# Costs and benefits of the energy transition for different local actors and under consideration of macro-economic effects

D4.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 957843 (MAESHA). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein

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# Costs and benefits of the energy transition for different local actors and under consideration of macro-economic effects

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Date (06/10/2023)

# DELIVERABLE 4.3 – VERSION 3
# WORK PACKAGE N° 4

| Nature of the deliverable | | |
|---|---|---|
| **R** | Document, report (excluding the periodic and final reports) | x |
| **DEC** | Demonstrator, pilot, prototype, plan designs | |
| **DEM** | Websites, patents filing, press & media actions, videos, etc. | |
| **O** | Software, technical diagram, etc. | |

| Dissemination level | | |
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| **PU** | Public | x |
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**Quality procedure**

| Revision | Date | Created by | Short Description of Changes |
|---|---|---|---|
| **V1** | 11/09/2023 | TUB | Deliverable draft |
| **V2** | 25/09/2023 | TUB, ALDV, E3M | Draft with all partner inputs |
| **V3** | 06/10/2023 | TUB | Final version |

**Document Approver(s) and Reviewer(s):**

NOTE: All Approvers are required. Records of each approver must be maintained. All Reviewers in the list are considered required unless explicitly listed as Optional.

| Name | Role | Action | Date |
|---|---|---|---|
| **Juan Varo, Pablo Kobylinski (CREARA)** | Reviewer | External review | 29/09/2023 |
| **Panagiotis Fragkos (E3M), Ihab Taleb (ALDV), Lukas Otte (TUB)** | Authors | Internal review | 29/09/2023 |
| **Nikolas Schöne (TUB)** | Reviewer | Final review | 04/06/2023 |

# ACKNOWLEDGEMENT

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More information on the project can be found at https://www.maesha.eu

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# EXECUTIVE SUMMARY

Previous studies (ADEME, 2020; Flessa et al., 2023) have shown that the energy transition in Mayotte is feasible in both technological and economic regards. While the energy transition requires a far-reaching restructuring of the current energy system on the island towards renewable energy sources (RES), and concerted efforts to swiftly implement the necessary steps, the long-term gains of the energy transition are immense, compared to the current, unsustainable system with its considerable operating expenses for diesel-based power generation. This is true for all energy system trajectory scenarios that were developed for Mayotte as part of the E3-ISL modelling (Flessa et al., 2022, 2023).

Building on these previous modelling results, we deepen the analysis of the costs and benefits of the energy transition for Mayotte in the present Deliverable 4.3, considering a time horizon spanning the years 2015 to 2054. Out of the four decarbonization scenarios that were developed in the scope of E3-ISL, we particularly focus on the Decarb_Demand scenario for the analysis, which we deem highly relevant considering current energy system developments and the scope and emphasis of the MAESHA project. The Decarb_Demand scenario assumes an energy transition which is strongly based on citizen participation and demand-side efforts, such as energy efficiency gains, flexibility options and small-scale, distributed energy generation.

In line with the literature on cost benefit assessments of energy transitions (Breitschopf et al., 2016), the analysis aims at a holistic assessment on three levels, namely i) the macroeconomic level, covering economy-wide effects of the transition, ii) the energy system level, and iii) the micro-level, focusing on costs and benefits for energy market actors. The cost benefit assessment leverages the long-term planning energy-economy modelling tools, methodology and projections into an integrated evaluation of economic, social, employment and distributional impacts of the island transition, including actor-suited cash flow analysis, and provides important indications for desirable energy system trajectories and potential policy designs. Given the considerable solar potential of Mayotte, we lay particular focus on an analysis of optimal solar photovoltaic (PV) distribution and local consumption of (shared) electricity, and the economic viability of the technology, particularly for prosumers and other small-scale producers.

On the economy-wide level, we investigate the effects of RES-induced electricity price reductions, employment effects, and the role of the current diesel subsidies for Mayotte. Our analysis reveals significant benefits of the energy transition for Mayotte’s economy, including economic growth, increased economic competitiveness and job creation, with an additional 10-11,000 jobs created over the modelling horizon. These benefits are strongly driven by the savings realized by the replacement of costly diesel-based electricity production and associated electricity price reductions.

On the level of the energy system, we enrich previous analyses by a detailed investigation of regional energy demands, RES potential and existing grid infrastructure to determine suitable power plant locations, particularly for solar PV installations. By minimizing grid connection costs and considering the particularities of differing RES sources, this analysis feeds into an optimization of regional consumption and RES integration. In addition, the costs and subsidization of the current diesel-based system for power generation emerge as cross-cutting themes, extending from the level of the energy system to costs and benefits on the macro- and microeconomic level.

On the micro-level of individual energy market actors, we focus on costs, benefits and incentives for producers, investors, prosumers and consumers. We investigate the economic feasibility of selected technologies, comparing the profitability of an investment in renewables, namely commercial solar PV, rooftop solar PV, wind onshore, wind offshore, and geothermal to a conventional investment, i.e., the current diesel-based generation. Even without additional support such as Feed-in Tariffs (FiTs), many renewable technologies are highly profitable investments. An investment in diesel capacity, on the other side, is never profitable at market prices, and with increasing carbon prices under the Decarb_Demand scenario, the fuel switch to biodiesel becomes an economic necessity. The high economic feasibility of utility-scale RES in Mayotte, particularly for solar PV, points at non-economic barriers to their widespread adoption.

We also investigate the economic attractiveness of rooftop solar PV for prosumers, who present an important pillar of the citizen-driven transition in the Decarb_Demand scenario. Investments in rooftop solar PV is economically attractive for prosumers across all system sizes, ranging from under 3 to 100 kWp. Under a continuation of the current FiT system, smaller rooftop solar PV systems profit from higher per-kWh FiT compensation, which is a main driver of prosumer system profitability. Without access to wholesale electricity markets, prosumers rationally decide to self-consume the generated electricity once FiTs fall below average after-tax electricity prices. With a yearly maximum self-consumption rate limited to 30% without storage, and a relative economic advantage of electricity feed-in over self-consumption in most periods, however, total self-consumption of prosumers remains limited in our analyses.

Lastly, we discuss cross-cutting issues related to energy policies, with a focus on their potential distributional effects. This includes a discussion of the costs and benefits of the transition for consumers, including the effects of reduced electricity prices resulting from higher RES penetration and a potential fade-out of energy subsidies for Mayotte. We identify the current energy subsidies for non-interconnected zones, which lower the electricity prices on islands to the level of electricity tariffs in mainland France, as an important policy lever. While the subsidy protects consumers from unaffordable electricity prices, it favours the current diesel-based system, leading to a potential carbon lock-in with immense economic and ecological costs. Under a continuation of the status quo, the diesel-based system reaches a negative net present value (NPV) of over one billion Euros and carbon emissions of nearly 13 million tons by 2054. A gradual phase-out of diesel subsidies from 2030 onwards, on the other hand, results in savings of 758 million Euros in direct subsidies alone, which outweighs the costs of rising electricity prices for consumers. Redistributing these savings to consumers through direct transfers or other support measures would achieve the objective of the current subsidy of protecting consumers from unaffordable energy costs, while providing incentives for energy efficiency and RES investments.

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# 1. INTRODUCTION

The transition of energy systems has emerged as a critical focus area in the global effort to combat climate change and ensure a sustainable energy future, entailing a far-reaching transformation of these systems. The European Union (EU) is actively pursuing ambitious goals to reduce carbon emissions and the transition to cleaner and more sustainable energy sources. Its islands and non-interconnected zones face particular challenges and opportunities in this regard, including smaller scale grids and associated balancing requirements, but high renewable energy sources (RES) and innovation potential at the same time.

This report offers a detailed exploration of the costs and benefits of the energy transition, of Mayotte, an island in the Indian Ocean and overseas department of France. In line with the literature on cost benefit assessments of energy transitions (Breitschopf et al., 2016), the analysis aims at a holistic assessment on three levels, namely i) the macroeconomic level, covering economy-wide effects of the transition, ii) the energy system level, and iii) the micro-level, focusing on costs and benefits for energy market actors (see Figure 1).

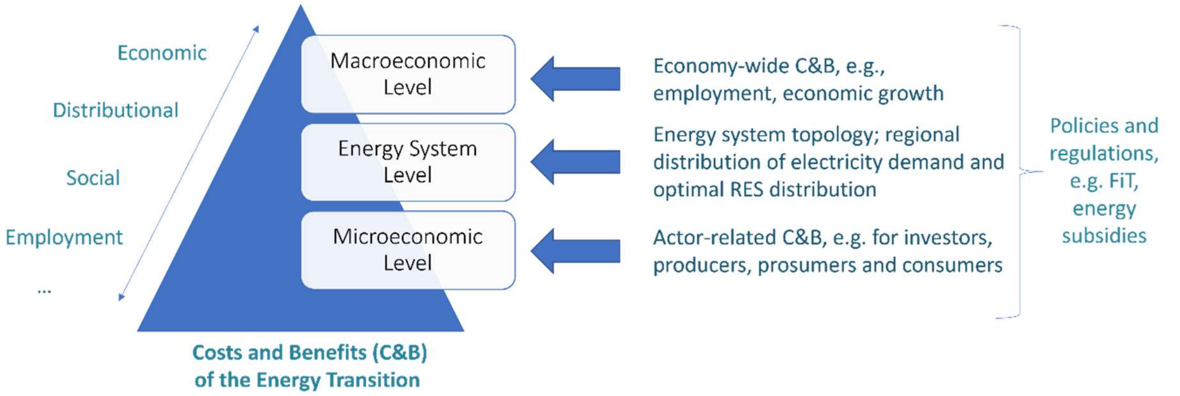

Figure 1: Topics and scope of the cost benefit analysis

Further developing previous energy system modelling for Mayotte, we investigate the potential economic, distributional, social, and employment effects of the transition both today and in the future, covering the modelling horizon of the years 2015 to 2054 for baseline and decarbonization scenarios. As an orientation for decision-makers and stakeholders, we discuss the policy environment underlying our analysis, and the implications that arise for the design of enabling frameworks for clean, just and inclusive energy transitions. Based on these detailed analyses, this report aims to provide valuable insights into the challenges and opportunities associated with Mayotte's energy transition. Beyond the specific case of Mayotte, our findings have broader applicability for the energy transition of other island communities, pioneering global efforts to combat climate change.

While many topics considered in the analysis have important implications on all three levels, we assign each to one of the respective levels. Following this outline, the report is structured as follows: Section 2 provides a short overview of the local context, followed by a detailed description of the methodology and modelling approach in Section 3 . Section 4 provides an overview of economy-wide effects. Section 5 outlines relevant costs and benefits on the energy system level, with a particular focus on regional optimization. Section 6 explores the economic viability of power generation investments in detail, covering the perspectives of producers, investors and prosumers, as well as the distributional effects of the transition for consumers and the role of electricity price subsidies in Mayotte. Section 7 shortly discusses the results and draws general conclusions.

## 2. ECONOMY AND ENERGY SYSTEM OF MAYOTTE

Mayotte is an overseas French island, located in the Mozambique Channel of the western Indian Ocean. Its area is 374 km$^2$ with a population of around 310 000 inhabitants and it is characterized by its unique geographical, socio-economic, and demographic dynamics. As an integral part of the Comoros archipelago, it stands as an essential hub in the region, serving as a crucial link between diverse cultural and economic spheres. The island, blessed with a rich natural environment, also offers significant opportunities for sustainable development, particularly in the utilization of solar photovoltaic (PV) technology for energy production.

In recent years, Mayotte has embarked on a journey to revolutionize its energy landscape. Traditional reliance on thermal power plants, which primarily utilize fossil fuels, is gradually giving way to more sustainable and environment-friendly options. Several projects have been initiated in this direction, focusing on harnessing the potential of renewable energy resources.

PV installations have emerged as a promising avenue, with projects aiming to increase the use of solar panels that can effectively meet the island's energy demands. Parallelly, investigations into the viability of wind turbines as an alternative renewable energy source are underway, aiming to diversify the energy portfolio of the island further. Furthermore, recognizing the environmental implications of continued reliance on thermal power plants, there is an increasing emphasis on transitioning towards greener alternatives. This shift marks a significant milestone in Mayotte's journey towards sustainable development, setting a precedent for integrating ecological considerations into economic planning and infrastructure development.

In this section we will discuss a general overview on the background of the island of Mayotte, including the demographic profile, economy, and the power generation in the island.

Mayotte's population, although relatively small, is dense and characterized by a blend of various ethnic groups. The population embodies a vibrant mixture of African, Malagasy, and Indo-Iranian roots, resulting in a rich tapestry of cultures and traditions. Mahorais, as the inhabitants are called, predominantly follow Islam, and the official language in Mayotte is the French language. Buildings are distributed around the island near the sea (Figure 1) and land use is lowest in the south of the island (Figure 2).

Figure 2: Buildings distribution across the island

Figure 3: Land use distribution across the island

The age distribution in Mayotte is notably youthful, with a substantial proportion of the population being under 25 years of age. This presents both challenges and opportunities in terms of education, employment, and infrastructure development.

The GDP of Mayotte has shown to be growing steadily in recent years. The island's economy is principally anchored in the tertiary sector as well as the agricultural and fishing sectors. It highly depends on financial transfers and subsidies from the French government. These transfers account for a significant portion of the island's GDP.

Mayotte’s electric grid has two thermal power plants, one non-operating biomass power plant, and solar power distributed across the island. Mayotte's primary source of electricity generation is through thermal power plants, utilizing fossil fuels as the primary energy source. These plants have been the backbone of the island's electricity supply, providing power to meet the region's demands. However, there has been a growing recognition of the environmental impacts of these plants, prompting a shift towards more sustainable and renewable sources of energy. For this purpose, PV parks has been and is being installed across the island with the aim to decarbonize the energy of the island in the next years. As of 2023, Mayotte has about 20 MW of maximum capacity generation in PV, distributed across the island. Two high voltage lines, high voltage A, called HTA (20 KV) and high voltage B, called HTB (90 KV), distribute power over long distances.

Figure 4: PV production by regions of Mayotte (source: EDM Open Data)

With the aim of decarbonizing the energy of Mayotte, we provide an analysis of the electric grid, the regional demand, and the potential photovoltaic installations in Chapter 5.

# 3. METHODOLOGY

## 3.1. SCOPE AND FOCUS OF THE ANALYSIS

The cost benefit analysis under Task 4.4 builds considerably on and extends the work performed within Work Package 2 and is particularly linked with the Task 2.3 that was focused on the assessment of the medium- and long-term energy system, technology, socio-economic and emissions impacts triggered by the clean energy transition of the island of Mayotte by 2050. The cost benefit assessment leverages the long-term planning energy-economy modelling tools, methodology and projections into an integrated evaluation of economic, social, employment and distributional impacts of the island transition, including actor-suited cash flow analysis and provides important indications for desirable energy system trajectories and potential policy designs.

In the additional analyses, particular focus has been laid on the integration of the energy system modelling assumptions, inputs, and outputs, thereby presenting a holistic assessment in line with previous results and ensuring comparability and ease of replicability. Going beyond the future impact of the MAESHA project, the analysis focuses on the entire energy system and its long-term transition, as well as the effects of this shift on Mayotte's economy and population, including incentives, costs and benefits for diverse energy market stakeholders. Ongoing and future project activities and outputs, such as the complementary analysis (T8.1) and the life-cycle-assessment (T9.1) further complement the presented results with additional methods and findings. Given the considerable solar potential of Mayotte, we lay particular focus on an analysis of optimal solar PV distribution and local consumption of (shared) electricity, and the economic viability of the technology, particularly for prosumers and other small-scale producers.

Our analyses are based on a thorough review of relevant scientific literature and the compilation of additional data. Still, we found the available data for Mayotte needed for certain analyses to be limited, and hope that future research can profit from an improved data scope with higher regional resolution. For example, detailed socio-economic data for Mayotte is missing, complicating the estimation of the distributional effects of the energy transition.

## 3.2. OVERVIEW OF MODELLING APPROACH, SCENARIOS, AND RESULTS

### 3.2.1. Modelling approach

The work was based on inputs from previous work concluded by other work packages (WP1, WP2). The methodology for the analysis of the costs and benefits of the energy transition for the island of Mayotte has been structured across the following pillars:

1. Definition of the requirements of the analysis – selection of scenarios/pathways to be studied;
2. Selection of relevant modelling parameters and results from the scenario analysis and impact assessment performed within Task 2.3 (linked with Deliverable 2.3), such as energy consumption, energy supplied, energy production capacity, investment cost for energy system expansions, energy technologies within the system, and operation and maintenance cost of the energy system, energy prices, the share of renewable energy technology, and the shares of convectional fuel energy technologies in the energy market;
3. Data collection – most of the data were obtained from the energy database (Deliverable 1.3) and the local partner (EDM);
4. Examination of the monetised costs and economic benefits for energy transition investments across the various actors.

The cost benefit analysis relied largely on the model-based impact assessment performed in Task 2.3. The scenarios were simulated with the use of the energy-economy modelling tool (E3-ISL and GEM-E3-ISL) developed for Mayotte within Tasks 2.1 and 2.2. The integrated island-scale modelling framework E3-ISL/GEM-E3-ISL has been developed and customised to capture adequately the complex interlinkages of the energy system with the economy as well as the specificities of the economy and the energy system of a non-interconnected geographical island, i.e., service-oriented economy, already installed fossil-fired power plants, RES potentials, load seasonality, costs of RES and fossil fuels, energy efficiency potential in industries and households, flexibility services both on demand and supply side (i.e., demand response, rooftop solar PV, V2G, batteries, Power-to-X), etc. The main purpose of this modelling suite is to quantify and assess the energy- and emission-related as well as socio-economic impacts of various sectoral technology and policy pathways towards energy transition with optimal utilization of the available resources.

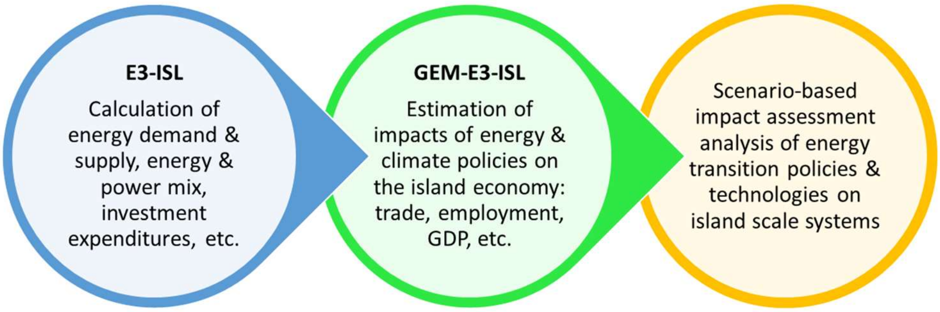

Figure 5: Energy-economy modelling framework for island-scale systems

#### 3.2.1.1. Energy system planning model E3-ISL

The energy system planning model **E3-ISL** is a fully-fledged energy demand and supply model for detailed energy system projections[1], energy demand forecasting, power sector planning, as well as for impact assessment of national and local climate and energy policy decisions with a horizon up to 2050. Methodologically, it is a version of the model **CompactPRIMES** developed by E3Modelling, customised to the specificities of geographical islands, and calibrated on the energy system of Mayotte.

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[1] Model projections include structure of energy demand by sector and by energy form, power generation mix by technology, investments per energy sector, $CO_2$ emissions, explicit calculation of electricity prices and overall energy system costs.

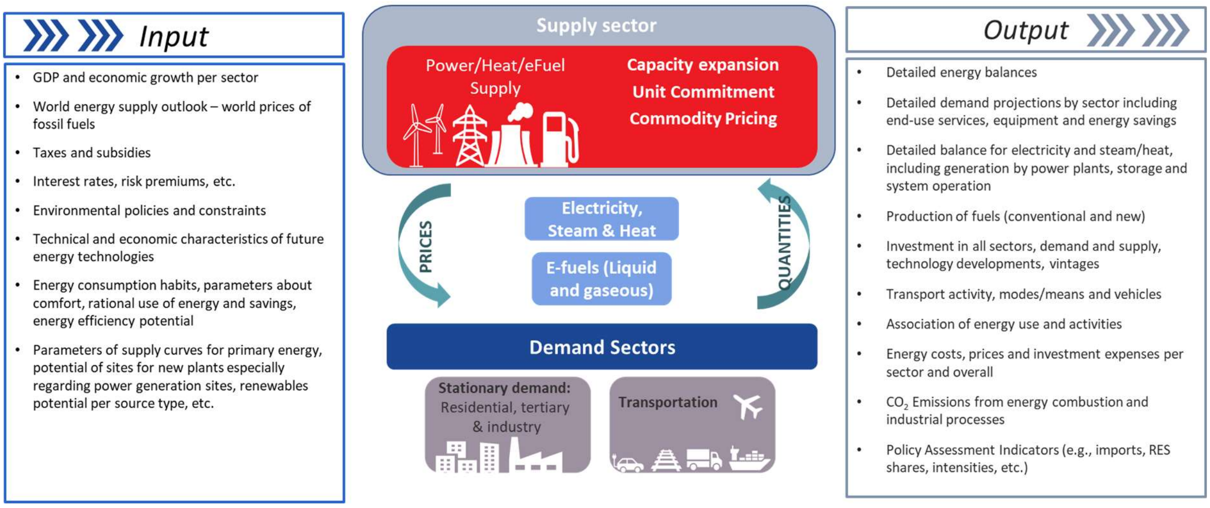

Figure 6 Structure and components of CompactPRIMES modelling tool.

The model is actor- and market-oriented, in the sense that it represents individual actors' decisions for the demand and supply of energy and the balancing of their decisions in simultaneous energy markets cleared by prices. As economic theory suggests, the simultaneous market clearing under perfect competition conditions leads to an overall optimum of economic welfare, which coincides with the minimum cost of energy for the end-users. In this sense, the model explicitly projects electricity prices into the future as derived from cost minimization in the supply side and the price-elastic behaviors of demanders for energy, thus achieving market equilibrium.

The model is executed in 5-year time steps from the base year (2015) up to 2050 and it is structured in modular way allowing for different mathematical principles and methodologies by sector depending on the specificities and the decision-making principles of the various agents in each sector. The Modules run sequentially, performing user-induced iterations. The Balancing and Reporting Modules produce the final results of the E3-ISL tool and reports them in user-friendly Excel-based files, which can be customized to include additional energy indicators relevant for Mayotte.

- **Demand Module**: it projects the demand for energy commodities and investments for energy efficiency in the industrial, tertiary, agricultural, residential and transport sectors. The module has also the capacity to simulate the inertia of the consumer's attitude on the energy-related options and decisions as well as the gradual change of their behaviours, habits and practices towards cleaner and environment-friendly choices paving the way for a clean energy transition, considering the impact of energy communities.

