energy Strategy 2033 of the Union of Comoros identified targets to be achieved. On the basis of the national and regional energy systems model developed in the LEAP tool, five scenarios are identified from the Energy Strategy 2033 to demonstrate the utility of the model for policy analysis and planning. The Reference Scenario is based on historic growth trends. The National Energy Independence Scenario requires the share of renewable energy in the energy mix to increase to 10% by 2018 and 55% by 2033. To achieve this goal, the national installed capacity of renewables on each of the islands will need to be 9.4 MW, based on the baseline electricity demand projection.

The Accelerated Electricity Access Scenario looks at increasing electrification to 60% by 2018 and 100% by 2033. To meet this goal, electricity demand would increase by 55% in 2033 to 135 GWh, requiring an additional capacity of 23 MW to satisfy demand. The Biomass Energy Transition Scenario seeks to reduce reliance on wood fuels to 65% by 2018 and 25% by 2033. In implementing this policy, Comoros would be able to save 20% of total final energy demand from the baseline and reduce total wood requirement for final energy delivery by 64%. This scenario requires expanded use of LPG requiring concerted action and active private sector involvement.

Combined, these policy interventions intended by the government are expected to yield the following results. On the supply side, the National Energy Independence scenario results in the decrease of electricity generation by 25% (from 145 GWh to 109 GWh) in 2033. This is attributed to grid stabilisation and reduced grid losses. The Biomass Energy Transition (BIO) Scenario has minimum effect on electricity supply. The Accelerated Electricity Access Scenario sharply increases electricity demand, increasing the generation requirement to 226 GWh – 56% higher than the Reference Scenario. A combined implementation of the Accelerated Electricity Access and National Energy Independence scenarios is expected to keep the increase at 17%.

In conclusion, the energy balance statistics for Comoros (2017) showed that 51% (or 3,820 TJ) of the total energy consumed is imported, while 49% (or 3,742 TJ) is generated within Comoros. Most of this generated energy is the firewood used in the residential sector for cooking. The total primary supply of energy on each of the three islands was 4,392 TJ for Grande Comore, 2,759 TJ for Anjouan and 411 TJ for Mohéli in 2017. However, an average of 13% of this energy is lost during transformation, transmission and distribution. Comoros has a great opportunity to reduce these losses through grid stabilisation. On the demand side, it is projected to grow from 6,597 TJ in 2017 to 11,189 TJ in 2033 in the baseline scenario. This would be met by 9,383 TJ total energy supply, made up of 72% oil products, 22% biomass and 6% renewable.

The following key recommendations are offered to strengthen Comoro's energy planning capacity and organization of energy statistics:

1. **Based on the 2017 Energy Balance Statistics developed at island and national levels, subsequent updates and reporting of energy balance statistics should be pursued by organizing national data in accordance with the baseline balance statistics established and the IEA guidelines.**

2. **Strengthen the Energy Planning Unit within the Directorate General of Energy, Mines and Water Resources as a hub for collecting and organizing energy sector data and to implement the national energy systems model to respond to energy sector policy and planning requirements.**

3. **Support institutionalization of the annual production of the national Energy Balance Statistics report by the Directorate General of Energy, Mines and Water Resources.**

4. **Maintain a national biomass inventory to support evaluation of sustainable biomass use and improve on biomass energy planning.**

5. **Conduct additional data gathering to fill the gaps in the developed national and regional energy systems models to improve the accuracy of the model for policy and planning uses.**

Finally, it is essential that Comoros continually build capacity in all energy sub-sectors and relevant government agencies if the country is to achieve the National Energy Strategy and Agenda 2030 Sustainable Development Goals, particularly goal #7 on energy.

It will be crucial for Comoros to mobilize resources for investment in the energy sector, including for needed infrastructure upgrades to reduce high losses. This measure will be crucial to raise the interest of the private sector to invest in the energy sector with concerted policy and operational efforts. Improvement in recovering fees is also a crucial area tied to improving the sector and attracting investment. These efforts should be supported by institutional and technical capacity development.