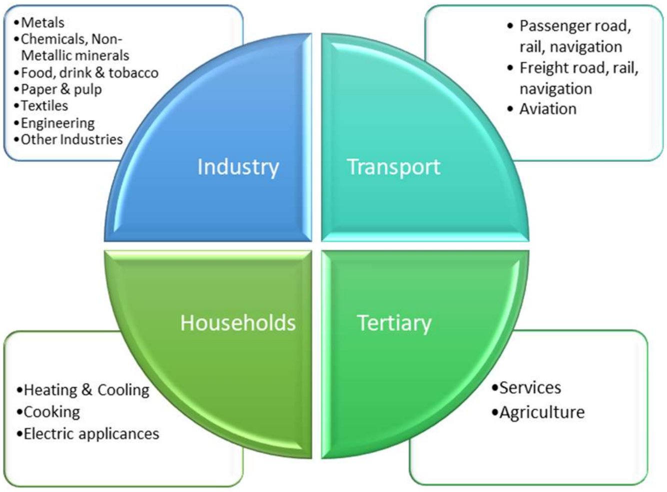

Figure 7 Sectoral coverage of E3-ISL Demand Module.

- **Supply Module**: This Module decides on how to cost-optimally serve the energy demand requirements for electricity and steam as well as hydrogen and clean fuels when eligible. The Supply Module incorporates a separate sub-module for commodity pricing. The Pricing sub-module calculates the tariffs of electricity and steam per sector of final demand considering the differential grid costs, as well as the tariffs for green hydrogen and synthetically produced fuels (clean fuels). The updated prices feed in the Demand Module in the next model iteration and fine-tune/adjust accordingly the demand for energy commodities (price-elastic behavior of energy consumers).

Table 1: E3-ISL – Power generation technologies

| Fuel | Technologies | | |
|---|---|---|---|
| Gas | Steam Turbine | Combined Cycle | Gas Turbine |
| Oil | Internal combustion | | |
| Wind | Wind onshore | Wind offshore | |
| Solar | Solar PV | Solar thermal | |
| Hydro | Hydro dam | Run of River | |
| Biomass | Biosolids fired | Biogas fired | Waste fired |
| Geothermal | Steam turbine | | |

The storage options, embedded in the model, are summarized in the following table:

Table 2: E3-ISL – Storage options

| Storage technologies | | | |
|---|---|---|---|
| Batteries | Hydrogen | Demand response | Pump storage |

Green hydrogen is anticipated to play a key role in the future as it is considered both as a blend in gas grid for buildings and as a primary fuel for the “hard-to-abate” sectors such as metal industries and transport. Regarding modelling perspective, the Supply Module generates the quantity of hydrogen needed by the end-use sectors, to be channelled either for direct use or as feedstock for the production of synthetic liquids for transport such as ammonia and synthetic kerosene. No time constraints are considered for the demand of hydrogen.

E3-ISL accommodates several climate- and energy-related policy drivers that lead to reductions in $CO_2$ emissions, penetration of renewable energy sources and energy savings. These drivers represent price-related and non-price-related policy instruments as well as regulatory standards. The most significant policy drivers are presented below. Among the price-related policy drivers of E3-ISL, the most significant one is carbon price. The **carbon price** represents either a carbon tax or the price of an emission allowance in case of an emission trading scheme.

**Table 3: E3-ISL model – Policy drivers**

| Policy driver | Description | Relevant Sector |
|---|---|---|
| Carbon price | Implicit emission reduction target | Demand and Supply sectors |
| Fuel Taxation | Excise taxes imposed on fuel prices | Demand and Supply sectors |
| Discount rates | Risk premium, which affects the weighted average cost of capital (WACC) of an investment. | Demand and Supply sectors |
| Subsidies | Promotion of efficient equipment | Demand-side sectors |
| | Support for heat recovery | Manufacturing sector |
| | Promotion of renewable fuels (solar, biofuels, etc.) | Demand-side sectors |
| Support schemes for RES, storage, Power-to-X, CCS | Feed-in-Tariff/Feed-in-Premium mechanism for power generation by RES, battery storage, Power-to-X facilities (including hydrogen) | Energy supply sector |
| Phase-out/Lifetime extension | Policies for lifetime extension of power plants and retrofitting or early retirement of plants | Power supply sector |
| Enabling conditions | Removal of non-price-related barriers (market failures, behavior/perception, etc.) associated to the use of emerging technologies and fuels | Demand and Supply sectors |
| | Technology progress/Learning-by-doing reducing the technology costs over time | |
| Regulation for ban of equipment or fuel | Policies to forbid the use of polluting equipment/fuel | Demand-side sectors |
| Regulations on technology standards | Emission performance standards | Transport sector |
| Biofuel mandates | Mandatory blending of conventional fuels with conventional and advanced biofuels as well as e-fuels in transport sector. | Transport sector |

Other features, embedded in the model, that represent the island-scale systems are:

- **Load seasonality**: The E3-ISL model accounts for the load variability within a year by using representative daily hourly load curves with a specific frequency/occurrence. These representative daily load curves vary according to season (winter, summer) and/or type of day (working day, holiday, peak, off-peak) to adequately capture the load variability and the peak load demand in Mayotte. The current version uses 6 typical days with average load, 1 typical day including the peak load of the power system, one typical day with low generation from variable renewable energy sources (rainy days, etc.) and one typical day with high RES generation (with increased flexibility needs).
- **Agent heterogeneity:** The Demand Module distinguishes three (3) agent classes with different preferences in the choice of *house equipment* and *private cars* based on the housing living standards, used as proxy to the socioeconomic status. With respect to the different agent classes, certain parameters in the model are differentiated across the agent classes such as the private discount rate for investment in energy technologies or energy efficiency, the utilization rate of equipment implying that there are different levels of demand for activity by agent class, etc.

- **Imports:** Regarding international trade, E3-ISL is linked with the international markets via the international prices. As a single-country modelling tool, it does not account for the simulation of the regional electricity markets.
- **Electricity tariff scheme**: The model simulates a well-functioning market, where the tariffs of electricity, hydrogen, and synthetically produced fuels per sector are calculated assuming that total energy system costs are recovered by agents, including also possible stranded investment costs. The tariffs distinguish between electricity generation and the provision of grid services (Transmission and Distribution). The price of electricity is calculated by type of voltage (base, medium, high) and consumer (households, industries, transport). Negative profit rate is used to simulate the price subsidization. Cross-subsidization between the sectors is used to calibrate the electricity prices in the base year.
- **Flexibility and balancing**: Various storage options are included in the model such as pure pumped storage plants, batteries and power-to-X plants, including the production of green hydrogen. Demand Response practices are embedded in the model and act as demand shifting (e.g., shifting the use of equipment, so as to smooth the daily peak). Another flexibility solution is the bi-directional EV charging – electricity can flow from the grid to the vehicle and vice-versa. Thus, the electric car´s battery can be used as a secondary home power source. Spinning reserves as well as non-operating reserves are considered to secure reliability of supply.

#### 3.2.1.2. Macroeconomic tool GEM-E3-ISL

GEM-E3-ISL is a compact version of the computable general equilibrium (CGE) model GEM-E3 - widely used by the European Commission for several studies and impact assessments for energy, climate and transport policies – developed in the MAESHA project. GEM-E3 is a multi-sectoral, recursive dynamic which provides details on the macro-economy and its interactions with the environment and the energy system. It is an empirical, large-scale model, written entirely in structural form. It covers the interlinkages between productive sectors, consumption, price formation of commodities, labour and capital, trade, and investment dynamics. The model provides projections for multiple sectors and covers the entire economy, including national accounts, investment, consumption, public finance, foreign trade, and employment.

The GEM-E3-ISL version identifies Mayotte as a single region, but also its linkage with the Rest of world through endogenous trade and financial transfers. The model represents various production sectors, including agricultural sectors, energy sectors, industrial manufacturing, multiple service-related sectors (both public and private), transport sectors by mode, construction, and multiple electricity generation technologies. The model features perfect competition market regimes, discrete representation of energy, transport, and power producing technologies, detailed energy and climate policies, carbon pricing and carbon taxation, including the possibility of various systems of carbon revenue recycling. The model is driven by the accumulation of capital, equipment and knowledge, features equilibrium unemployment, energy efficiency standards and carbon pricing and can quantify the socio-economic impacts of policies ensuring that in all scenarios the economic system remains in general equilibrium.

The model performs dynamic simulations, covering the period up to 2050 with a five-year time step and projects to the future the National Accounts, investment, consumption, activity by sector, prices, employment, and trade. It represents major aspects of public finance including all substantial taxes, social policy subsidies, public expenditures, and deficit financing, as well as policy instruments; . GEM-E3-ISL incorporates a detailed representation of the energy system, including electricity production with distinct power technologies, transport sector restructuring with electric vehicles and biofuels linked to agriculture, energy efficiency improvements and fuel switch potential by sector of activity.

Table 4: Energy system representation in GEM-E3-ISL

| | |
|---|---|
| **-Electricity production**<br>GEM-E3-ISL adopts a bottom-up approach for electricity sector with power producing technologies treated as separate production sectors. | **-Energy use in households**<br>Energy demand for households is divided into Heating and cooking demand and Electric Appliances and separated into different fuels. |
| **-Transport**<br>A bottom-up representation of the transport sector is included in GEM-E3-ISL, simulating the choice of alternative (public and private) transport modes and technologies and the way of using transport equipment. | **-Representation of hydrogen**<br>GEM-E3-ISL represents the production and demand of green hydrogen, which is triggered by ambitious climate policies (e.g., high carbon pricing). |

The GEM-E3-ISL model is calibrated to a base year data set (here 2015) that comprises a full Social Accounting Matrices for each country/region represented in the model. Bilateral trade flows are also calibrated for all sectors represented. Consumption and investment are built around transition matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. The initial starting point of the model, therefore, includes a very detailed treatment of taxation and trade.

The most important results, provided by GEM-E3-ISL are: Full Input-Output tables for each country/region identified in the model, dynamic projections of national accounts, employment by economic activity and unemployment rates, capital, interest rates and investment by country and sector, private and public consumption, bilateral trade flows, consumption matrices by product and investment matrix by ownership branch, GHG emissions by country, sector and fuel and detailed energy system projections (energy demand by sector and fuel, power generation mix, deployment of transport technologies, energy efficiency improvements).

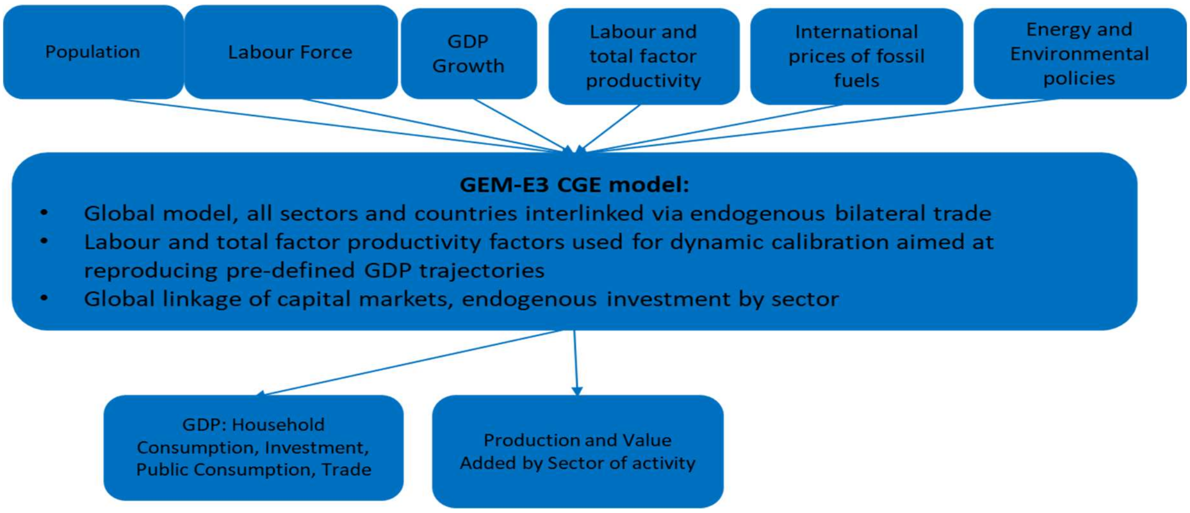

Figure 8: Main inputs and outputs to create scenarios in GEM-E3-ISL model

GEM-E3-ISL includes a detailed representation of energy system and technologies, thus enhancing the credibility of CGE modelling for energy transition and climate policy analysis as the substitution patterns in energy supply and demand are based on 'true' technologies rather than restrictive functional forms. Several mitigation options are available in GEM-E3-ISL, including a variety of renewable technologies, electric vehicles, biofuels, heat pumps, building retrofits, CCS, hydrogen, fuel substitution towards low-emission energy carriers and uptake of efficient equipment. The model endogenously decides on the optimal mix of mitigation options to achieve the climate target, choosing first the options with lower abatement costs. The uptake of specific technologies depends on the availability of other mitigation options, as the model captures the complex interlinkages among sectors and mitigation options.

### 3.2.2. Scenario outline

Multiple perspectives with different technology and policy focus, horizon of policy action, etc. were examined within Task 2.3 to define feasible energy transition pathways towards net-zero for the island of Mayotte. Based on a co-design approach of the MAESHA partners with relevant stakeholders, whose work is based on scenarios, several scenarios and variants were developed underpinning different future configurations of the energy system of Mayotte towards carbon neutrality by 2050 or sooner.

These scenarios simulate alternative visions of how the energy, policy, technology, and socio-economic context of Mayotte might evolve in the medium and long-term. Their impacts on energy consumption, fuel mix, technology uptake, $CO_2$ energy-related emissions, required investment, energy system costs and prices were quantified with the use the energy system planning model E3-ISL and the macroeconomic tool GEM-E3-ISL, and assessed against predetermined criteria for the future energy system of Mayotte, including the project KPIs like share of renewable energy, reduction of $CO_2$ emissions, etc.

The Table 5 below provides a comprehensive outline of the co-developed scenarios and summarizes their key features.

Table 5: Scenario outline

| Identifier | Policy focus | Transition horizon |
|---|---|---|
| *Base* | No significant change in attitudes, activities and policies with regard to the energy system.<br>Currently implemented energy and climate policies continue by 2050 but do not intensify, but reduction in low-carbon technology costs is included | No long-term target<br>Used as benchmark/business-as-usual case |
| *Decarb_Demand* | Active involvement of communities in the transition (energy savings, demand response, V2G, car sharing, high rooftop PVs, etc.), high electrification in demand side.<br>Policies: economy-wide carbon pricing, enabling conditions[2], emission and technology standards | Decarbonization of Mayotte's energy system by 2050 |
| *Decarb_Supply* | Moderate communities' response, moderate electrification, extensive utilization of hydrogen, e-fuels and biofuels to decarbonise the Mayotte's energy system<br>Policies: economy-wide high carbon pricing, emission and technology standards, blending mandates in transport, uptake of clean e-fuels | Decarbonization of Mayotte's energy system by 2050 |
| *Early_Decarb* | Early policy action and high ambition both in demand and supply side | Decarbonization of Mayotte's energy system by 2040-45 |
| *MAESHAfocus* | Full implementation of MAESHA proposed solutions by 2030<br>Achievement of MAESHA's relevant KPIs | Intermediate targets by 2030-2040 as set out in MAESHA<br>Decarbonization of Mayotte's energy system by 2050 |

For the purpose of the cost benefit analysis of the Task 4.4, two (2) scenarios have been selected for the primary analyses:

1. Baseline scenario
2. Decarb_Demand scenario

The Baseline scenario is used as a reference point against which the energy transition scenario will be compared in terms of costs and benefits. The consumer-driven transition scenario (Decarb_Demand scenario) entails lower energy system costs, since it assumes a gradual, not disruptive emission reduction effort and introduction of new clean energy technologies and a limited uptake of expensive mitigation options, like hydrogen and e-fuels, as communities are actively involved in the transition reducing their consumption requirements and adopting car sharing, rooftop PV and energy demand response (Figure 9). Moreover, the latter scenario generates more positive economic impacts compared to the other transition scenarios, pointing to the positive effects of energy efficiency, electrification, and active citizen participation in the transition to carbon neutrality.

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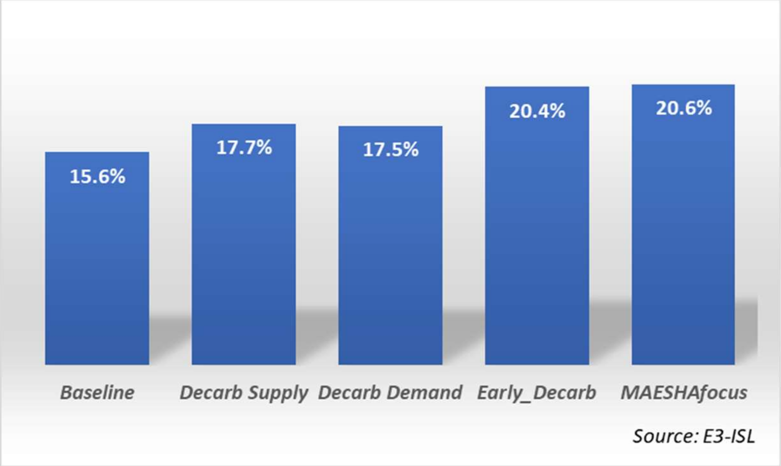
[2] Enabling conditions represent a set of policies aiming at the removal of uncertainties or non-price-related barriers associated with the use of new technologies or fuels. There are several relevant drivers in the model such as perceived costs and learning-by-doing.

The Early_Decarb and MAESHA_Focus scenarios assume rapid decarbonization, which entails higher initial costs, but increasing gains in the long term. While early decarbonization is an important trajectory to be followed, we opt for a detailed analysis of the more gradual decarbonization as foreseen in Decarb_Demand since i) Early_Decarb heavily focuses on a transition of the mobility sector, which is not the primary focus of the presented analysis and ii) the MAESHA_Focus scenario assumes a continuation of conventional diesel power generation, without a switch to biodiesel. Given current developments in Mayotte, however, we expect a timely switch to biodiesel, which should be incorporated in an analysis of the costs and benefits of the transition.

The Decarb_Supply scenario, lastly, considers a utility and supplier-driven decarbonization path focused on larger-scale energy generation assets and heavy electrification of overall higher energy demands, resulting in higher overall costs. We thus focus on the Decarb_Demand scenario, which is more closely aligned with MAESHA's focus on flexibility options and a citizen-driven transition.



*Source: E3-ISL*

Figure 9: Cumulative system costs as % of cumulative GDP by scenario

## 3.3. PROFITABILITY ANALYSIS OF INVESTMENTS IN POWER GENERATION ASSETS

### 3.3.1. Purpose, scope, and selected indicators

We conduct detailed analyses to assess the profitability of investments in power generation assets in Mayotte and allow for a comparison of investments, both over time and in different generation technologies. The analysis covers multiple timeframes, covering potential investment at the start of each five-year-period of the E3-ISL model ranging from 2015 to 2050. This methodology allows to i) compare the profitability and economic attractiveness of standard-sized investments, i.e., for 1 MW installed capacity, as well as ii) an assessment of the overall costs of the modelled energy system topology, particularly for diesel-based generation.

### 3.3.2. Methodological steps for the Cash Flow Analysis

The calculation of key indicators for the economic analysis follows four steps: We first compile technical data for each investment in power generation assets, including the installed capacity (gross and net), yearly runtime, and annual production (gross and net). Underlying data for these calculations include the self-consumption rate, dispatch according to modelling results, and the efficiency rate or capacity factor of the technology. We further calculate the fuel consumption (gross and net), and $CO_2$ emissions based on emission factors. The compilation of technical data is largely based on E3-ISL assumptions and inputs.

In a second step, we compile all cash flows over an investment's lifetime, based on the underlying technical data. This includes capital expenditures (CAPEX), operational expenditures (OPEX), costs related to taxation and revenues from electricity sales.

- The CAPEX represents the initial investment costs associated with purchasing and installing the power generation assets, such as construction, equipment, and infrastructure costs. It further accounts for the costs of capital, including financing expenses and the cost of raising capital. Capital costs relate to the installed capacity of assets, i.e., Euros per kW. In line with the modelling assumptions, the CAPEX is distributed as an annuity over the investment's economic lifetime, assuming a WACC of 8.5% for all technologies and investments.

- The OPEX is composed of fixed O&M, variable non-fuel O&M, as well as variable fuel costs for diesel-based power generation. Fixed O&M represent the ongoing costs required to maintain and operate the power generation assets, such as expenses for staffing, regular maintenance, and administrative costs. Fixed O&M costs are calculated based on installed capacity, i.e., Euros per kW. Variable O&M costs relate to operational variability of the power generation assets, including repair intervals, additional maintenance or replacement of components, and are calculated as costs per unit of electricity produced (Euros per kWh), i.e., based on the annual power production of each asset. Variable O&M costs do not apply to commercial and rooftop solar PV. The variable fuel costs for diesel, finally, represent the cost of (bio-) diesel for power production, based on fuel consumption for gross annual power production according to the fuel price at the time.

- Tax-related costs that are relevant for the analysis only include emissions taxation costs, given that all other taxes are profit-neutral or outside the scope of analysis. Emission taxation costs are calculated using the previously calculated $CO_2$ emissions from power production and projected carbon prices from the modelling scenarios, i.e., as Euros per ton.

- Revenues finally, are considered on a pre-tax basis, again in line with modelling assumptions, and based on the annual generated power sold to end consumers. All power producers receive the pre-tax electricity price calculated in E3-ISL for each unit sold, i.e., Euros per kWh. In E3-ISL, this price is calculated based on the total energy system costs divided by total energy generation, thereby recovering all system costs. It therefore varies according to the energy system setup and dispatch, e.g., between scenarios. RES generation technologies can additionally receive compensation through FiTs.

- The sum of CAPEX and OPEX represents the operational costs of the generation assets. Operational and taxation costs represent the total cost, while revenues from electricity sales represent the only source of producer revenues. The sum of costs and revenues results in the net cash flows, i.e., a profit or loss, in a given year.

In most cases, the assumptions, inputs, and prices of Steps 1 and 2 cover all 5-year-periods between 2015 and 2050, with some data missing for 2015. The data for each 5-year-period is assumed for all years in this period, e.g., capital costs for solar commercial PV in 2015 remain the same for the years 2016 to 2019. Different than in the E3-ISL modelling processes, we consider gross power production, not net production, for the calculation of costs and emissions, meaning that we incorporate the costs for self-consumption of power plants and other losses in the analysis.

In a third step, we calculate the Net Present Value (NPV) of investments using an 8.5% discount rate, in line with the modelling assumptions. This means discounting all cash flows from Step 2 to their present value, using the formula

NPV = Σ [CF_t / (1 + r)^t]

Where:

NPV = Net Present Value
CF_t = Cash flow in year t
r = Discount rate (8.5%)
t = Time period (year 1, 2, …)

Importantly, this NPV refers to the present value at the time of the investment. For an investment in 2030, for example, we therefore calculate the present value of its future expected cash flows for the year 2030, taking on the perspective of an investor considering this investment in the year 2030, not today. If the resulting NPV is positive, the investment is expected to generate a return above the discount rate, and therefore profitable. If it is negative, this suggests returns below the discount rate, meaning that the investment is not financially attractive. NPV is thus intuitive to interpret, and we use it as the main evaluation criterion for determining the economic attractiveness of investments. A related criterion would be the internal rate of return (IRR). In the present case, however, we view NPV as the more appropriate measure, considering the financing structure of investments (annuity instead of one-time payment) and the aims of the analysis, including the comparability of investment options. We calculate the total NPV over an investment's lifetime and the per-unit NPV, by dividing the total NPV by the total electricity generated and sold to end customers in this investment horizon.

Lastly, we calculate the Levelized Cost of Electricity (LCOE) as an additional measure of economic viability of each investment. The LCOE is calculated by dividing the total discounted costs of electricity generation, including CAPEX, OPEX and emission taxation costs, by the total electricity generated and sold to end customers over the investment's lifetime. The LCOE represents the discounted production costs per unit, with a lower LCOE indicating more cost-effective generation. It thus allows for a direct comparison between generation technologies or investments. At the same time, the LCOE represents the minimum revenue or tariff that a given investment would need to receive per unit produced to achieve cost-neutrality.

# 4. MACROECONOMIC IMPACTS

## 4.1. SUMMARY OF E3-ISL RESULTS

The Deliverable 2.3 discusses and assesses a series of alternative pathways for Mayotte to reach carbon neutrality by mid-century, using the integrated energy-economy modelling framework E3-ISL/GEM-E3-ISL. The following scenarios were simulated and quantified, capturing the local specificities, circumstances, and priorities for Mayotte's future development:

- The *Baseline scenario* (Base) that accounts for the existing energy and climate policies adopted by the end of 2020 (Business-As-Usual scenario).
- The *Consumer-driven decarbonization* scenario (Decarb_Demand) that assumes the decarbonization of the energy system of Mayotte by 2050 and assumes the active role of the local communities and consumers in the clean energy transition pathway.
- The *Supply-side decarbonization scenario* (Decarb_Supply) that sets also the decarbonization horizon of Mayotte to 2050, but it focuses on actions related to the energy supply side with limited changes in energy demand dynamics.
- The *Early decarbonization scenario* (Early_Decarb), that assumes the rapid enactment of transition policies and measures from 2025 onwards, leading to a decarbonized energy system earlier than 2050, in contrast to Decarb_Demand and Decarb_Supply scenarios that consider the initiation of transition efforts roughly from 2030 onwards.
- The *MAESHA-focused decarbonization* scenario (MAESHAfocus) that explores the impacts of a full implementation of MAESHA project solutions by 2025-2030 as well as the achievement of the relevant KPIs of the project, while intermediate targets for 2030 and 2040 are set before the full decarbonization of Mayotte by 2050.

In the current study, GEM-E3-ISL is soft-linked to the E3-ISL energy system model through exchanges of model parameters and variables, as described in deliverable D2.3. The soft link was enabled by the harmonization of the sectoral and technology representation and granularity of the two models (i.e., models represent the same power generating technologies, the same passenger car types, and the same sectoral split in the energy and transport sectors). In addition, the technology cost assumptions, and the energy and climate policies in each scenario are harmonized between the two models. The soft-link approach is based on the dynamic calibration of the relevant parameters of GEM-E3-ISL to the energy and technology-related projections of the E3-ISL model for each scenario (baseline and decarbonization scenarios). This is achieved by synchronizing different sets of energy-related variables and parameters, including among others, power generation mix, energy demand, fuel mix by sector, transport by fuel and mode, and energy efficiency measures.

The energy transition is a complex and lengthy process that requires high uptake of clean energy technologies, low-carbon innovation, sufficient financial resources, and coordination of market players, including policymakers, industrial manufactures, R&D providers, banks, infrastructure developers and final consumers. Energy system decarbonization involves the substitution of fossil fuels (which are imported in Mayotte) by products and services for zero-carbon technologies and energy-efficient equipment and appliances. The installation, operation and maintenance of these technologies is performed domestically, thus creating comparatively more jobs and value added in the island, in contrast to the import of fossil fuels for power generation. However, Mayotte does not have industrial capacities to manufacture these low-carbon technologies and equipment (e.g., electric cars, PV panels, wind turbines etc.) and it needs to import those from other countries.

The substitution towards low-emission technologies, appliances, and vehicles is an investment-intensive and technology-intensive process that requires economic restructuring away from fossil fuels. This process may be costly in the short-term, thus increasing the average price of services (e.g., the cost of transport will increase as electric cars have higher purchase costs than conventional oil-fired ones). However, in the longer term the socio-economic transformation may bring positive externalities driven by technology progress and cost reduction of zero-carbon technologies, reduced energy import bill as well as environmental benefits (e.g., reduced climate damages).

## 4.2. ELECTRICITY PRICE REDUCTIONS AND SOCIO-ECONOMIC BENEFITS

In Mayotte, the large-scale deployment of renewable energy in the electricity sector is expected to reduce the average cost of electricity production, and thus the electricity price, as the currently dominant diesel-fired plants have much higher LCOE than renewable-based alternatives. The reduced electricity price would benefit both domestic demand (as households would face lower energy bills) and production (as industries and services would reduce their production costs), hence increasing domestic economic activity and providing socio-economic benefits. These benefits would be much larger if there is adequate, low-cost availability of finance.

In the decarbonization scenarios, the imposition of high carbon pricing drives emissions reductions both in energy supply and demand sectors, accompanied by sectoral measures (including $CO_2$ standards in transport, technology and efficiency standards, support policies for mitigation options, etc.). The high carbon pricing drives energy system transformation towards a more capital-intensive structure, with increased investment in renewable energy, energy efficiency and low-emission vehicles. Decarbonization would lead to increased upfront capital expenditures and lower energy purchasing costs in the long term. GEM-E3-ISL (as a CGE model) assumes full and optimal use of available capital resources in the Baseline scenario under strict financial closure. Therefore, the reallocation of investment towards low-carbon, energy efficient technologies in the decarbonization scenarios puts pressure on the capital markets and leads to ‘crowding-out’ effects: Firms and households finance their clean energy investment by spending less on other (non-energy) commodities and investment purposes.

High carbon prices increase the cost of mobility services for firms and households and hence production costs throughout the economy and tends to have a depressive impact on GDP. However, in Mayotte this is more than counterbalanced by the increased low-carbon investment and the large reduction of the electricity price, driven by the substitution away from the very expensive diesel-fired power generation. The overall impact of decarbonization on Mayotte’s economy is found to be minimal in the medium term; but as transformation progresses and the impacts on electricity prices increase, the transition positively influences the island’s GDP, which is projected to increase by 1.5%-4.5% in different decarbonization scenarios relative to Baseline in 2050. The scenario focusing on consumer-driven transition (Decarb_Demand) with the active involvement of communities and consumers (engaging in energy savings, demand response, V2G, car sharing, electrification, rooftop PVs) generates more positive economic impacts relative to Decarb_Supply where the transition is driven by supply-side changes and uptake of clean e-fuels and hydrogen. This is a result of the relatively high costs to produce or import these clean fuels at a large scale, pointing to the positive effects of efficiency, electrification, and active citizen participation in the transition to net zero emissions.

In the scenarios achieving early decarbonization (MAESHA Focus and Early_decarb), the rapid energy sector transformation poses stresses in capital markets in 2020-2030 with negative impacts on economic activity through increased production costs. In these scenarios, Mayotte’s GDP is projected to decline by about 0.6%-1% from the Baseline scenario levels in 2030. However, in the longer term, Mayotte’s economy would experience the benefits of the transformation (e.g., reduced fossil fuel imports, lower electricity prices) but without facing the high costs to invest in low- and zero-carbon technologies as the decarbonization process is completed by 2040 or 2045. This means that in these scenarios, GDP gains are even higher in 2050 amounting to more than 4% compared to Baseline levels. The model-based analysis shows that the transition to carbon neutrality would have positive impacts on domestic economic activity (Figure 10) especially in the longer term mostly triggered by the phase-out of expensive diesel-fired power plants, even without quantifying the benefits related to avoided climate impacts, air quality and human health.

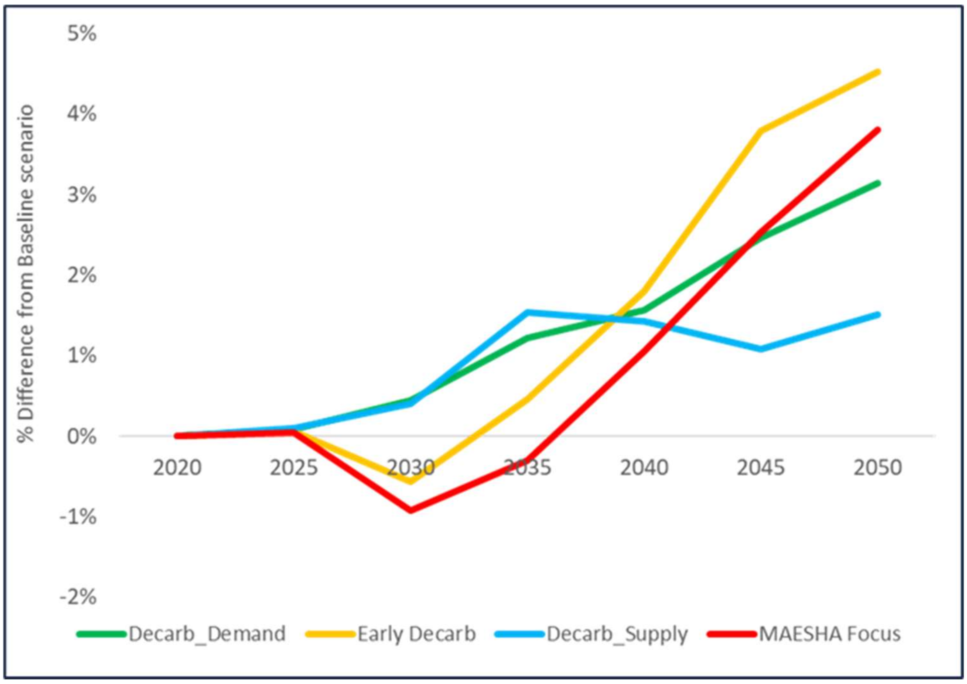


Figure 10: Impacts of decarbonization scenarios on Mayotte's GDP over 2020-2050

[1] Crowding-out effects can diminish in case a favourable financing scheme is assumed, as illustrated in (Fragkos & Paroussos, 2018). This study shows that if firms and households can borrow in capital markets without facing increasing unit costs of funding, GDP impacts of decarbonization are minimal and even positive (in the short term).

## 4.3. EMPLOYMENT IMPACTS BY SECTOR

The decarbonization of Mayotte's energy system would have profound impacts on employment and labour markets. As shown in Figure 11, the transition to climate neutrality would generate employment gains for Mayotte relative to the Baseline scenario. These are projected to amount to between 1%-3% in 2030, rising to about 8%-10% in 2050, following the growth of economic activity, which tends to increase the requirements for labour. In this context, the unemployment rate, which currently stands at about 25% in Mayotte, is projected to decline to around 12%-14% in 2050 in the decarbonization scenarios. The increased labour requirements have limited effects on wage rates, as the unemployment rate is relatively high, and the expanding sectors can attract new workers from the unemployed pool. In addition, the transition to carbon neutrality implies an economic restructuring away from imported fossil fuels and towards activities with higher labour intensity (e.g., installation of renewable energy technologies) with employment increasing relatively more than the economic activity in the island. These effects in the real world may be moderated as expanding sectors require different labour skills than those available in Mayotte's workforce, so a period of re-skilling and re-training would be required. However, this effect is not captured in the GEM-E3-ISL model due to the lack of data on skills in the island.

The positive impacts are more pronounced in the longer term, leading to the creation of about 10,000-11,000 additional jobs relative to Baseline in 2050 (for comparison, total employment in

Mayotte was about 55,000 in 2020). In the short-term, the increase in employment is more limited, amounting to 1,000 to 2,500 additional jobs in 2030. The transition to carbon neutrality requires the creation of jobs related to zero-carbon technologies (the so-called ‘green jobs’), namely jobs for the construction and operation of renewable energy plants, the installation of low-carbon equipment, energy efficient appliances, and electric vehicles, the production and use of new clean fuels (e.g., hydrogen), the management of an expanding electricity sector, the expansion of power grids, etc. Recent analyses (e.g., Fragkos & Paroussos, 2018) show that renewable energy and low-carbon technologies have a higher labour intensity than fossil fuels when jobs in the entire chain of related activities are considered; thus, expansion of low-carbon technologies that replace fossil fuels tends to increase job requirements and have positive impacts on labour markets.

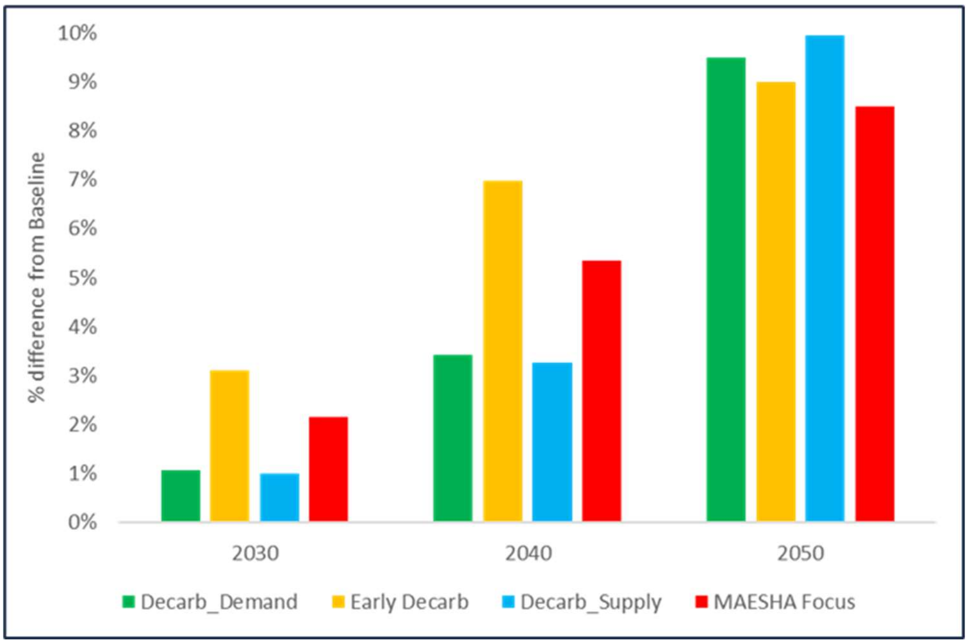


Figure 11: Impacts of decarbonization scenarios on Mayotte’s employment

The electricity sector in Mayotte is set for a rapid expansion under decarbonization scenarios as electrification of energy end uses is a key strategy to reduce emissions. Therefore, the electricity sector is projected to account for about 20% in 2050 of total jobs created in Mayotte relative to the Baseline scenario with more than 2000 additional jobs created. Most of these jobs are related to the operation and maintenance of renewable energy plants (mainly solar PV and wind), with lower number of hydrogen-related jobs. However, most of the job creation opportunities are created in the market and non-market services sector based on indirect impacts of decarbonisation on the island economy, i.e., those manifested through the supply chain effects and inter-sectoral linkages triggered mostly through the reduced electricity price that increases the consumption of households and firms and improves their competitiveness. Around 5,000-6,000 additional jobs are created in the services sector in 2050. The construction sector provides its services to install the renewable energy power plants, the expanded and reinforced power grids, the efficient equipment, hydrogen production, and low-emission vehicles, resulting in the creation of new construction jobs, which amount to about 20% of total job gains relative to Baseline scenario. The services sector accounts for more than 80% of island’s GDP and thus it is also influenced positively by the increasing economic activity. Finally, the manufacturing sector, despite its limited size in Mayotte, is also positively affected by the transition to carbon neutrality, triggered both by increased domestic demand and exports. Most new manufacturing jobs are created in the food industry and other industries, which account for most of the island’s manufacturing activity.

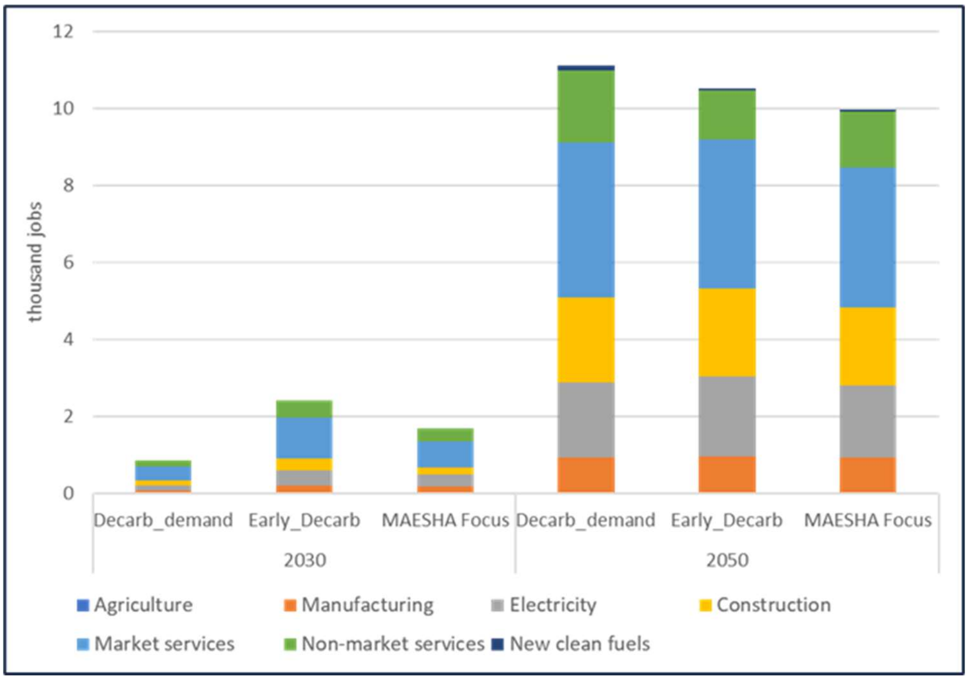


Figure 12: Impacts of decarbonization scenarios on Mayotte's employment by sector

# 5. ENERGY SYSTEM: OPTIMAL TOPOLOGY; COSTS AND BENEFITS OF THE TRANSITION

## 5.1. SUMMARY OF E3-ISL RESULTS

The study of Deliverable 2.3 discusses and assesses a series of alternative energy sector pathways for Mayotte to reach decarbonization by mid-century, with the use of the integrated energy-economy modelling framework E3-ISL/GEM-E3-ISL. The following scenarios were simulated and quantified, capturing the local specificities, circumstances, and priorities for the future development of the energy and economic sectors of Mayotte:

- The *Baseline scenario* (Base) that accounts for the existing energy and climate policies adopted by the end of 2020 (Business-As-Usual scenario).
- The *Consumer-driven decarbonization* scenario (Decarb_Demand) that assumes the decarbonization of the energy system of Mayotte by 2050 and assumes the active role of the local communities and consumers in the clean energy transition pathway.
- The *Supply-side decarbonization scenario* (Decarb_Supply) that sets also the decarbonization horizon of Mayotte to 2050, but it focuses on actions related to the energy supply side with limited changes in energy demand dynamics.
- The *Early decarbonization scenario* (Early_Decarb), that assumes the rapid enactment of transition policies and measures from 2025 onwards, leading to a decarbonized energy system earlier than 2050, in contrast to Decarb_Demand and Decarb_Supply scenarios that consider the initiation of transition efforts roughly from 2030 onwards.
- The *MAESHA-focused decarbonization* scenario (MAESHAfocus) that explores the impacts of a full implementation of MAESHA project solutions by 2025-2030 as well as the achievement of the relevant KPIs of the project, while intermediate targets for 2030 and 2040 are set before the full decarbonization of Mayotte by 2050.

These pathways are evaluated based on their impacts, against a series of criteria, including: 1) mid- and long-term energy transition and climate targets, 2) energy security and security of energy supply, 3) energy system costs, prices, and socio-economic implications. The full study of D2.3 is published in the MAESHA website[3].

This section will be principally devoted to the results of the Baseline and Decarb_Demand scenarios that were further analysed in terms of the costs, benefits and distributional effects within the framework of Task 4.4.

### 5.1.1. Key framework conditions of the scenario analysis

The development of the energy sector strongly depends on the long-term evolution of population, GDP, and sectoral production of Mayotte, as well as external determinants such as the energy prices (crude oil), the technology costs and EU-related climate and energy policies. The economic and demographic dynamics are underpinned by econometric projections, official economic development plans and international prospects. In this respect, the macroeconomic outlook builds on recent demographic and economic projections provided by the UN and IMF, as well as local economic reports. According to the UN world population prospects (medium variant), Mayotte's population is

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[3] https://www.maesha.eu/?smd_process_download=1&download_id=1096

expected to continue growing in the next decades, reaching 495 thousand inhabitants by 2050. The growth of the island's economy is assumed to continue in the period 2022-2026 with an average annual growth rate of 4%, 4.95% in 2027-2035, and about 4% in the period 2036-2050. Accordingly, the GDP per capita in Mayotte increases from about 9,500 EUR/capita in 2019 to 18,870 EUR/capita in 2050, growing with an average annual growth of 2.3% per annum over 2020-2050.

The major contributor to the local economy is the services sector (85%) followed by industry and energy (7% jointly), while the agriculture and construction sectors represent 3.5% and 4.5% of the island's economic activity respectively. The manufacturing branch is less developed in Mayotte and includes activities such as food processing (dairy, eggs, animal feed, beverages, bakery, beer), bottling, soap manufacturing printing, reproduction, metalworking, woodworks, and plastics. In this respect, no major structural economic changes are assumed to be materialized in Mayotte's economy in the long term. The economy of Mayotte is envisaged to continue to be dominated by the services sector, which currently accounts for more than 85% of the island's GDP, while a slight increase is assumed in the share of construction sector, based on the population rise and the current living standards, accompanied by a respective reduction in the share of agriculture based on international trends as incomes grow. The majority of the value added of the services corresponds to the public sector – this could be changed in the future, assuming higher growth of tourism on the island.