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8. Appendices

Appendix 1. Data entered in the current account

	DEMAND SIDE BEST MODELLING DATA					
	Assumptions/Demographic	**Comoros**	**Grande Comore (Nga)**	**Anjouan (Anj)**	**Mohéli (Moh)**	**Source**
K1	Rural households	Rural household/rural household size				Population census projection; 2003
K2	Urban households	Urban population/urban household size				
K3	Urbanisation	100*Urban population/total population				
K4	Urban population	Nga+Anj+Moh	101808	100495	30345	
K5	Rural population	Nga+Anj+Moh	320077	250364	25059	
K6	Total population	Urban population+rural population				
K7	Urban Household size	5.1	-	-	-	Demographic and Health survey, 2014
K8	Rural Household size	5.5	-	-	-	
	Assumptions/Economics					
K9	GDP constant price (Million KMF)	516137	-	-	-	Bureau of statistics projections
K10	GDP adjustment (Million KMF)	446	-	-	-	
K11	Primary Sector Value added	215508	-	-	-	
K12	Secondary sector value added	63428	-	-	-	
K13	Tertiary Sector value added	236755	-	-	-	
	Energy Demand	Comoros	Grande Comore	Anjouan	Mohéli	
D1	Household	Activity				
	Urban	28%	24%	29%	55%	
	Cooking	100% saturation	Energy Intensity per household			
	LPG (Kg/hhd_year)	8.70%	131.4	131.4	131.4	
	Kerosene (Liters/hhd_year)	43.80%	96.0	96.0	96.0	
	Charcoal (Kg/hhd_year)	2.50%	60.0	60.0	60.0	
	Wood (Kg/hhd_year)	43.40%	1861.5	1861.5	1861.5	
	Biomass (Kg/hhd_year)	0.60%	1861.5	1861.5	1861.5	
	Electricity (kWh/hhd_year)	1%	100.9	222.0	277.4	
	Lighting	100% saturation				
	Electricity (kWh/hhd_year)	0	100.9/ 88.64%	222/ 65.23%	277.4/ 61.85%	
	Kerosene (Liters/hhd_year)	24	3.61%	31.44%	32.97%	
	Paraffin waxes	0	6.48%	1.39%	1.09%	
	Solar (kWh/hhd_year)	1221.9	1.17%	0.70%	3.68%	
	Others	0	0.10%	1.24%	0.41%	
	Others	100% saturation				

	Electricity (kWh)		22867.0	144500.0	210136.5	
	Wood (Kg)					
	Rural	72%	76%	71%	45%	
	Cooking	100% saturation				
	LPG	1.60%	131.4	131.4	131.4	
	Kerosene	5.50%	96.0	96.0	96.0	
	Charcoal	1.40%	60.0	60.0	60.0	
	Wood	90.90%	1861.5	1861.5	1861.5	
	Biomass	0.30%	1861.5	1861.5	1861.5	
	Electricity	0.30%	100.9	222.0	277.4	
	Lighting	100% saturation				
	Electricity	0	100.9 / 81.71%	222/ 65.23%	277.4 / 61.85%	
	Kerosene	24	11.46%	31.44%	32.97%	
	Paraffin waxes	0	4.77%	1.39%	1.09%	
	Solar	1221.9	1.64%	0.70%	3.68%	
		0	0.42%	1.24%	0.41%	
	Others	100% saturation				
	Electricity (kWh)	100%	-	-	-	
	Wood (Kg)	100%	-	-	-	
D2	Industrial and commercial Sector	Comoros	Grande Comore	Anjouan	Mohéli	
	Activity Level	GDP Value added secondary and Tertiary				
	Commercial Buildings					
	Electricity (j/KMF)	100%	71	63.6	120.9	
	Solar PV (j/KMF)	100%	5.4	5.4	5.3	
	LPG Gas (j/KMF)	100%	63.6	63.6	62.4	
	Essential oil distilleries (Tons of oil as at 2013)		3.50	45.50	4.00	
	Firewood		86%	95%	37%	
	Improved Firewood boiler (t of wood/t of oil)	182.9	17%	11%	100%	
	Traditional Firewood boiler (t of wood/t of oil)	365.9	83%	89%	0%	
	Hybrid solar _wood boiler (t of wood/t of oil)	0	-	-	-	
	Kerosene		14%	5%	63%	
	Kerosene boiler (t of wood/t of oil)	57.8	100%	100%	100%	
D3	Transport Sector	Comoros	Grande Comore	Anjouan	Mohéli	
	Activity Level	GDP at Constant price				
	Road	100%	-	-	-	