The rising population and income, as well as the trend of increasing car ownership in the medium and long run[4], is expected to drive primarily the growth of private road transport, accounting for over 60% of total passenger activity. Likewise, freight transport activity is projected to grow vigorously until 2050, owing to the high economic activity and demand for transportation of goods and products.

The trajectories of the international fossil fuel prices are derived from the "EU Reference Scenario 2020, Energy, transport and GHG emissions – Trends to 2050"[5]. The long-term estimates of the international fuel prices are derived from the Global Energy and Climate Outlook (GECO[6]) JRC report, also considering the recent increase in oil and gas prices, that is assumed to continue in the midterm.

The technology cost estimates and their evolution in E3-ISL model are derived from the most recent and official source available, i.e., the European Commission in its assessments for Fit for 55 package[7] as well as the ASSET study - Technology pathways in decarbonization scenarios[8].

Belonging to the EU, Mayotte's climate policy framework should be aligned with relevant EU directives and climate regulations. In this respect, already established policy instruments in the EU, such as the EU-ETS, have been taken into consideration.

### 5.1.2. The baseline scenario

The Baseline Scenario depicts a future state of the energy system of Mayotte in which only the energy and climate policies that are already in the pipeline today are implemented and follows the current and emerging trends regarding energy technologies and practices. This scenario serves as a benchmark point upon which the transition pathways have been developed and assessed. The policies considered are those derived from the French legislation (e.g., on fuel taxation) and the relevant EU Directives (EU-ETS, technology performance standards for cars and vans).

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[4] The motorization rate is currently low in Mayotte (less than 100 cars per 1000 inhabitants).

[5] https://data.europa.eu/doi/10.2833/35750

[6] https://ec.europa.eu/jrc/en/geco

[7] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

[8] Available at: https://ec.europa.eu/energy/sites/ener/files/documents/2018_06_27_technology_pathways_-_finalreportmain2.pdf

The Baseline Scenario reflects policies at EU and Member State level, including the Ecodesign Directive[9] and the Energy Labelling Regulation[10] as well as the implementing measures, the revised Energy Efficiency Directive[11] (EED) and the revised Energy Performance of Buildings Directive[12](EPBD). Mayotte, as part of the EU, participates also in the EU-ETS. The Baseline scenario considers the application of a carbon price for the sectors currently covered by the EU-ETS (heavy industry, power and heat/steam generation, aviation). The trajectory for 2020-2050 is derived from the official Reference scenario 2020[13] of the European Commission.

An important policy instrument to reduce emissions from road transport is the regulation on $CO_2$ emission performance standards for new passenger cars and light commercial vans[14]. E3-ISL considers such fleet-wide emission targets in the decision process regarding new investments for cars and vans.

Table 6 Baseline – Policy drivers

| Policy Driver | Unit | Sector/End-use | 2015 | 2020 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|
| **Carbon price** | €/ton$CO_2$ | Industry-Power - Aviation | 25.0 | 25.0 | 80.0 | 80.0 | 120.0 | 150.0 |
| **Carbon standards** | % reduction vs 2020 | Passenger cars | - | - | -15% | -28% | -44% | -50% |
| | | LDVs | - | - | -15% | -28% | -40% | -40% |

In the Baseline scenario, a relative decoupling of energy demand growth from GDP is observed due to the reduction in energy intensity – 110% growth of Gross Inland Consumption and 259% of GDP increase in the period 2020-2050. Oil products are anticipated to continue being the dominant energy carrier in the fuel mix of the demand-side sectors with a small decline in their share from 62% in 2020 to 59% in 2050. Transport remains the most energy-consuming sector (51% in 2020 and 54% in 2050) assuming limited decoupling of activity from energy consumption and a low electrification rate, mainly owing to the population growth, rising standards of living and higher car ownership rates. Limited energy efficiency improvements are anticipated in buildings and manufacturing in the long run, driven mainly by technology progress and low electrification rate.

Regarding the power supply sector, E3-ISL considers all current and candidate power plants in Mayotte. Based on the feedback provided by local stakeholders and EDM on the future planning of the power system, the four (4) older units G01-G04 of Badamiers plant are decommissioned before 2020, whilst the units G05-G08 of Badamiers plant are to be decommissioned by 2023. No other plant decommissioning is scheduled – Longoni I &II and Badamiers G21-24 will be operating until 2050, albeit with higher utilisation rate. The ongoing battery storage project of 11.5 MW is envisaged to enter the system by 2025.

Diesel oil is expected to continue dominating the power supply sector until 2050, albeit with decreasing share. New solar PV and wind capacities will differentiate the power mix of Mayotte, mainly driven by the decreasing technology costs of solar panels and wind turbines. In the short term, all PV plants that have already acquired license to operate are assumed to be connected gradually to the grid by 2030. The current trend of slow penetration of variable RES persists by 2030, corresponding merely to solar PV, whilst capacity investments on wind onshore are assumed to be materialised only in 2040 onwards. The pre-tax electricity tariff is expected to rise driven by the increasing diesel price

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[9] Directive (EU) 2009/125/EC

[10] Regulation (EU) 2017/1369

[11] Directive (EU) 2018/2002

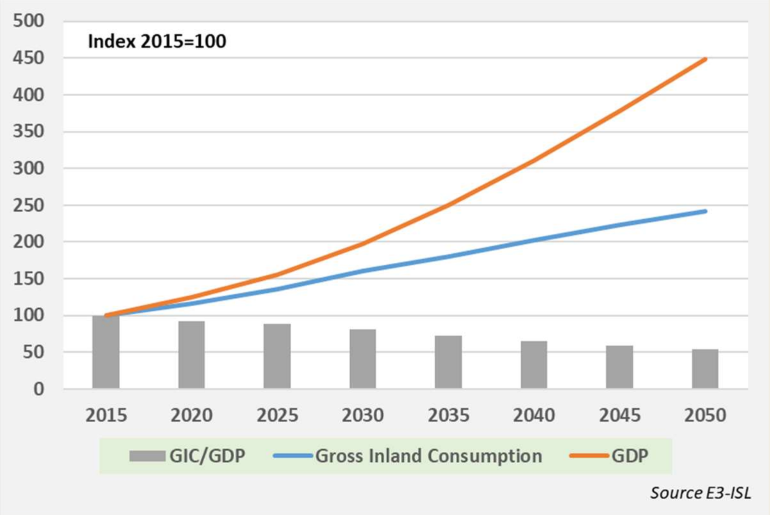
[12] Directive (EU) 2018/844

[13] https://data.europa.eu/doi/10.2833/35750

[14] https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en

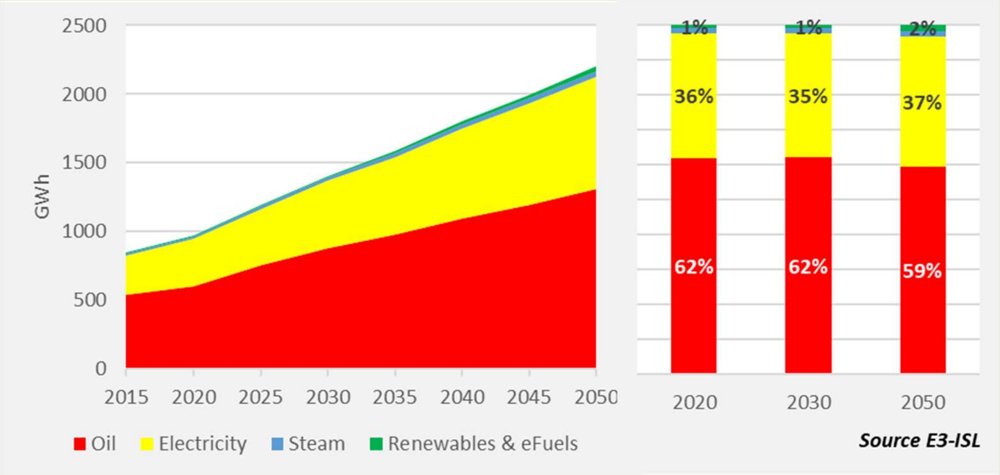
in conjunction with the growth of carbon price. The penetration of cost-efficient RES in the long term retains the electricity prices to the level of 103 Euros per $MWh_e$. Emission taxation contributes to a great extent to this rise.

As expected, $CO_2$ emissions present a constantly rising trend by 2050, surpassing 750 kilotons in total, due to the continuously wide use of fossil-based liquids in power generation and transport, which are the main carbon emitters of the island. This implies an increase of 89% of the island's $CO_2$ emissions over 2020-2050 driven by the growth of population and economic activity; however, the gradual introduction of renewable energy technologies and the (limited) energy efficiency improvements lead to a relative decoupling of $CO_2$ emissions from GDP growth in Mayotte.



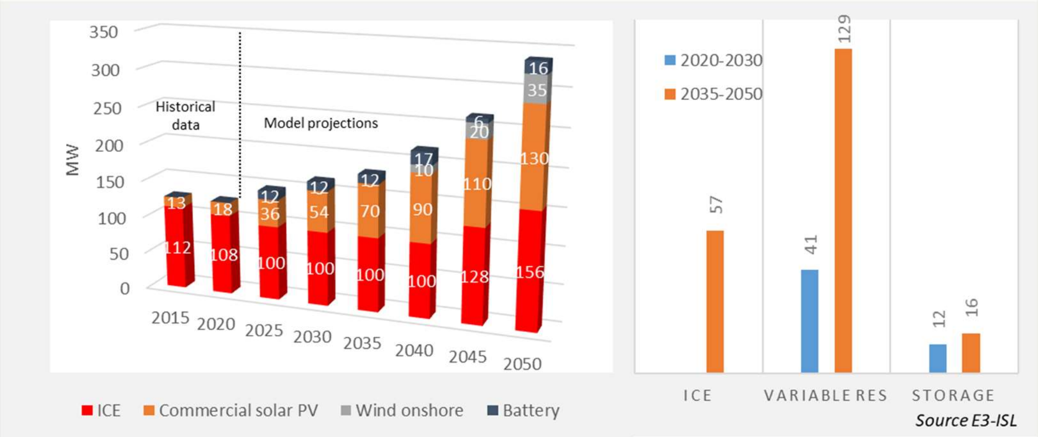
Source E3-ISL

Figure 13: Baseline – GIC and GDP evolution by 2050.



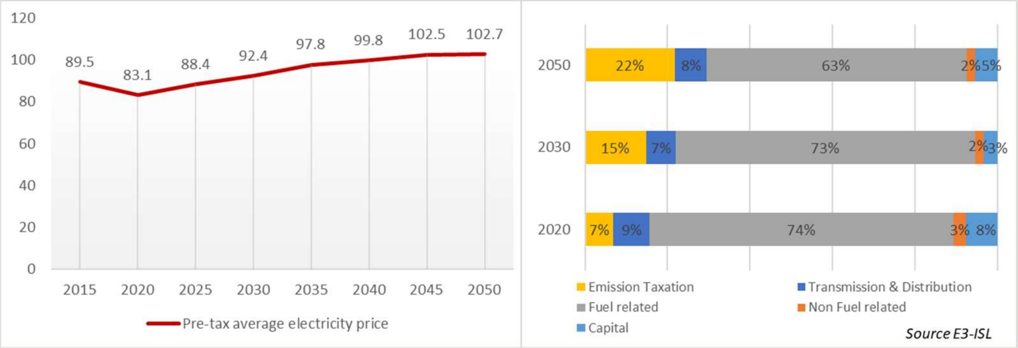
Source E3-ISL

Figure 14: Baseline – Final energy consumption by energy carrier.



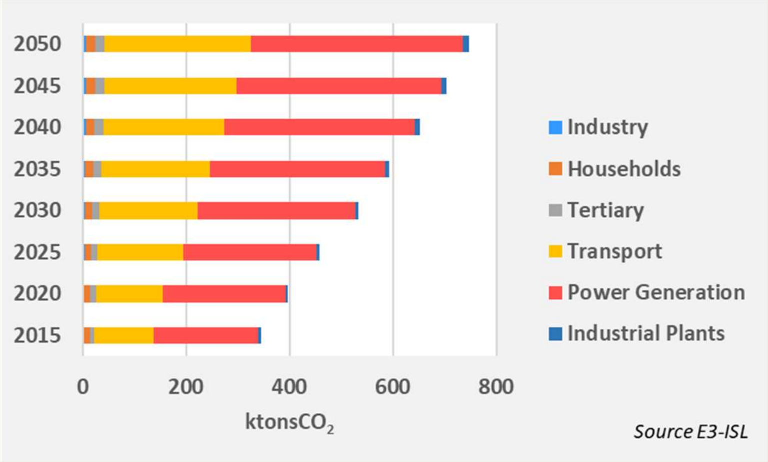
*Source E3-ISL*

Figure 15: Baseline – Operating power capacities and investment in new capacities by plant type.



*Source E3-ISL*

Figure 16: Baseline – Projection of electricity tariff and its components.



*Source E3-ISL*

Figure 17: Baseline – Energy related CO2 emissions by source.

### 5.1.3. The alternative clean energy transition pathway Decarb_Demand

The scenario Decarb_Demand anticipates the decarbonization of Mayotte's energy system by 2050, initiating the policy actions from 2030 onwards. This scenario assumes the enhancement of role of the local communities in the clean energy transition pathway. This points to the increasing public acceptance of low- and zero-emission energy projects (especially small-scale rooftop PV, efficiency actions, purchase of electric cars) and provides direct benefits towards carbon neutrality by increasing energy savings and lowering electricity bills. The engagement of the local community can also support the provision of cost-efficient flexibility services to the electricity system through demand-response and storage. More particularly, this scenario considers:

- High energy savings in all end-use sectors (buildings, agriculture, manufacturing, transport)
- Maximum heat recovery in manufacturing sectors
- High demand response potential, V2G and car sharing practices as well as the promotion of soft mobility, reducing the amount of private cars
- Wide installation of rooftop solar PVs
- High electrification in all transport modes with limited use of green hydrogen and e-fuels such as synthetic liquids and ammonia
- Fuel switching is performed in Longoni and Badamiers power plants as well as the industrial boilers in 2030 onwards. Longoni and Badamiers operate until 2050, limiting gradually their production and providing ancillary services in the long term.
- Wide use of biofuels in all transport modes

The following table summarises the key policy drivers of this pathway:

Table 7 Decarb_Demand – Key policy drivers

| Policy Driver | Unit | Sector/End-use/Fuel | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| **Carbon price** | €/tonCO₂ | Industry-Power - Aviation | 80 | 80 | 213 | 300 |
| **Carbon value**[15] | €/tonCO₂ | Buildings-Industry | 80 | 80 | 213 | 300 |
| **Carbon standards** | % reduction vs 2020 | Passenger cars | -15% | -32% | -85% | -96% |
| | | LDVs | -15% | -40% | -83% | -96% |
| | | HDVs | - | -58% | -92% | -99% |
| | | Buses/Coaches | - | -55% | -89% | -92% |
| | | Marine vessels | - | -51% | -84% | -97% |
| **Blending mandates in Transport** | % of sectoral energy consumption | Biogasoline | 9% | 12% | 18% | 25% |
| | | Biodiesel | 8% | 15% | 24% | 33% |
| | | Ammonia (in navigation) | - | 2% | 10% | 50% |
| | | Biokerosene (in aviation) | - | 4% | 24% | 35% |
| | | Synthetic kerosene (aviation) | - | 1% | 8% | 30% |
| **Heat recovery incentive** | €/MWh saved | Industry | - | - | 29.1 | 51.6 |

In the Decarb_Demand scenario, the final energy consumption follows roughly the Baseline scenario trend until 2025, as it assumes the scale up of clean policies after 2030. The trend continues upward, driven by the rapid economic growth and rising living standards on the island, albeit 25% lower than the levels in the Baseline scenario in 2050. Compared to the Baseline, the Decarb_Demand scenario is assumed to achieve significant energy savings from the demand side and accelerated

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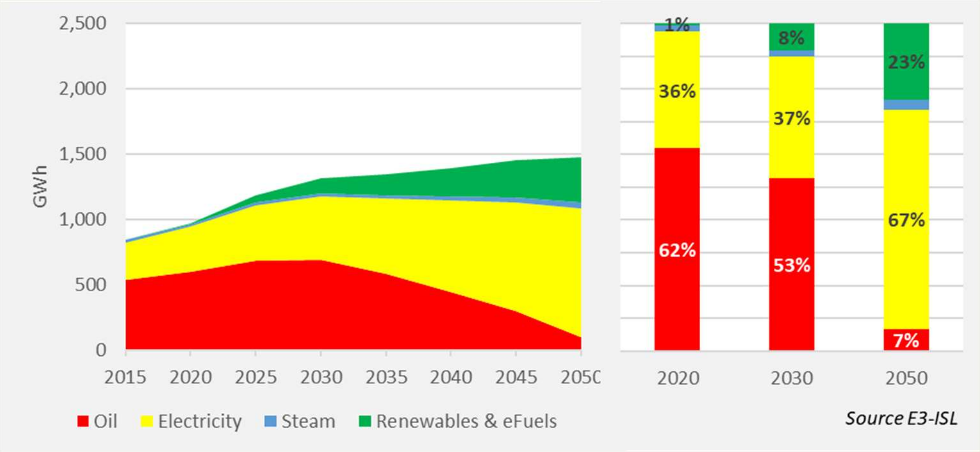
[15] A price signal that makes the carbon-intensive fuels unattractive. Carbon value is a driver that behaves as an implicit $CO_2$ reduction target and represents carbon emission taxation and other emissions reduction policies but is not finally paid. Carbon value applies to sectors not burdened with carbon price.

electrification of stationary applications and mobility. The stringent technology performance standards and the blending mandates drive the massive penetration of pure battery electric vehicles in the road transport sector and beyond.

It is noteworthy that, due to the decreasing costs of variable RES and the rising carbon price, the variable RES and especially solar PV is the most cost-efficient power generation technology in the mid- and long-term. The penetration of rooftop solar PV is pronounced in this scenario reaching 140 MW, driven by strong consumer willingness to embrace the transition and perform decentralized emission reduction actions. In the long run, the capacity mix is dominated by solar PV plants, whilst onshore wind plants are constrained by the relatively limited potential of Mayotte reaching 43MW by 2050. The first wind-offshore power plants are projected to be commissioned in 2035, whilst the geothermal potential is partly utilized in the period after 2040. Demand response practices are widely applied in this scenario, retaining the need for battery storage.

The transition to carbon neutrality is projected to entail rising energy system costs in Mayotte above Baseline scenario levels, mostly due to the increase of investment and capital expenditure for clean technologies, efficient equipment, and low-emission vehicles. This increase is mostly triggered by the high capital expenditure to decarbonize the transport sector, which results in an increase of total energy system costs of about 2 percentage points of Mayotte's GDP above the Baseline scenario. Assuming that the Mayotte power sector continues to be subsidized with the same rate as in the Baseline scenario, the electricity prices are projected to decline in the decarbonization scenario relative to the Baseline scenario. This reduction is driven by the penetration of cost-efficient RES (solar PV, wind power) that replace the expensive diesel-fired power plants and the absence of auction payments. The reduction in pre-tax electricity price in Mayotte is projected to be significant, reaching 36% compared to Baseline levels in 2050.

Power generation and transport sectors account for about 94% of total emissions in 2020 in Mayotte. The decarbonization scenario Decarb_Demand focuses on high electrification of transport, heat recovery in industry and the use of highly efficient equipment in buildings, which end up with an emissions reduction of about 97% in 2050. In 2030 a steep decrease is observed, stimulated by the fuel switching of the ICE plants from diesel to biodiesel.



*Source E3-ISL*

Figure 18: Decarb_Demand – Final energy consumption by energy carrier.

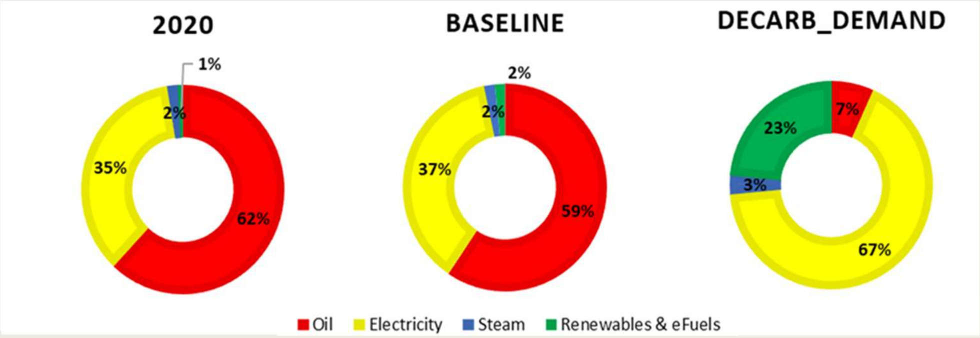
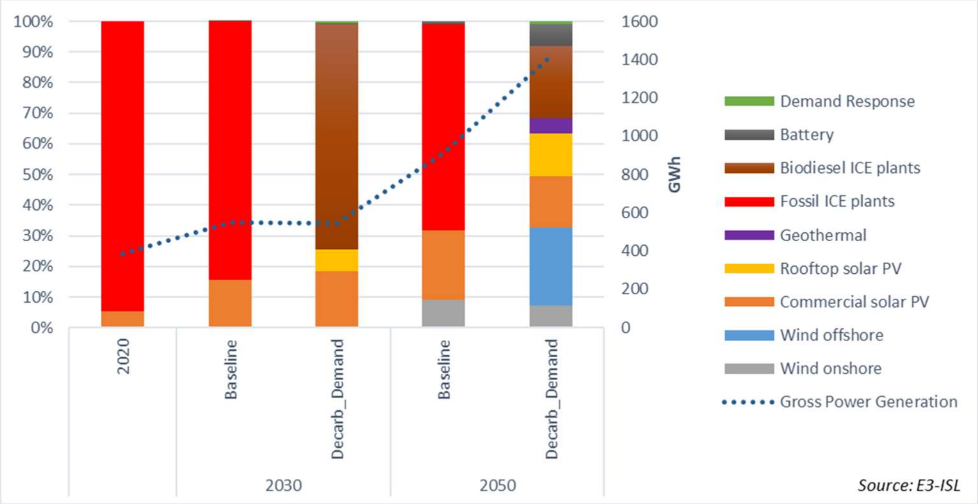
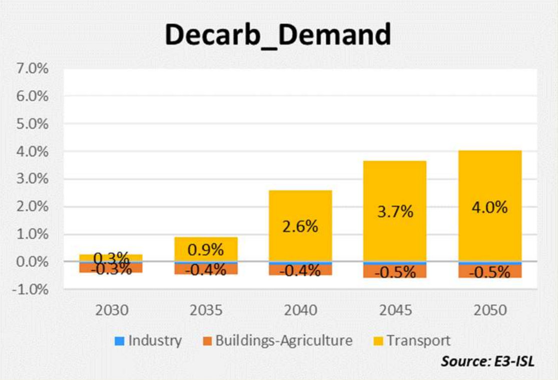


Figure 19: Decarb_Demand and Baseline – Fuel mix in final energy consumption in 2050 vs 2020.



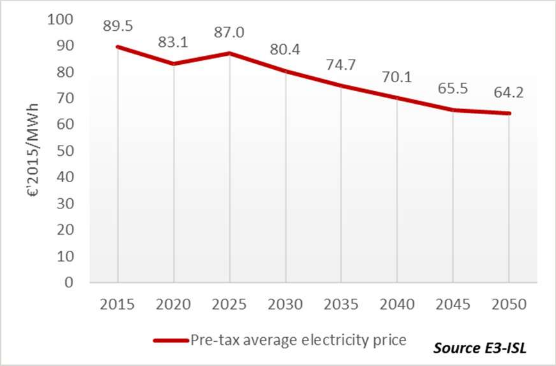
*Source: E3-ISL*

Figure 20: Decarb_Demand and Baseline – Power mix in 2030 and 2050 vs 2020.



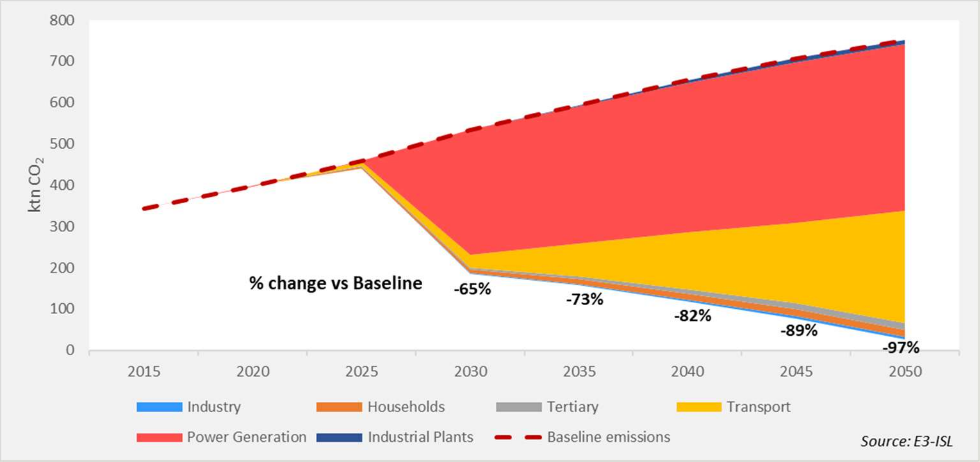
*Source: E3-ISL*

Figure 21: Decarb_Demand – Energy system cost difference as % of GDP vs Baseline



*Source E3-ISL*

Figure 22: Decarb_Demand - Evolution of pre-tax average electricity price



*Source: E3-ISL*

Figure 23: Decarb_Demand – $CO_2$ emission reduction by sector vs Baseline.

## 5.2. REGIONAL DISTRIBUTION OF ELECTRICITY DEMAND

### 5.2.1. Big Consumers

Big consumers distribution is a crucial factor for understanding the variances in energy demand between different regions on the island. To comprehend the spatial distribution of big consumers in Mayotte, a heatmap graph was created to represent their geographical density.

Through this heatmap, we can get insights into the regions with higher consumer density, which can be instrumental in planning for infrastructure development and devising targeted strategies to meet the specific demands of these regions and avoiding partial blackouts.

In addition, this visualization not only depicts the density and distribution of these consumers across the island but also particularly highlights Mamoudzou as a focal point. As the capital of Mayotte, Mamoudzou is the economic driver of the island and houses most of the big consumers. Recognizing Mamoudzou's pivotal role in energy consumption is essential for infrastructure planning, allowing for targeted strategies to meet the unique demands of this region and prevent partial blackouts.

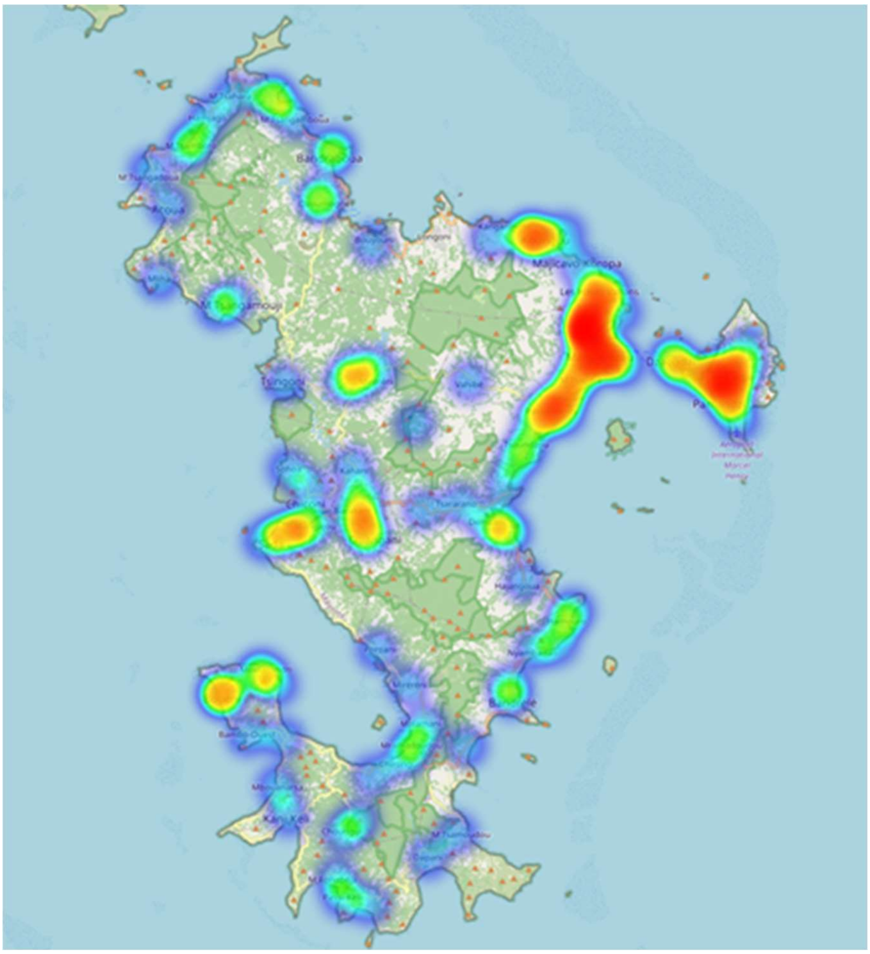


Figure 24: Distribution of big consumers (red is high density, blue is low density)

To estimate the regional demands for residential and industrial sectors, an approach grounded in the analysis of population and big consumers' regional distribution was adopted. First, regional population data for Mayotte's regions (communes) for the year 2017 was used to quantify the distribution of the population and thereby, the distribution of residential electricity demand. Secondly, a dataset containing the electricity consumption and location of big electricity consumers in Mayotte for the year 2022 served as the basis of the regional demand of the industrial sector. Due to a lack of detailed forecasting data on these two consumer groups and for enhanced comparability of results, the assumptions and results of the E3-ISL model were used to project the regional demand distribution into the future. To this end, a proportional estimation strategy was applied to the Baseline scenario assumptions and results of the E3-ISL model, assuming that today's distribution of the population and big consumers will remain unchanged in the future. This involved calculating proportions based on available data and assuming these proportions to be representative of the broader population and industry dynamics in Mayotte. For example, around 28% of the population lived in Mamoudzou in 2017 according to the population dataset, and we assume that in 2050, the same share of the population will reside in this region, even though the total population will have significantly increased by then according to the modelling assumptions. While this method presents limitations in terms of accuracy, it offers a preliminary insight into the potential demand distribution across different regions of Mayotte. Figure 25 and Figure 26 provide an overview of the projected regional demands for the residential and industrial sectors in Mayotte.

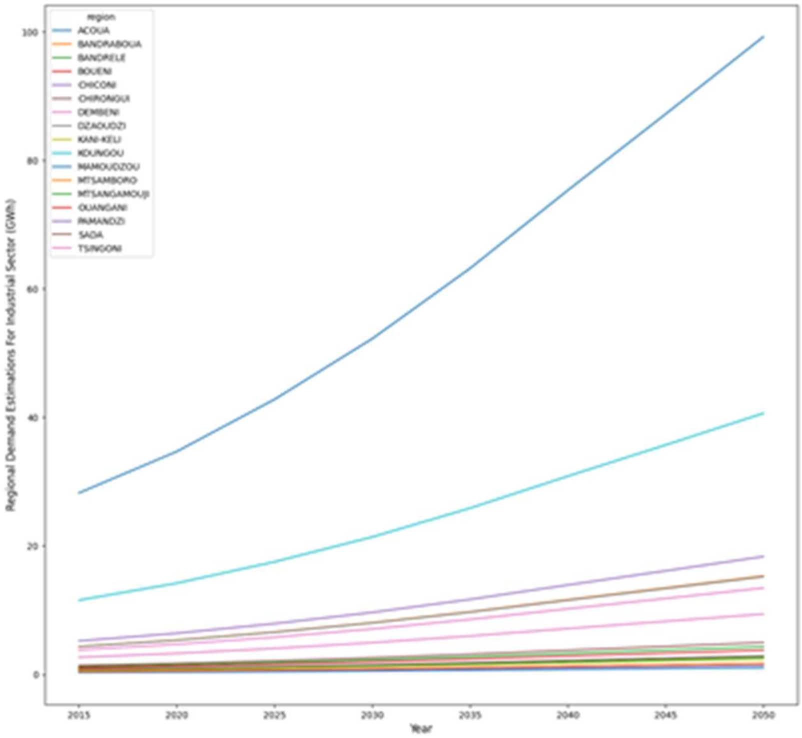


Figure 25: Regional demand estimations for the industrial sector in baseline scenario

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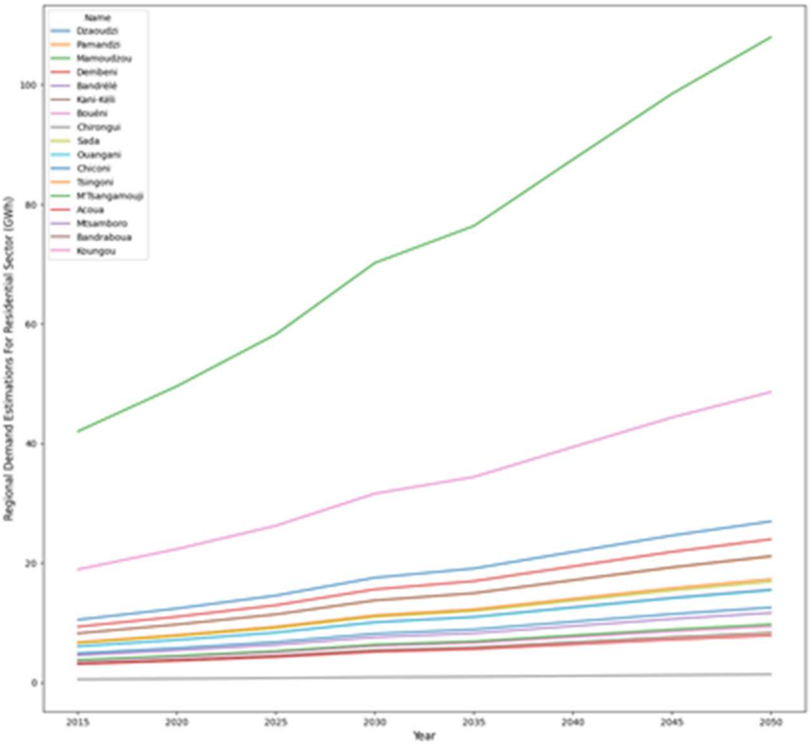

Figure 26: Regional demand estimations for the residential sector in baseline scenario

## 5.3. Optimal Distribution of RES

### 5.3.1. ELECTRICAL DISTRIBUTION INFRASTRUCTURE

With the goal of studying potential PV integration in the electric grid of Mayotte, it is important to scrutinize and showcase the existing distribution lines (HTA and HTB) along with the substations (HTB/HTA and HTA/BT). This necessity stems from the foundational role these entities play in the broader power distribution in the island. Firstly, understanding the intricate layout of these lines is fundamental in identifying feasible zones for PV installation; these lines essentially mark the pathways through which the generated solar power will be transmitted. Moreover, an analysis of these lines aids in optimizing the power network by allowing for the pinpointing of areas where solar power integration can augment existing capacities and improve grid stability.

Secondly, highlighting the substations is pivotal, as these nodes act as critical junctions in the power flow, facilitating the transition of electricity between various voltage levels, thus ensuring an efficient and regulated distribution to the end consumers. Evaluating the current capacity and capabilities of these substations provides an analytical ground to propose enhancements or expansions necessary to accommodate the additional load from the new PV sources. Moreover, it aids in strategizing the integration in a manner that it complements the existing grid infrastructure, thereby maximizing the use of PV while ensuring the grid stability.

#### *5.3.1.1. DISTRIBUTION LINES*

The electric grid in Mayotte has two high voltage lines: HTA and HTB. HTA operates at 20 KV and delivers the energy to all regions in the island. HTB line operate at 90 KV and it is connected to HTA via two substations in Mamoudzou and Sada. In addition: HTB has a third connection which connects the thermal power plant in Longoni.

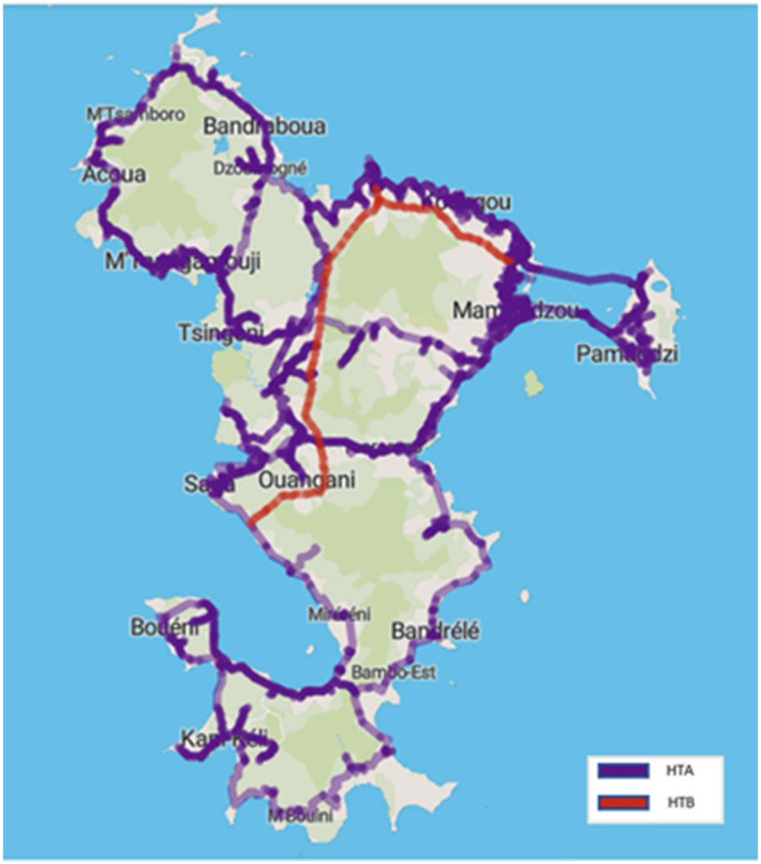

**Figure 27: HTA and HTB transmission lines (source: EDM Open Data)**

#### 5.3.1.2. SUBSTATIONS AND DISTRIBUTION SUBSTATIONS

To facilitate a more nuanced analysis of the electrical infrastructure in Mayotte, we developed an algorithm to estimate the locations of substations (postes sources in French, HTB/HTA) and distribution substations (postes de distribution in French, HTA/BT) posts across the region. It follows the starting points and the ending points of HTB and HTA transmission lines to detect the connections and the endings of lines. As a result, each line-ending is considered as a distribution post. This algorithm can provide estimates that can aid in understanding the present state of electrical distribution infrastructure and planning for future expansions or modifications.

Figure 28: High voltage substation (postes source, HTB/HTA

Figure 29: distribution substations (postes de distributions, HTA/BT)

### 5.3.2. Optimal distribution of solar PV assets

To explore the potential for PV integration in Mayotte, a dataset illustrating potential sites for on-the-ground, parking, and rooftop installations was studied. This visualization encompasses various parameters such as geographical suitability and proximity to existing electrical infrastructure. Since the integration of new installations into the existing grid presents a significant challenge due to high costs and bureaucratic burdens, we classify the locations into ‘easy’ and ‘all difficulties’ based on their proximity to the grid. For the purposes of this classification, 'easy' installations are those situated near the distribution line (BT) and the distribution post HTA/BT. Furthermore, taking into consideration the demographic distribution, big consumers distribution and the grid infrastructure in the island, it is recommended to give preference to sites located in Mamoudzou and Longoni these regions are not only close to the BT and HTA/BT infrastructure but are also proximate to the key HTB/HTA posts. This graphical representation serves as a potent tool to identify viable regions for PV integration, offering a visual aid to stakeholders and decision-makers in the planning and implementation of solar power projects.

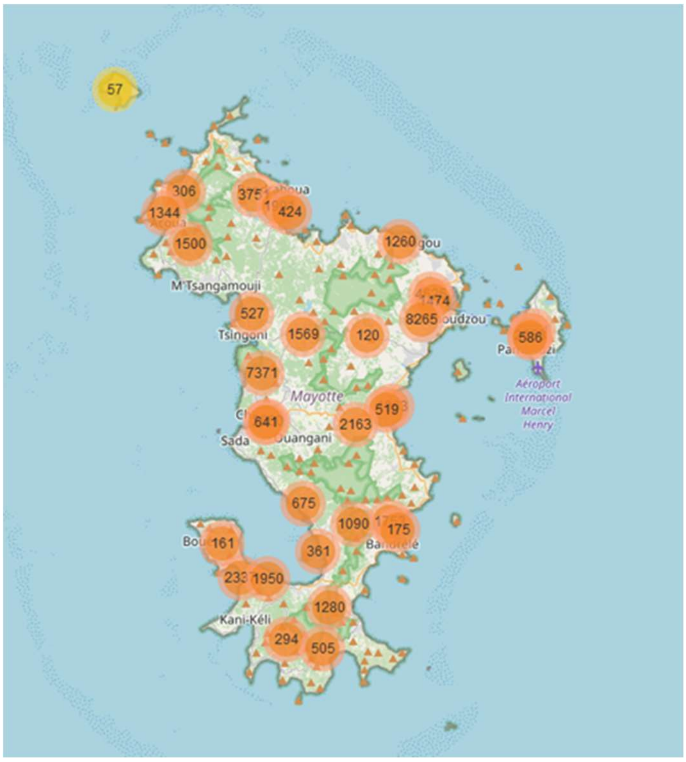

Figure 30: PV rooftops potential (all easy and hard installations)

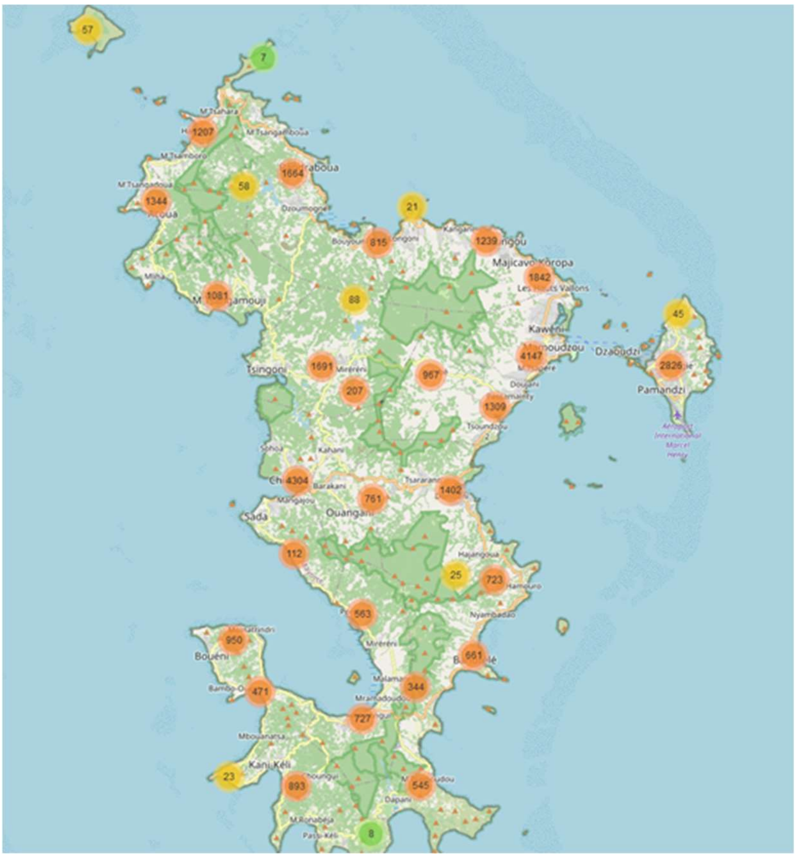

Figure 31: PV rooftops potential (only easy installations)

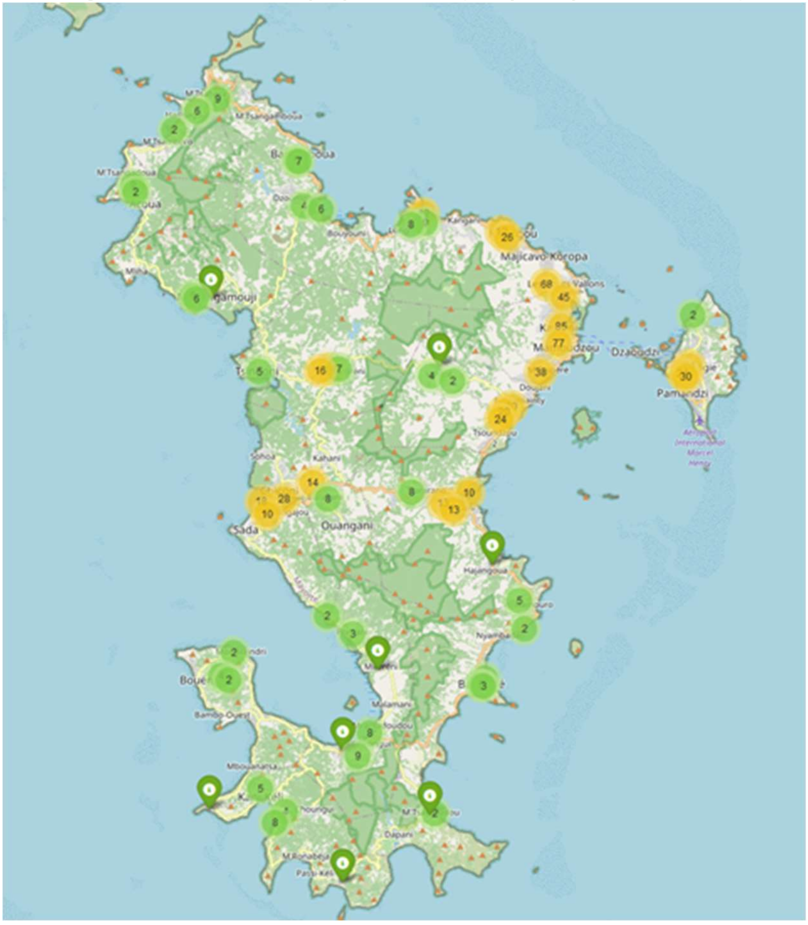

Figure 32: PV parks (all easy and hard)