	Diesel	100%	2379.2	902.4	701.6	
	Gasoline (Joules/KMF)	100%	2382.3	1012.9	1658.6	
	Marine (Boat_km)		5306256	5835348	1771308	
	Kerosene (Liters/Boat_km)	0.48	-	-	-	
	Aviation	100%	-	-	-	
	Jet Kerosene	100%	220.1	220	217.6	

Appendix 2

	2017 Current Account					2021 Mitigation of Forest degradation					2033 Mitigation of Forest degradation			
Household														
Urban	Comoros	Grande Comore (Nga)	Anjouan (Anj)	Mohéli (Moh)		Comoros	Grande Comore (Nga)	Anjouan (Anj)	Mohéli (Moh)		Comoros	Grande Comore (Nga)	Anjouan (Anj)	Mohéli (Moh)
	Current account cooking fuel share					Cooking Energy Transitions					Cooking Energy Transitions			
	100.00%	0	0	0		100.0%	0	0	0		100.0%	0	0	0
LPG	8.70%	-	-	-		20.0%	-	-	-		60.0%	-	-	-
Kerosene	43.80%	-	-	-		40.0%	-	-	-		24.4%	-	-	-
Charcoal	2.50%	-	-	-		1.9%	-	-	-		0.0%	-	-	-
Wood	43.40%	-	-	-		35.5%	-	-	-		10.0%	-	-	-
Biomass	0.60%	'//';oijy-	-	-		0.6%	-	-	-		0.6%	-	-	-
Electricity	1%	-	-	-		2.0%	-	-	-		5.0%	-	-	-
Rural	Comoros	Ngazidja (Nga)	Anjouan (Anj)	Mohéli (Moh)		Comoros	Grande Comore (Nga)	Anjouan (Anj)	Mohéli (Moh)		Comoros	Grande Comore (Nga)	Anjouan (Anj)	Mohéli (Moh)
						Cooking Energy Transitions					Cooking Energy Transitions			
	100.00%					100%	0	0	0		100%	0	0	0
LPG	1.60%	-	-	-		10%	-	-	-		30%	-	-	-
Kerosene	5.50%	-	-	-		13%	-	-	-		29%	-	-	-
Charcoal	1.40%	-	-	-		1.40%	-	-	-		0.00%	-	-	-
Wood	90.90%	-	-	-		75%	-	-	-		40%	-	-	-
Biomass	0.30%	-	-	-		0.30%	-	-	-		0.30%	-	-	-
Electricity	0.30%	-	-	-		0.30%	-	-	-		0.30%	-	-	-
Industry and Commerce Sector														
Essential Oil Distilleries														
Firewood	0	86%	95%	37%									70%	
Improved Firewood burner	0	17%	11%	100%			30%	30%				45%	45%	
Traditional Firewood burner	0	83%	89%	0%			70%	70%				55%	55%	
Firewood _ Solar hybrid	0	-	-	-										10%
Kerosene		14%	5%	63%									30%	
Kerosene burner	100%													

Appendix 3

Mohéli					Anjouan					Grande Comore				
Groupes	Puissance Installée (KW)	Puissance disponible (KW)	Année installation	Stopped	Groupes	Puissance Installée (KW)	Puissance disponible (KW)	Année installation	Stopped	Groupes	Puissance Installée (KW)	Puissance disponible (KW)	Année installation	Stopped
Groupe1	580	450	2004	2011	Groupe1	1280		2006		Groupe1				
Groupe2	528	400	2006	2010	Groupe2	800	2207	2006		Groupe2				
Groupe3	800	700	2009	2014	Groupe3	2920		2006		Groupe3				
Groupe4	890	700	2014	2016	Groupe4	2500	2599	2008		Groupe4				
Groupe5	890	700	2014	2016	Groupe5	2500	3004	2010		Groupe5				
Group 6	1200	1000	2016	2017	Group 6	3000	4350	2015		Group 6				
Groupe 6	2,000	1,800	May-17	running	Group 7	1,500	5,700	2017		Groupe 6				
Groupe 7	2000	1800	May-17	running						Groupe 7				