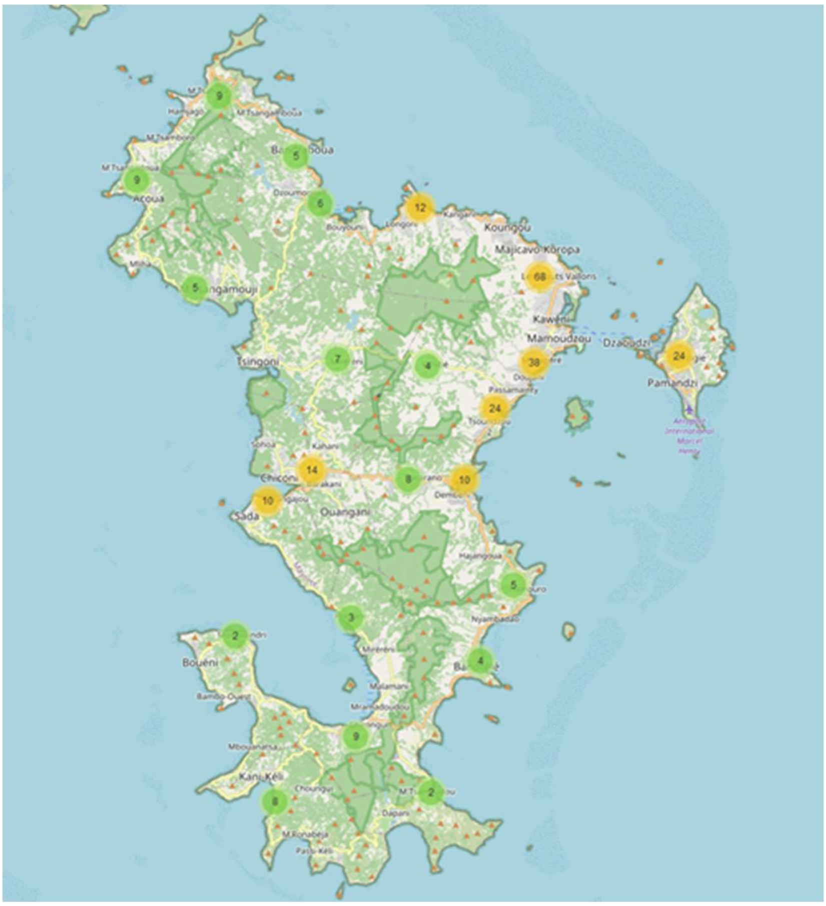

Figure 33: PV parks (only easy)

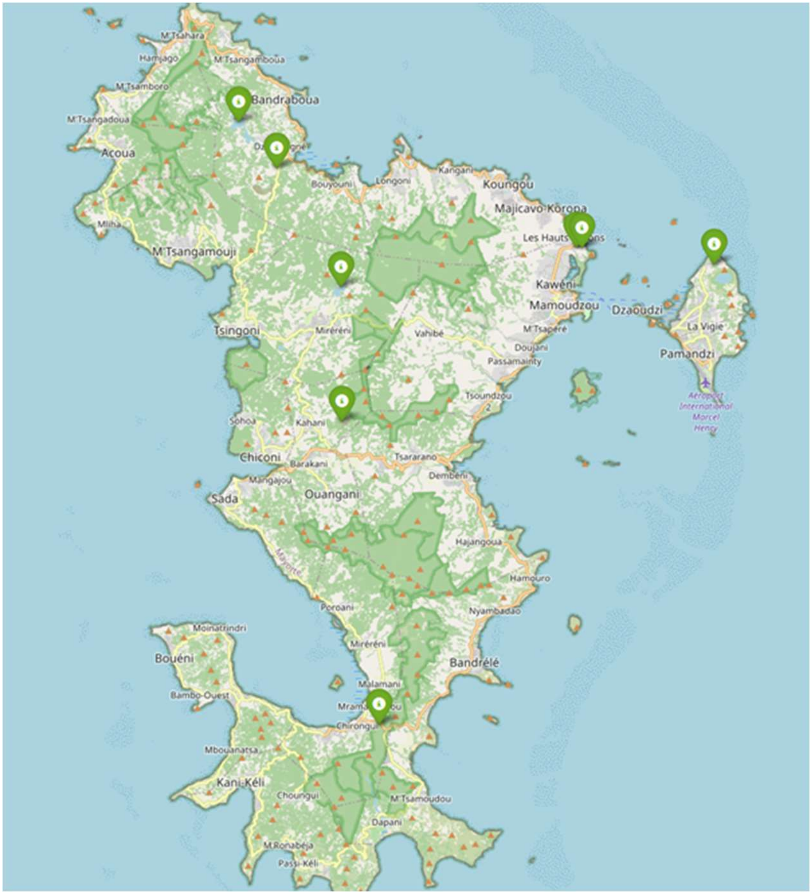

Figure 34: PV on-the-ground (all easy and hard)

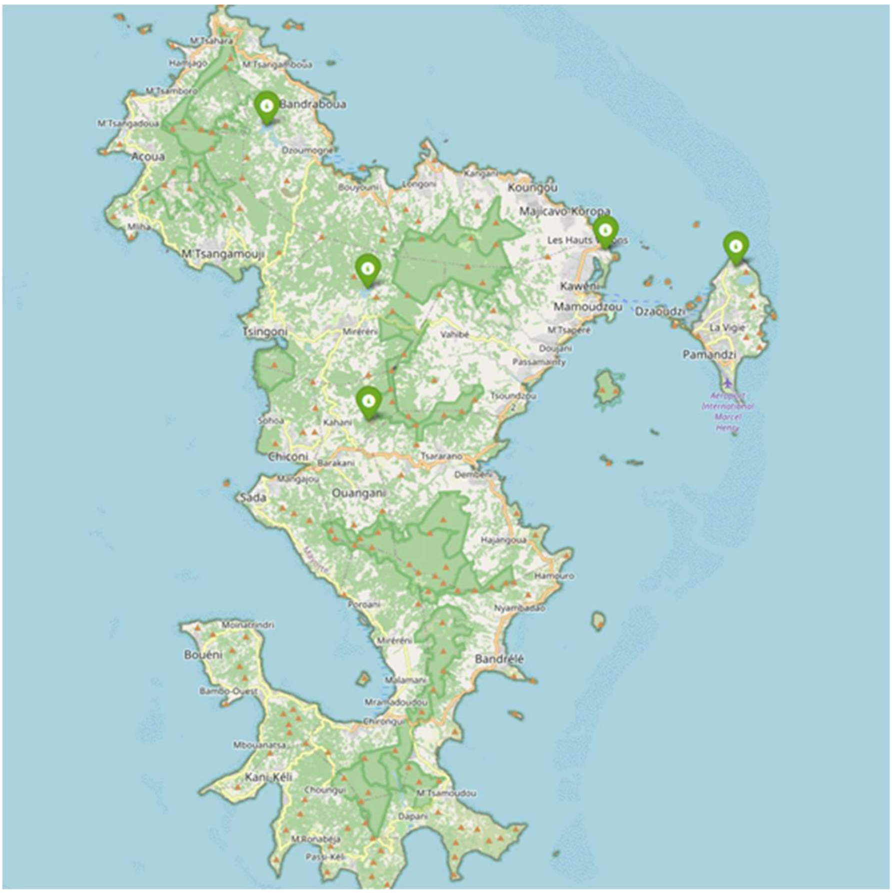

Figure 35: PV on-the-ground (only easy)

# 6. MICROECONOMIC EFFECTS OF THE TRANSITION: COSTS AND BENEFITS, POLICIES AND DISTRIBUTIONAL EFFECTS

## 6.1. COSTS AND BENEFITS FOR POWER PRODUCERS AND INVESTORS

Investments by the private sector present an important lever for RES deployment. To incentivize such investments, newly built power plants need to be financially profitable over their economic lifetime. In the case of Mayotte, the current energy system based on diesel-powered electricity generation is cost inefficient. As the revenues from electricity sales do not cover generation costs, the system is operating at a loss, which is compensated by subsidies paid by all French electricity consumers. This results in a distortion of the market, in which the laws of profitable investment do not apply to existing power generation assets, which can operate at a loss. In contrast, rational investors entering the market would only finance new generation assets that achieve a certain financial return over their economic lifetime.

Based on i) the modelling assumptions and results and ii) additional data and assumptions, we compare the investments cases for a fossil-based (diesel power plant) and renewable generation technologies as suggested in the literature (Breitschopf et al., 2016). We conduct this analysis for the Baseline and the Decarb_Demand scenarios, and at different points in time. Given the modelling horizon and an assumed economic lifetime of 15 years for these assets, we can project the profitability of investments for all five-year-periods between 2015 and 2040.

Developing the investment cases based on modelling assumptions allows for a holistic, expanded picture of the modelling results and high comparability to similar analyses foreseen for the follower islands. By incorporating additional data and assumptions on the other hand, we can conduct additional analyses exceeding the modelling scope, such as considerations on feed-in tariffs or profitability calculations for prosumers.

### 6.1.1. Investment case based on modelling assumptions

#### *6.1.1.1. Assumptions*

We assume an economic lifetime of 15 years for all power plant investments, except for geothermal power plants (20 years), in line with the modelling assumptions. In the present case, the economic lifetime refers to the time period in which profitability must be reached for an investment to be considered attractive. Also, the investment's CAPEX is distributed as an annuity spanning the economic lifetime, with same-sized payments in each year. Over the economic lifetime, the full CAPEX is thus returned. The technical lifetime, on the other hand, refers to the actual time that an asset can keep operating given the technologies' properties. When it ends, the asset is disposed of, or its lifetime is extended by additional investment. As the technical lifetime exceeds the economic lifetime, additional profits might be made if an asset continues to operate after reaching its economic lifetime. Since these additional profits cannot be guaranteed, they are not considered in the profitability calculations but present an additional potential benefit. For our analysis, the term extended lifetime refers to the prolonged operation of power generation assets beyond their technical lifetime. In the E3-ISL model, the lifetime of existing diesel generators is heavily extended, allowing them to operate until the end of the modelling horizon in 2054. The same assumptions apply for the analysis of diesel-powered generation in this chapter. The CAPEX and OPEX assumptions used in the E3-ISL model are based on extensive research and confirmed by the local DSO, and thus serve as a reliable basis for the investment cases. While the cost assumptions for commercial solar PV might appear comparatively low, we assume them to be realistic, given potential economies of scale for larger installations and the foreseen learning-by-doing over time.

#### 6.1.1.2. *Profitability analysis and investment cases*

##### Conventional investment: diesel-based electricity production

We investigate the profitability of investments in diesel power plants in three cases, building on the results of the Baseline and Decarb_Demand scenarios of E3-ISL, and based on the costs of gross generation. In the Baseline scenario, conventional diesel is used throughout the entire modelling period, and carbon prices remain comparatively low. In 2045 and 2050, additional diesel generation capacities are installed to meet rising energy demand. In the Decarb_Demand scenario, a policy-induced fuel switch towards biodiesel occurs in 2030 for all diesel power plants, and carbon prices strongly increase after 2035 compared to the Baseline scenario. This fuel switch is introduced as a policy decision based on the current developments in Mayotte, regardless of technology costs and carbon prices. No additional diesel capacities are installed after 2015. The Baseline and Decarb_Demand cases mirror the exact results and assumptions of E3-ISL. In the third case, Decarb_Demand_Conv, finally, we slightly adapt the assumptions of the Decarb_Demand scenario, assuming that decision-makers opt for a strict continuation of the status quo of conventional diesel-based power generation, so no fuel switch occurs even though carbon prices rise over time. This third case is only introduced for the profitability analysis, using the existing outputs of the Decarb_Demand scenario. The scenario is not re-run as a model in E3-ISL, and no new energy system modelling results are produced. The strict continuation of this fossil-based path in a decarbonization environment could produce different energy-system interactions and results. Conventional diesel is more expensive under higher carbon prices, which could result in lower diesel-based power generation and less installed diesel capacity, counterbalanced by a higher share of renewables. In this way, the actual capacities and runtimes of power plants in Decarb_Demand_Conv should slightly differ from the assumptions used in the profitability analysis. Still, the results should sufficiently illustrate the consequences of a non-switch under decarbonization. For all cases, the economic lifetime is set at 15 years, the technical lifetime at 25 years, and the extended lifetime between 35 and 60 years, allowing all four generators to operate until 2054. Overall, the assumptions in the profitability analysis are favorable for diesel-based generation, as the technical lifetimes of the Badamiers 3 and 4 and Longoni 1 and 2 generators are extended until the end of the modelling horizon in 2054, at no additional cost for extension or retrofit.

Table 8 provides an overview of the NPV of each generator and the diesel fleet as whole, as well as the total $CO_2$ emissions, for all three cases and the economic, technical, and extended lifetimes. In all setups, the NPV over the respective lifetime is negative, highlighting the persistent high costs and non-profitability of both diesel- and bio-diesel-based power generation. In the current policy environment, these high losses are compensated by the electricity price subsidies for Mayotte. With the additional diesel capacity installed in 2045 and 2050, the Baseline scenario produces the highest overall costs and carbon emissions. Even under the comparatively low carbon prices in this scenario, the economic costs of fossil-based generation are enormous, amounting to a negative NPV of over one billion Euros for the extended lifetimes until 2054. In the Decarb_Demand_Conv case, where generation is completely based on fossil fuel, too, overall costs and emissions are lower because of the lower total diesel-based production both in existing power plants and the non-investment in additional generation capacities. Interestingly, the total NPV in the Decarb_Demand case is higher than in the Decarb_Demand_Conv case, where all assumptions are the same except for the use of biodiesel, which only occurs in Decarb_Demand. This highlights that under rising carbon prices, the switch to biodiesel becomes an economic imperative, not just an ecological one. Still, biodiesel-based power generation is associated with high costs and not economically attractive without a continuation of energy subsidies for power generation. The negative NPV per unit of electricity produced, high per-unit carbon emissions and high LCOE all underscore these considerations (see Table 9 and Table 10). Overall, investments in diesel power generation capacity are not economically attractive in any of the periods, considering NPV and NPV per unit. Together with a high LCOE and the carbon emissions of conventional diesel, all indicators speak against an investment in these capacities for power generation alone.

Table 8: NPV (million €) and carbon emissions (million tons) of diesel investments, total

| Scenario | Investment Horizon | Badamiers 1 | Badamiers 2 | Badamiers 3 | Badamiers 4 | Longoni 1 | Longoni 2 | 2045 | 2050 | Total | Carbon emissions (mio. tons) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Baseline | Economic (15y) | -2.45 | -16.90 | -28.17 | -37.00 | -237.80 | -211.55 | -157.66 | -20.28 | -711.82 | 4.17 |
| | Technical (25y) | -2.45 | -16.90 | -40.87 | -58.86 | -325.20 | -289.62 | -157.66 | -20.28 | -911.84 | 7.12 |
| | Extended (40y) | -2.45 | -16.90 | -54.52 | -75.97 | -401.55 | -357.82 | -157.66 | -20.28 | -1087.15 | 12.80 |
| Decarb_Demand | Economic (15y) | -5.04 | -16.90 | -24.44 | -33.66 | -238.90 | -212.53 | 0.00 | 0.00 | -531.47 | 3.36 |
| | Technical (25y) | -5.04 | -16.90 | -27.92 | -38.48 | -309.18 | -295.18 | 0.00 | 0.00 | -692.71 | 3.36 |
| | Extended (40y) | -5.04 | -16.90 | -28.44 | -39.04 | -336.88 | -352.34 | 0.00 | 0.00 | -778.64 | 3.36 |
| Decarb_Demand_Conv | Economic (15y) | -5.04 | -16.90 | -24.45 | -33.67 | -239.01 | -212.63 | 0.00 | 0.00 | -531.70 | 3.62 |
| | Technical (25y) | -5.04 | -16.90 | -28.03 | -38.65 | -316.42 | -307.12 | 0.00 | 0.00 | -712.18 | 5.81 |
| | Extended (40y) | -5.04 | -16.90 | -28.73 | -39.40 | -358.11 | -395.42 | 0.00 | 0.00 | -843.62 | 8.78 |

Table Notes: NPV calculated over investment horizon, with 8.5% discount rate. The modelling horizon covers the years 2015 to 2054. For the investments in 2045 and 2050, the investment horizon is highly limited due to the modelling horizon ending in 2054. Between 2020 and 2040, no additional capacity is installed, therefore these columns are omitted. For installed capacities and runtimes see Chapter 3.2.2. Carbon emissions refer to total emissions of the entire diesel fleet.

Table 9: NPV (€/kWh) and carbon emissions (kg/kWh) of diesel investments, per unit of generated electricity

| Scenario | Investment Horizon | Badamiers 1 | Badamiers 2 | Badamiers 3 | Badamiers 4 | Longoni 1 | Longoni 2 | 2045 | 2050 | Carbon emissions (kg/kWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| Baseline | Economic (15y) | -0.12 | -0.09 | -0.09 | -0.09 | -0.10 | -0.10 | -0.23 | -0.42 | 8.65 |
| | Technical (25y) | -0.12 | -0.09 | -0.07 | -0.07 | -0.08 | -0.08 | -0.23 | -0.42 | 14.75 |
| | Extended (40y) | -0.12 | -0.09 | -0.05 | -0.05 | -0.05 | -0.05 | -0.23 | -0.42 | 26.53 |
| Decarb_Demand | Economic (15y) | -0.12 | -0.09 | -0.09 | -0.10 | -0.10 | -0.10 | 0.00 | 0.00 | 6.96 |
| | Technical (25y) | -0.12 | -0.09 | -0.09 | -0.09 | -0.08 | -0.08 | 0.00 | 0.00 | 6.96 |
| | Extended (40y) | -0.12 | -0.09 | -0.08 | -0.09 | -0.07 | -0.05 | 0.00 | 0.00 | 6.96 |
| Decarb_Demand_Conv | Economic (15y) | -0.12 | -0.09 | -0.09 | -0.10 | -0.10 | -0.10 | 0.00 | 0.00 | 7.51 |
| | Technical (25y) | -0.12 | -0.09 | -0.09 | -0.09 | -0.09 | -0.08 | 0.00 | 0.00 | 12.04 |
| | Extended (40y) | -0.12 | -0.09 | -0.08 | -0.09 | -0.07 | -0.06 | 0.00 | 0.00 | 18.20 |

Table Notes: NPV calculated over investment horizon, with 8.5% discount rate. The modelling horizon covers the years 2015 to 2054. For the investments in 2045 and 2050, the investment horizon is highly limited due to the modelling horizon ending in 2054. Between 2020 and 2040, no additional capacity is installed, therefore these columns are omitted. For installed capacities and runtimes see Chapter 3.2.2. Carbon emissions refer to average per-unit emissions of the entire diesel fleet.

Table 10: LCOE (€/kWh) and carbon emissions (kg/kWh) of diesel investments, per unit of generated electricity

| Scenario | Investment Horizon | Bada-miers 1 | Bada-miers 2 | Bada-miers 3 | Bada-miers 4 | Longoni 1 | Longoni 2 | 2045 | 2050 | Carbon emissions (kg/kWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| Baseline | Economic (15y) | 0.19 | 0.15 | 0.14 | 0.14 | 0.15 | 0.15 | 0.29 | 0.49 | 8.65 |
| | Technical (25y) | 0.19 | 0.15 | 0.10 | 0.11 | 0.11 | 0.11 | 0.29 | 0.49 | 14.75 |
| | Extended (40y) | 0.19 | 0.15 | 0.07 | 0.07 | 0.07 | 0.07 | 0.29 | 0.49 | 26.53 |
| Decarb_Demand | Economic (15y) | 0.19 | 0.15 | 0.14 | 0.15 | 0.15 | 0.15 | 0.00 | 0.00 | 6.96 |
| | Technical (25y) | 0.19 | 0.15 | 0.13 | 0.14 | 0.12 | 0.11 | 0.00 | 0.00 | 6.96 |
| | Extended (40y) | 0.19 | 0.15 | 0.12 | 0.13 | 0.09 | 0.07 | 0.00 | 0.00 | 6.96 |
| Decarb_Demand_Conv | Economic (15y) | 0.19 | 0.15 | 0.14 | 0.15 | 0.15 | 0.15 | 0.00 | 0.00 | 7.51 |
| | Technical (25y) | 0.19 | 0.15 | 0.13 | 0.14 | 0.12 | 0.11 | 0.00 | 0.00 | 12.04 |
| | Extended (40y) | 0.19 | 0.15 | 0.12 | 0.13 | 0.10 | 0.08 | 0.00 | 0.00 | 18.20 |

Table Notes: NPV calculated over investment horizon, with 8.5% discount rate. The modelling horizon covers the years 2015 to 2054. For the investments in 2045 and 2050, the investment horizon is highly limited due to the modelling horizon ending in 2054. Between 2020 and 2040, no additional capacity is installed, therefore these columns are omitted. For installed capacities and runtimes see Chapter 3.2.2. Carbon emissions refer to average per-unit emissions of the entire diesel fleet.

### Investment in RES for power generation

Due to its small size and the current system of a single utility, which additionally produces most of the electricity consumed on the island, no advanced (wholesale) market structure exists in Mayotte. We therefore assume that all power producers sell their generated electricity at average the pre-tax electricity price calculated in the model. The model calculates this pre-tax electricity price (Euros per MWh) on a cost-covering basis, dividing the total system costs (Euro) by the total amount of power generation (MWh) sold to end consumers. This market setup differs from that of a merit order, where producers offer their supply bids at marginal generation prices. Still, the effects of RES integration might be similar to conventional merit order effects. On one side, RES-based producers gain from considerable contribution margins due to receiving the same average electricity price as all other producers in the market while facing lower operational costs. On the other side, a cannibalization of these additional RES profits can occur with ever higher RES penetration, resulting in a sinking pre-tax electricity price and thereby, reduced contribution margins for RES producers.

As long as the expensive diesel production maintains a high pre-tax electricity price for the whole system, many RETs are profitable when receiving market prices even without additional financial support such as FiTs, resulting in positive NPVs over the projects' economic lifetimes. In the Baseline scenario, this is the case for rooftop solar PV, commercial solar PV and geothermal in all periods after 2020, and for offshore wind after 2035 (see Table 11). Note that for all presented results, the underlying economic lifetime of 20 years for geothermal power plants results in a hypothetical operation of geothermal assets installed in 2040 beyond the E3-ISL horizon in 2054. Therefore, the results for 'Geothermal 2040' should in all tables should be treated with caution.

Table 11: NPV (million €) over economic lifetime under market sales only, Baseline Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 0.140 | 0.367 | 0.482 | 0.549 | 0.597 |
| Commercial solar PV | -0.152 | 0.343 | 0.589 | 0.687 | 0.753 | 0.797 |
| Wind onshore | NA | -1.387 | -0.986 | -0.915 | -0.919 | -0.885 |
| Wind offshore | NA | -1.389 | -0.657 | -0.129 | 0.034 | 0.150 |
| Geothermal | NA | 0.469 | 0.904 | 1.174 | 1.336 | 1.301 |

Table 12: NPV (million €) over economic lifetime under market sales only, Decarb_Demand Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 0.092 | 0.237 | 0.235 | 0.203 | 0.186 |
| Commercial solar PV | -0.162 | 0.292 | 0.445 | 0.416 | 0.372 | 0.345 |
| Wind onshore | NA | -1.474 | -1.218 | -1.336 | -1.490 | -1.563 |
| Wind offshore | NA | -1.467 | -0.869 | -0.562 | -0.580 | -0.588 |
| Geothermal | NA | 0.131 | 0.189 | -0.049 | -0.293 | -0.541 |

Solar PV emerges as a particularly attractive option in Mayotte, given the high and continuous irradiation and resulting high runtimes and capacity factors for this technology. Commercial solar PV and rooftop solar are profitable in all periods after 2020, both in the Baseline and the Decarb_Demand scenario. This can be seen in high positive total (see Table 11 and Table 12) and per-unit NPVs (see Table 13 and Table 14) over the investments' economic lifetime.

Table 13: NPV per generated unit (€/MWh) over economic lifetime under market sales only, Baseline Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 7.02 | 17.09 | 22.41 | 25.56 | 27.76 |
| Commercial solar PV | -7.61 | 15.98 | 24.89 | 29.03 | 31.83 | 33.69 |
| Wind onshore | NA | -36.80 | -25.88 | -24.86 | -25.92 | -24.95 |
| Wind offshore | NA | -42.74 | -18.81 | -3.40 | 0.88 | 3.88 |
| Geothermal | NA | 4.51 | 7.94 | 10.31 | 11.73 | 11.43 |

Table 14: NPV per generated unit (€/MWh) over economic lifetime under market sales only, Decarb_Demand Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 4.61 | 11.01 | 10.95 | 9.47 | 8.66 |
| Commercial solar PV | -8.09 | 13.57 | 18.81 | 17.57 | 15.74 | 14.59 |
| Wind onshore | NA | -39.11 | -31.96 | -36.32 | -42.01 | -44.05 |
| Wind offshore | NA | -45.15 | -24.90 | -14.86 | -15.21 | -15.22 |
| Geothermal | NA | 1.26 | 1.66 | -0.43 | -2.58 | -4.75 |

Only in 2015, commercial solar PV is not profitable in neither of the scenarios without additional RES support, due to its high CAPEX at the time. In the Baseline scenario, investment in these technologies is even more attractive, since the higher diesel-based power generation costs raise the total costs of the system, thereby increasing the pre-tax electricity price that all producers receive for the power they supply, and therefore the revenues of producers. On the flip side, with the increasing RES penetration in the Decarb_Demand scenario leading to lower market prices, a cannibalization of additional RES profits occurs. Still, investments in these RETs remain highly profitable under high RES penetration. The LCOE for solar PV in Mayotte is low, especially in comparison to wind on- and offshore. Commercial solar PV has the lowest LCOE of all technologies throughout all time periods under consideration (see Table 15). Importantly, both rooftop and commercial solar PV are already profitable from 2020 on, suggesting that their slow expansion in Mayotte in recent years was not caused by a lack of economic attractiveness, but other barriers.

Table 15: LCOE (€/MWh) over economic lifetime, Baseline and Decarb_Demand Scenario

| **Year of Construction** | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 39.97 | 34.02 | 30.89 | 29.65 | 28.42 |
| Commercial solar PV | NA | 31.01 | 26.22 | 24.26 | 23.38 | 22.49 |
| Wind onshore | NA | 84.69 | 76.99 | 78.16 | 81.13 | 81.13 |
| Wind offshore | NA | 89.76 | 69.92 | 56.69 | 54.28 | 52.27 |
| Geothermal | NA | 36.08 | 36.18 | 35.61 | 35.63 | 35.65 |

This is not the case for less established RETs in Mayotte, particularly technologies with high CAPEX, such as offshore wind. At the lower market pre-electricity prices in the Decarb_Demand scenario, the revenues of offshore wind power generation cannot recover the investment costs, resulting in negative NPVs over the economic lifetime for investments in any period. With the high initial investment costs, the LCOE over the economic lifetime more than doubles compared to solar-based power generation. In the Baseline scenario, offshore wind generation becomes economically attractive after 2035, through a combination of increasing carbon prices and reduced CAPEX for offshore wind technology. In previous years, however, investments cannot be recovered within the economic lifetime of 15 years. With a technical lifetime of 25 years and a comparatively high, profitable generation after the initial CAPEX expenses, investments might still be recovered, or turn profitable in the long run. Still, investors might not be willing to take on such risks given the comparatively low economic attractiveness and high complexity of offshore wind. Adoption of this technology thus only seems feasible with additional financial incentives, such as high FiT or subsidies for the initial investment, as well as technical and political support.

The CAPEX for land-based wind generation is lower than for offshore installations, and further decreases over time. For assets installed in 2020, this results in a lower LCOE over the investment's lifetime compared to offshore generation (see Table 15). However, the higher and increasing efficiency rates of offshore generation soon make up for its high initial investment costs, resulting in lower LCOE over the economic lifetime than for land-based generation for all investments after 2025. In both the Baseline and Decarb_Demand scenario, onshore wind generation is not economically attractive under market sales only, with negative NPVs for all investment periods (see Table 11 and Table 12).

In the Baseline scenario, investments in geothermal in all periods achieve positive NPVs over their lifetime without FiT support, due to high pre-tax electricity market prices (see Table 11). In the Decarb_Demand scenario, the sinking electricity price induced by increasing RES penetration lowers producers' revenues, resulting in negative NPV for geothermal power plants built from 2030 onwards (see Table 12). Still, these results point at the economic attractiveness of geothermal for Mayotte under given assumptions. While the technology has potential for providing a share of clean, non-intermittent energy in the future, the potential for geothermal in Mayotte should be confirmed first, as should be the assumptions on the cost and revenue structures that can be achieved in reality.

### 6.1.2. Investment case based on additional assumptions

#### Feed-in tariffs and other measures of RES support

In the E3-ISL modelling, no FiT was assumed for any of the RES technologies. Still, RES investments are attractive based on, among others, the high carbon prices in the decarbonization scenarios and the economic competitiveness of RES in Mayotte, and consequently, high RES rollout and decarbonization occur over time. To add to this analysis, we repeat the profitability analysis conducted before (see Chapter 6.1.1) under the assumption of FiT support. While FiT support should further strengthen the already strong investment case for solar PV in Mayotte, it might also allow the non-profitable investments, such as wind on- and offshore, to become economically viable. While different FiT provisions exist for RETs in Mayotte, with differing rates and time horizons for each technology, we assume the same FiT compensation and structure for all cases. The assumed FiT scheme is based on the (projected) FiTs for solar PV installations between 36 and 100kWp and paid out during the economic lifetimes of investments.

#### FiT Projection

Using quarterly data for feed-in tariffs for large solar power plants (36 to 100 kWp) in Mayotte ranging from mid-2017 to mid-2023 (CRE, 2023), we project the development of feed-in compensations until 2054 (see Figure 36). Assuming a linear trend, the feed-in tariff for these solar PV power plants will reach zero shortly after the projection period, in 2055. In line with the modelling approach, we calculate the average FiT compensation for each 5-year period between 2015 and 2050, with the FiT for the missing years 2015 and 2016 treated as zero, resulting in a lower average compensation in the 2015-2019 period.

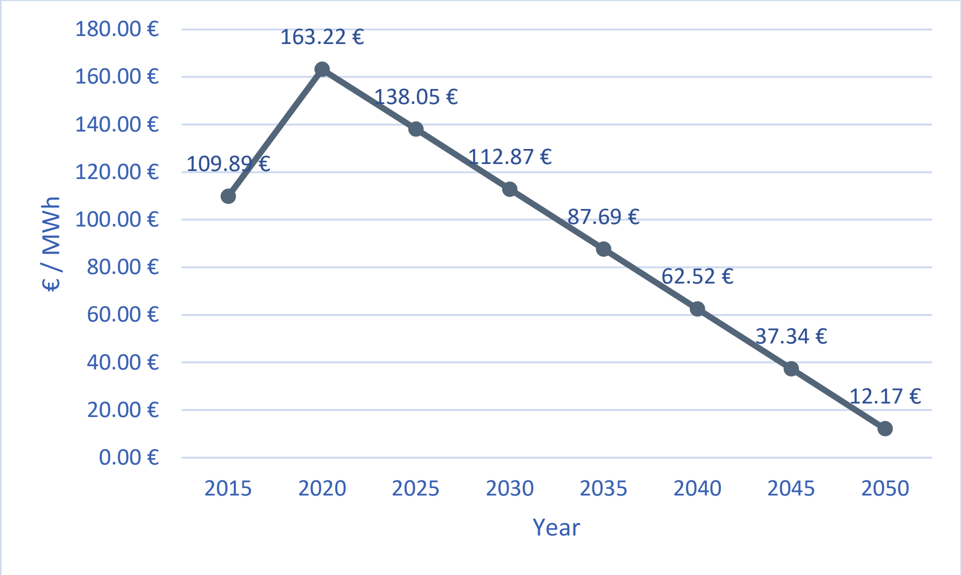

**Figure 36: Linear projection of feed-in tariffs for solar PV (36-100kWp) in Mayotte, 5-year average**

FiT compensation decreases over time, sinking over time below the pre-tax electricity prices that producers receive for power generation. At this point, no FiT support occurs, and RES producers receive the same compensation as any other energy market actor. This switch occurs in the year 2030 for the Baseline scenario, and 2032 in the Decarb_Demand scenario (see Figure 37). On a mathematical basis, RES producers optimize between FiT compensation and market prices, receiving the higher compensation for their sold production in each year.

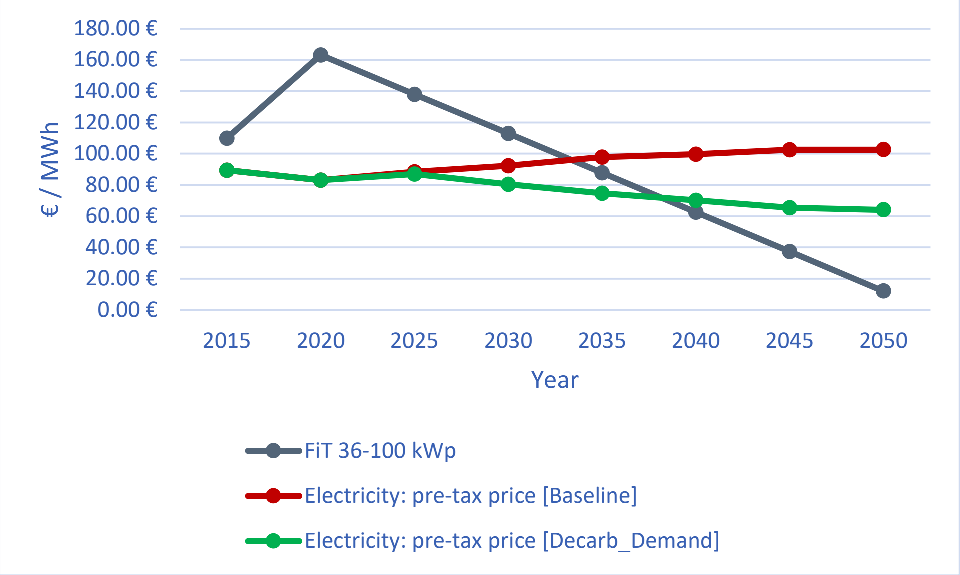

Figure 37: Development of projected FiT and pre-tax electricity prices

### Investment in RES for power generation under FiT support

Since FiT compensations fall below the projected pre-tax electricity in 2035 (Baseline) and 2041 (Decarb_Demand), they only influence the profitability of RES that operate between 2015 and 2035/2041, i.e. investments from the periods 2015, 2020, 2025 and 2030 in the Baseline scenario, and the same periods plus investments made in 2035 in the Decarb_Demand scenario. As FiTs sink steadily over time, their supporting effects are strongest for early investments, and decrease for later investments, resulting in high NPVs for early investments in solar PV and geothermal in the Baseline scenario (Table 16) and for solar PV in the Decarb_Demand scenario (Table 17).

Table 16: NPV (million €) over economic lifetime under optimization of market sales and FiT, Baseline Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 0.675 | 0.684 | 0.578 | 0.549 | 0.597 |
| Commercial solar PV | 0.345 | 0.918 | 0.937 | 0.793 | 0.753 | 0.797 |
| Wind onshore | NA | -0.316 | -0.425 | -0.750 | -0.919 | -0.885 |
| Wind offshore | NA | -0.518 | -0.143 | 0.041 | 0.034 | 0.150 |
| Geothermal | NA | 2.514 | 2.161 | 1.556 | 1.336 | 1.301 |

Table 17: NPV (million €) over economic lifetime under optimization of market sales and FiT, Decarb_Demand Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 0.670 | 0.644 | 0.441 | 0.265 | 0.186 |
| Commercial solar PV | 0.345 | 0.913 | 0.893 | 0.642 | 0.439 | 0.345 |
| Wind onshore | NA | -0.324 | -0.496 | -0.985 | -1.390 | -1.563 |
| Wind offshore | NA | -0.525 | -0.208 | -0.201 | -0.472 | -0.588 |
| Geothermal | NA | 2.413 | 1.807 | 0.767 | -0.050 | -0.541 |

Many RETs, including commercial and rooftop solar PV and to a certain extent geothermal, are already profitable without FiT support (see Table 11 and Table 12). The additional FiT support further strengthens the investment case for these technologies.

For the technologies that were not profitable under a market sales only revenue scheme, the higher revenues from FiTs can bridge this gap and result in profitable operations over the project's economic lifetime. With the support of the FiT, commercial solar PV installations constructed in 2015 become financially viable in both the Baseline and the Decarb_Demand scenario, which they were not under a market sales only revenue structure (see Table 11 and Table 12).

In the Baseline scenario, the projected FiTs are sufficient for a profitable operation of wind offshore assets installed in 2030 (Table 16), which previously reached a negative NPV over their economic lifetime. Still, the assumed FiTs are not sufficient to redeem the high CAPEX of earlier investments in offshore wind, i.e. in 2020 and 2025. For the periods 2035 and 2040, FiTs already sink below electricity price levels of the Baseline scenario, resulting in the same NPV as for the market sales only revenue scenario. In the Decarb_Demand scenario with its lower wholesale electricity prices, however, not even the proposed FiT can enable a profitable investment of offshore wind assets, resulting in negative total NPV in all investment periods (Table 17).

In the Baseline scenario, geothermal can operate with positive per unit NPV in all investment periods (Table 18), due to the high pre-tax electricity prices earned for the sold generation. In the Decarb_Demand scenario, the FiT supports the economic viability of geothermal assets installed in 2030 and 2035, reaching positive total and per unit NPVs for 2030 investments, and, on average, NPV close to zero per generated unit of electricity for assets installed in 2035 (Table 19).

Table 18: NPV per generated unit (€/MWh) over economic lifetime under optimization of market sales and FiT, Baseline Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 33.77 | 31.81 | 26.89 | 25.56 | 27.76 |
| Commercial solar PV | 17.25 | 42.72 | 39.61 | 33.51 | 31.83 | 33.69 |
| Wind onshore | NA | -8.39 | -11.16 | -20.38 | -25.92 | -24.95 |
| Wind offshore | NA | -15.94 | -4.09 | 1.08 | 0.88 | 3.88 |
| Geothermal | NA | 24.20 | 18.98 | 13.67 | 11.73 | 11.43 |

Table 19: NPV per generated unit (€/MWh) over economic lifetime under optimization of market sales and FiT, Decarb_Demand Scenario

| Year of Construction | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| Rooftop solar PV | NA | 33.56 | 29.96 | 20.51 | 12.31 | 8.66 |
| Commercial solar PV | 17.25 | 42.51 | 37.76 | 27.13 | 18.58 | 14.59 |
| Wind onshore | NA | -8.60 | -13.02 | -26.77 | -39.17 | -44.05 |
| Wind offshore | NA | -16.15 | -5.95 | -5.30 | -12.37 | -15.22 |
| Geothermal | NA | 23.22 | 15.86 | 6.74 | -0.44 | -4.75 |

For onshore wind generation, however, the assumed FiT scheme is not sufficient for cost-neutral or profitable operation during an economic lifetime of 15 years. This is the case both for the Baseline and the Decarb_Demand scenarios. Within the expected technical lifetime of 25 years, these investments might still reach breakeven, but it is unlikely that private investors would be willing to take on such risks. Only with higher FiT support or other forms of subsidization, would wind onshore generation become economically attractive to investors under the modelled assumptions.

While an optimal design of FiTs is complicated to achieve, our results might provide a first indication: If only a FiT and no other support measure were in place, then the average FiT over the investment's economic lifetime would need to match or surpass its average LCOE over the economic lifetime, presented in Table 15 above.

## 6.2. COSTS AND BENEFITS FOR PROSUMERS

The Decarb_Demand scenario represents a consumer-driven decarbonization path, building on energy efficiency and decentralization. One important pillar of the transition in this scenario is the expansion of rooftop solar PV installations, profiting from the large solar potential of Mayotte. On the most basic level, such assets can feed the generated electricity into the grid, acting as another producer in the energy system. This is particularly relevant for large-scale installations, the profitability of which were investigated in Chapter 6.1. More efficient, however, is the direct consumption of electricity at the place where it is produced, for example in shared consumption or prosumer models, as this local consumption reduces stress on the grid. In Mayotte, the rollout of such models has only recently been attempted, despite the large solar potential of the island. This is partly due to a lack of appropriate standards and regulations for such models, particularly for shared consumption, and a structure of economic incentives that currently favours direct feed-in over local consumption. In the following sections, we investigate the economic attractiveness of prosumer models in Mayotte over the modelling horizon, establishing first indications of the economic attractiveness of such models on the island which could present an incentive or burden to their large-scale adoption.

We investigate the investment case for prosumers on different scales, namely rooftop solar PV for households (up to 3 and up to 9 kWp) and larger consumers (up to 36 and 100 kWp), e.g., administrative or office buildings. This selection of system sizes is based on the current FiT classification for solar PV systems in Mayotte and represents the upper limit of each FiT category. FiT categories currently cover systems of <3, 3-9, 9-36 and 36-100 kWp, with per-unit FiT decreasing with system size. Again, we use available data on these FiT schemes to project their development until the year 2054 using linear extrapolation. Figure 38 outlines the FiT projection for each asset class, as well as the projected after-tax electricity prices in the Baseline and Decarb_Demand scenarios. To our knowledge, FiTs were first introduced in Mayotte in the second quarter of 2017, and we therefore treat them as zero for the previous periods. This lowers the average FiT compensation calculated for the 5-year period between 2015 and 2019, even though the 'actual' FiTs after Q1 2017 range between 188 and 241 Euros per MWh. The intersection of the projected FiTs and the modelled after-tax electricity prices represents the point in time where self-consumption becomes economically attractive, which happens earlier in the Baseline scenario due to its higher electricity prices based on higher average costs of (diesel-intense) generation. In the Baseline scenario, self-consumption becomes attractive in 2031 (36-100 kWp), 2033 (9-36 kWp), 2035 (3-9 kWp) and 2036 (<3 kWp) for the respective system sizes. In the Decarb_Demand scenario, this shift occurs with a slight delay, in the years 2033 (36-100 kWp), 2036 (9-36 kWp), 2038 (3-9 kWp) and 2039 (<3 kWp).

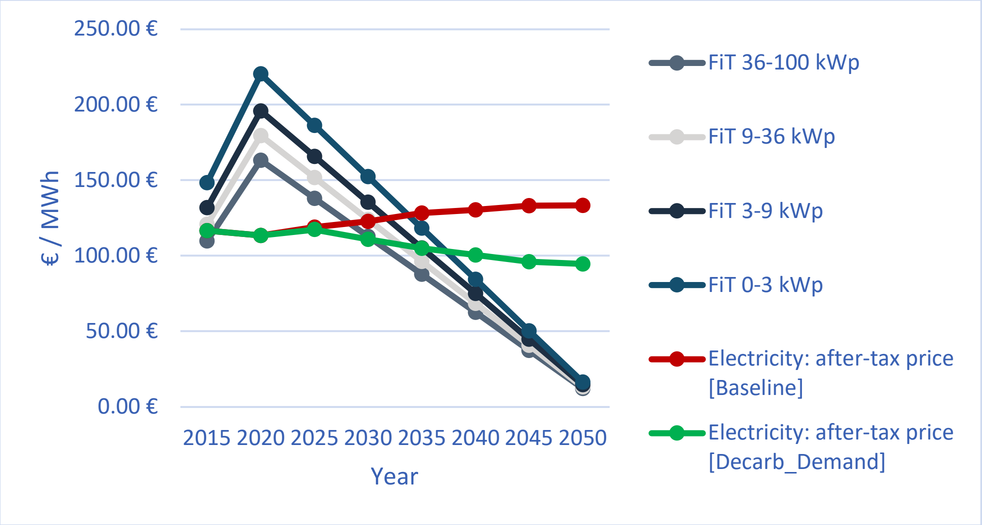

Figure 38: Projected FiT for rooftop solar PV for prosumers and after-tax electricity prices

We assume a maximum self-consumption rate of 30% of generated electricity for all systems, with no additional storage installed. This rate is in line with literature on self-consumption rates for households with similar assets in mainland Europe (Luthander et al., 2015). Still, this assumed rate is a simplifying assumption, and actual self-consumption rates may vary according to total household consumption and the demand patterns and load curves of prosumer types. Larger prosumers, such as public buildings and offices, may consume energy during the day for their operations, resulting in higher self-consumption of solar-based electricity.

The self-consumption model implies important differences to the previous models for rooftop PV used in Chapter 6.1, where producers sold all electricity at wholesale market or FiT rates. Small prosumers do not have access to wholesale electricity markets, and cannot sell at the modelled pre-tax electricity price, which represents the wholesale market price for Mayotte in our calculations. Instead, they can inject their production at the respective FiT rate. This is the case for all energy that cannot be self-consumed, i.e. 70% according to our assumptions. For the 30% of potential self-consumption, prosumers optimize between actually consuming the electricity themselves, or feeding it into the grid, according to which option is more economically attractive. When self-consuming, prosumers reduce their electricity demand from the grid, for which they pay the after-tax electricity price projected in E3-ISL. Consequently, prosumers will only self-consume when this after-tax electricity price is higher than the FiT for the respective asset. As another important difference to previous calculations, this optimization is conducted on a yearly basis, instead of the previous optimization of average FiT and electricity prices for each five-year period. Given these differences, the results for rooftop solar PV installations from 36 to 100 kWp for prosumers differ from results for the same asset class for producers (see Chapter 6.1), and we include both in subsequent Tables and Figures for ease of comparison.

For reasons of simplicity and comparability, we use the same costs and discount rates as in previous calculations, and again assume an economic lifetime of 15 years for all solar PV assets. It is clear however, that a more nuanced approach can provide a more detailed understanding, including higher capital and operating costs for smaller systems, longer economic lifetimes and differing discount rates for different consumer types. Future studies should take these differences into account and elaborate the profitability analysis for prosumers in more detail.

### 6.2.1. Investment case based on modelling assumptions & additional data

Under the given assumptions, investment in rooftop solar PV for prosumers is attractive for all system sizes and in all time periods, considering the positive total and per-unit NPV over the project's economic lifetime. This is the case for both the Baseline and the Decarb_Demand scenario. Table 20 and Table 21 present the estimated NPV for 1 MW of installed solar PV rooftop capacity for prosumers with a potential self-consumption rate of 30%, allowing for a comparison of the different system sizes.

**Table 20: NPV (million €) of rooftop solar PV for different prosumer classes over economic lifetime, 1MW installed capacity at 30% maximum self-consumption, Baseline Scenario**

| System Size/ Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| 36-100 kWp (Producer) | NA | 0.675 | 0.684 | 0.578 | 0.549 | 0.597 |
| 36-100 kWp (Prosumer) | NA | 0.590 | 0.595 | 0.447 | 0.311 | 0.165 |
| 9-36 kWp | NA | 0.730 | 0.715 | 0.520 | 0.358 | 0.192 |
| 3-9 kWp | NA | 0.870 | 0.843 | 0.606 | 0.408 | 0.226 |
| <3 kWp | NA | 1.079 | 1.037 | 0.743 | 0.480 | 0.273 |

**Table 21: NPV (million €) of rooftop solar PV for different prosumer classes over economic lifetime, 1MW installed capacity at 30% maximum self-consumption, Decarb_Demand Scenario**

| System Size/Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| 36-100 kWp (Producer) | NA | 0.670 | 0.644 | 0.441 | 0.265 | 0.186 |
| 36-100 kWp (Prosumer) | NA | 0.590 | 0.582 | 0.395 | 0.206 | 0.046 |
| 9-36 kWp | NA | 0.730 | 0.708 | 0.481 | 0.256 | 0.073 |
| 3-9 kWp | NA | 0.870 | 0.840 | 0.577 | 0.311 | 0.107 |
| <3 kWp | NA | 1.079 | 1.037 | 0.726 | 0.402 | 0.154 |

When comparing the results for one representative MW of installed capacity, the higher FiT for smaller system sizes becomes evident, resulting in higher returns over the project's lifetime. Comparing the case of a 100 kWp system participating in the energy market as a producer, and that of the same system size acting as a prosumer without access to wholesale markets, highlights a disadvantaged position of prosumers and small producers in the current market setup. Assuming a linear decline of FiTs over time, prosumers' revenues decrease over time, and the energy bill savings resulting from a limited share of self-consumption cannot recover these comparative losses. Systems with access to wholesale markets, on the other side, profit from FiT compensation if these rates are higher than the wholesale price and can afterwards stabilize their revenues at the level of the pre-tax electricity price, the same as other (large-scale) producers in the market. Without additional costly system modifications, e.g., for storage, increasing their rate of self-consumption, the prosumers' face a comparative disadvantage. Still, prosumer projects seem economically feasible under this simplified model, with a positive NPV per unit of electricity produced over their lifetime in both Baseline (Table 22) and Decarb_Demand scenario (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

**Table 22: NPV per generated unit (€/MWh) of rooftop solar PV for different prosumer classes over economic lifetime, 1MW installed capacity at 30% maximum self-consumption, Baseline Scenario**

| System Size/ Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| 36-100 kWp (Producer) | NA | 33.77 | 31.81 | 26.89 | 25.56 | 27.76 |
| 36-100 kWp (Prosumer) | NA | 42.18 | 39.56 | 29.71 | 20.65 | 10.95 |
| 9-36 kWp | NA | 52.22 | 47.54 | 34.56 | 23.80 | 12.78 |
| 3-9 kWp | NA | 62.21 | 56.00 | 40.28 | 27.08 | 14.99 |
| <3 kWp | NA | 77.12 | 68.91 | 49.38 | 31.90 | 18.15 |

**Table 23: NPV per generated unit (€/MWh) of rooftop solar PV for different prosumer classes over economic lifetime, 1MW installed capacity at 30% maximum self-consumption, Decarb_Demand Scenario**

| System Size/ Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| 36-100 kWp (Producer) | NA | 33.56 | 29.96 | 20.51 | 12.31 | 8.66 |
| 36-100 kWp (Prosumer) | NA | 42.18 | 38.68 | 26.25 | 13.71 | 3.04 |
| 9-36 kWp | NA | 52.22 | 47.08 | 31.94 | 17.01 | 4.87 |
| 3-9 kWp | NA | 62.21 | 55.86 | 38.36 | 20.68 | 7.08 |
| <3 kWp | NA | 77.12 | 68.91 | 48.22 | 26.68 | 10.24 |

Still, the total expected returns on investment are limited for prosumers, particularly for small system sizes. Table 24 and Table 25 present the NPV for the maximum installed system size in each

FiT class, i.e., a system of 3, 9, 36 and 100 kWp respectively, outlining the 'estimated discounted cash flows of a 'real'-sized project.

Table 24: Total NPV (€) of rooftop solar PV investments for different prosumer classes over economic lifetime, 30% maximum self-consumption, Baseline Scenario

| System Size/ Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| 100 kWp (Producer) | NA | 67469.43 | 68381.87 | 57803.23 | 54940.86 | 59676.84 |
| 100 kWp (Prosumer) | NA | 58988.01 | 59525.52 | 44706.95 | 31069.27 | 16472.84 |
| 36 kWp | NA | 26292.67 | 25753.61 | 18721.77 | 12890.81 | 6921.23 |
| 9 kWp | NA | 7830.07 | 7583.18 | 5455.15 | 3667.71 | 2029.90 |
| 3 kWp | NA | 3235.67 | 3110.61 | 2229.14 | 1439.80 | 819.27 |

Table 25: Total NPV (€) of rooftop solar PV investments for different prosumer classes over economic lifetime, 30% maximum self-consumption, Decarb_Demand Scenario

| System Size/Year | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|
| 100 kWp (Producer) | NA | 67042.80 | 64389.64 | 44086.48 | 26459.10 | 18620.35 |
| 100 kWp (Prosumer) | NA | 58988.01 | 58196.01 | 39491.19 | 20634.30 | 4578.53 |
| 36 kWp | NA | 26292.67 | 25502.80 | 17301.55 | 9211.80 | 2639.27 |
| 9 kWp | NA | 7830.07 | 7564.40 | 5194.61 | 2799.88 | 959.42 |
| 3 kWp | NA | 3235.67 | 3110.61 | 2176.81 | 1204.54 | 462.44 |

As FiTs gradually decrease, total expected returns diminish, the later a project is set up in time, reaching levels that investors 'in the real world' might not consider worth the risks and effort involved. Particularly in the Decarb_Demand scenario, the lower electricity prices diminish prosumers' energy bill savings. Ironically, these lower prices are the result of increasing RES penetration and decarbonization, exemplifying a cannibalization effects of RES revenues through their wide-scale deployment. Still, investments in rooftop solar PV could allow small-scale prosumers to participate in the energy transition and profit through economic benefits. For the smallest systems, monthly total costs including capital repayments and O&M costs, amount to circa 290 Euros (3 kWp) to 865 Euros (9kWp) in 2020, with the largest share going towards the repayment of the CAPEX. The costs for new investments after 2020 steadily decrease over time due to technological advancements and learning-by doing. Under these assumptions, such investments should be affordable for middle-class households, as well as larger shares of the population once additional support measures are put into place. Importantly, FiT support or similar measures should continue for prosumers and other small producers without access to wholesale markets, allowing them to generate and inject electricity at cost-recovering prices.

## 6.3. COSTS AND BENEFITS FOR CONSUMERS

### 6.3.1. Distributional effects of reduced electricity prices and energy policy

Energy transitions encompass profound changes of energy systems and the wider economy, resulting in potential distributional effects through different channels. Using a general equilibrium model, (Fragkos et al., 2021) for example, forecast that inequality will slightly increase in the context of the EU's emissions reductions targets, with low income households affected the most, and propose carbon tax revenue recycling to support employment and reduce inequality. And in a review of the literature on just energy transitions, (García-García et al., 2020) find a small positive effect of clean energy transitions on employment, and a negative effect on income distribution.

In the decarbonization scenario, the lower operating costs of RES lead to reduced electricity system costs, and thus to lower electricity prices as RES-based generation replaces the expensive diesel-fired turbines. Through various channels, these lower prices have important effects on the welfare of consumers, and the distribution of benefits among actors in the economy, as (1) they increase the available income of consumers that can be directed to other, non-energy purposes and (2) reduce the production costs of firms that use electricity, leading thus to increased competitiveness and production of the private sector (both industries and services).

Under the Decarb_Demand scenario, increasing RES penetration leads to lower total energy system costs, resulting in lower end-user electricity prices. As a direct consequence of increasing RES penetration, consumers thus pay lower costs for electricity, thereby lowering their energy bills. Secondly, end uses are increasingly electrified, with lower costs for electrified than non-electrified, fossil-based end uses. As a consequence, the expenditure for these energy uses sink as well. The most significant example of this electrification is consumers' shift from conventional to e-mobility, allowing them to pay lower costs for electric- than for fossil-based individual mobility.

Beyond these effects for the average consumer, the energy transition and associated policies result in differing effects for different income classes. Certain tax duties and levies are raised as fixed part of the electricity bill, e.g. a fixed (Euros per kWh) or relative (% increase on price per kWh) charge per unit of electricity sold to end consumers (Farrell & Lyons, 2015), regardless of household income. A well-known example of such additional charges, or Public Service Obligations (PSOs) is the German EEG, the distributional effects of which have been extensively discussed in the literature. In the case of Mayotte, excise taxes are levied on the fixed and variable components of electricity tariffs. These taxes considerably raise the price of electricity for end consumers and are regressive, as they target all customers irrespective of their income level. Households with lower incomes thus pay relatively higher contributions.

Researchers further highlight that a pure carbon tax is regressive, as it charges all consumers the same, regardless of their income , and should therefore be coupled with tax revenue recycling (Wang et al., 2016). Carbon taxes have been highly debated in the French context, and some have argued that the carbon tax is regressive and enhances energy poverty (Berry, 2019), and propose to use carbon tax revenues to finance cash transfers or energy poverty policies to counter these effects.

Some financing models and regulations, such as feed-in tariffs, benefit particular groups. In the case of feed-in tariffs, only households who are willing and able to invest in RES, e.g., solar PV on their private rooftops, can profit from the often very attractive feed-in tariff schemes. Households that cannot afford such investments are excluded from these benefits. Adding to this imbalance, in private-financed FiT models, all electricity consumers pay the costs of the subsidy regardless of their incomes, again resulting in a regressive structure. In an empirical study for the German context building on detailed microeconomic panel data and the use of inequality-indices, (Winter & Schlesewsky, 2019) find that high-income households profit from FiTs, while the even distribution of subsidy costs leads to regressive effects.

Counterbalancing the regressive effects of excise taxes, PSOs and other fixed levies, reduced electricity prices, caused for example by higher RET penetration, can benefit lower income households (Farrell & Lyons, 2015). While all energy customers profit from lower electricity prices, households with a large share of energy expenditures in their total budget, which are usually those with lower incomes, profit relatively more from reduced energy prices than households with a lower share of energy expenditures. In this sense, the reduced electricity prices in the decarbonization scenarios have a progressive effect. Due to limitations in available data, however, we cannot estimate the size of this effect in Mayotte.

Generally, the distributional effects of reduced electricity prices can be quantified on the basis of income and energy expenditure data (Fragkos et al., 2021). Using detailed data on household energy consumption and incomes, for example, allows to quantify energy expenditure shares for different socio-economic groups, as well as energy poverty and other measures of (energy-related) inequality (Frondel et al., 2015). In the case of Mayotte, however, data for both could not be identified. Income data is limited to per capita income and rough estimates of the highest and lowest deciles (INSEE, 2023). For an analysis of distributional effects, more granular income data would be needed, detailing at least all deciles of income distribution. Granular data on energy expenditure is also unavailable, especially in relation to income levels. While average consumption data is part of the modelling inputs, no assumptions can be drawn on the distribution of consumption. While more detailed data is available for the national level, this aggregated data is not suited for the special case of Mayotte, which in many aspects differs from mainland France. For other and future research projects, these limitations will not pose a problem as long as the distribution of income and energy consumption of the islands under investigation are comparable to contexts where data is available. Alternatively, such data might be generated as part of the research, or at least be approximated.

## 6.4. SUBSIDIZATION OF NON-CONNECTED ZONES

### 6.4.1. Diesel price subsidies in Mayotte

The remote location and small size of islands typically result in higher energy prices and electricity generation costs. In Mayotte, the costs of electricity generation, which mainly depends on imported diesel, are higher by magnitudes compared to the French mainland. In May 2023, for example, generation costs in Mayotte were estimated at 350 Euros per MWh[16], with wholesale prices in France below 80 Euros per MWh in the same period[17]. To shield consumers from high prices and support economic competitiveness, the French government subsidizes the energy systems of regions that are not connected to the national grid, such as Mayotte and other outermost regions. Currently, this subsidy is financed by an additional contribution of electricity consumers on the mainland. The public energy service charges (CSPE) is a fixed levy for all electricity customers in mainland France, which subsidizes the higher costs of electricity generation in the non-interconnected zones (ZNI)[18]. Through the subsidy, electricity prices on the islands are lowered to the level of those on the mainland. Consequently, the lower generation costs of electricity in Mayotte caused by higher RES penetration reduce the subsidies needed for levelling the electricity price, and thus reduce the financial burdens on French customers as part of the CSPE. In this way, the energy transition in Mayotte extends beyond the island and benefits the population on the mainland.

Per-unit subsidies for energy consumption have several implications, which speak both for and against them. On the upside, they support end consumers' spending on vital goods and services, benefitting low-income households relatively more. Energy expenditures claim a higher share of these households' total budget, and in many cases, their absolute energy consumption is higher due to, for example, the households not being able to finance more modern and energy efficient appliances. These factors result in a progressive subsidy structure, with the low-income households benefiting the most. As the subsidies target all end users, they also support business customers, and thereby the economic competitiveness of the island.

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[16] https://www.pv-magazine.fr/2023/05/15/lao-zni-a-recompense-six-projets-photovoltaique-a-mayotte-pour-28-mw/

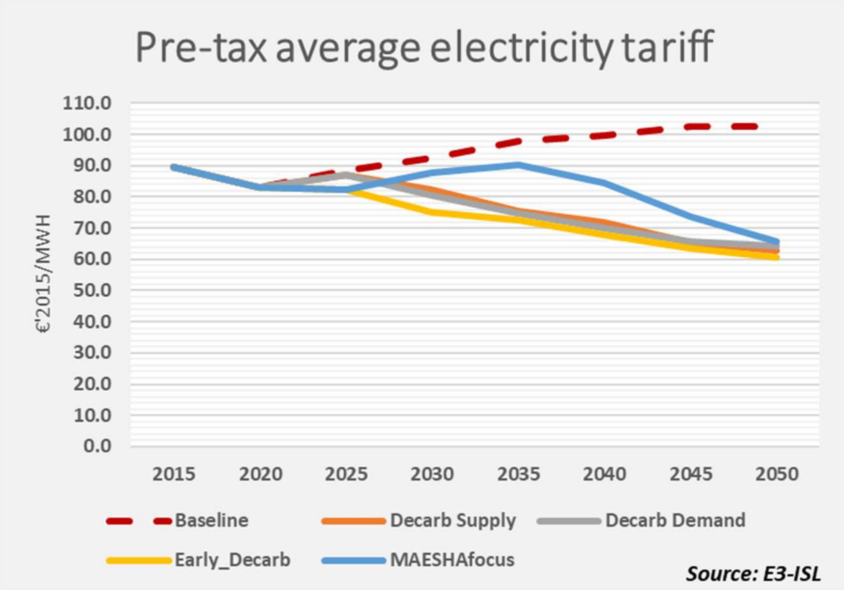
[17] https://www.statista.com/statistics/1267546/france-monthly-wholesale-electricity-price/

[18] https://clean-energy-islands.ec.europa.eu/system/files/2022-01/France%20Factsheet%20Final.pdf

However, these subsidies strongly support the status quo of energy consumption and electricity generation, causing detrimental effects for the environment and the advancement of the energy transition in Mayotte. Today, most of Mayotte's electricity is produced in large diesel power plants using expensive, imported fossil fuels. This energy system configuration results in considerable greenhouse gas emissions and the high generation costs that necessitate the subsidies in the first place. In an energy system with higher penetration of renewable sources with operating costs close to zero, such as solar PV, the operating costs of the system would be considerably lower, and arguably not need any end-user price subsidization to compete with the prices on the mainland. For both private and commercial consumers in Mayotte, the currently unsustainable energy system configuration does not have an impact in their daily lives, as they pay the same subsidized price regardless of the energy source. This reduces the incentive for lower energy consumption, a shift to more energy efficient appliances or production, and public support for alternative energy sources. While the support of (low-income) households for basic consumption and competitive energy prices for businesses are crucial, other, more tailored subsidy structures can be used to achieve the same ends. Taken together, the subsidies finance and support the current fossil-based energy generation in Mayotte, thereby leading to potential carbon lock-in and slowing the energy transition. The only exception to this negative chain would be a swift introduction of biodiesel, which would result in even higher costs of generation, and therefore an increase in the needed subsidies, but benefit the environment through lower net emissions. In the following section, we investigate the potential effects of a gradual fade-out of electricity price subsidies in Mayotte.

### 6.4.2. Gradual removal of electricity price subsidization

The analysis conducted in Deliverable 2.3 "Long-term energy transition assessments for islands – The case of Mayotte" assumed that the electricity prices in Mayotte continue to be subsidized with the same rate in all scenarios including the Baseline and Decarb_Demand. The electricity prices are projected to decline in the decarbonization scenarios relative to the Baseline scenario, driven by the penetration of renewable energies in the power mix that replace the expensive diesel-fired power generation. The cost-efficient RES stimulate a price reduction effect on the wholesale electricity market, propelled by the low investment costs and the exemption from carbon taxes.



Source: E3-ISL

Figure 39: Evolution of pre-tax average electricity prices by scenario

There is an ongoing policy debate on the impacts of energy subsidies that cause additional burden on governmental budgets or consumers. Therefore, we developed a variant of the Decarb_Demand scenario assuming the gradual removal of the electricity price subsidization by 2050 starting from 2030 aiming to assess the potential gains for the French public from reduced subsidies and the additional burden on household income. The subsidization is expressed with a negative profit rate in the model, which is used to calculate the end-user electricity price. According to our estimations in E3-ISL, the subsidization rate of the power system costs of Mayotte (excluding grid costs) is almost -300% in 2015. The formula that is used to calculate the revenues from the power system is the following:

$$Revenues = Transmission\&DistributionCosts + \frac{GenerationCosts}{1 - profit\_rate}$$

The following figure depicts the trajectories of the pre-tax electricity tariffs in the Decarb_Demand variants. In the variant with the gradual removal of price subsidy (scenario Decarb_demand_nosub), the pre-tax electricity price reaches 147 Euros per MWh in 2050 whilst the respective price in the original Decarb_Demand is 64 Euros per MWh in 2050.

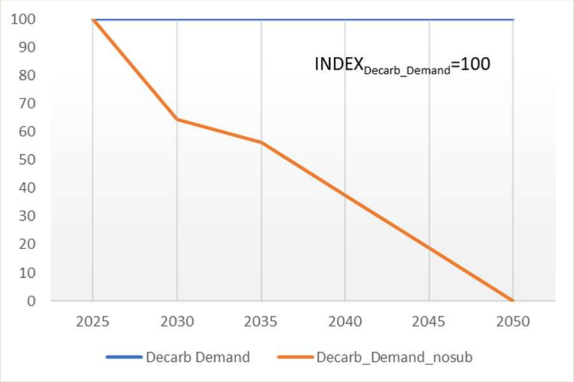
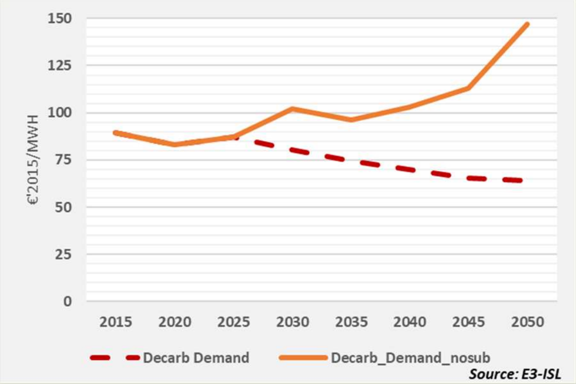


Figure 40: Indexed evolution of subsidization rate of the power system costs.



Source: E3-ISL

Figure 41: Decarb_Demand variants – Evolution of pre-tax average electricity prices.

Although the average cost of electricity generation in Decarb_Demand_nosub scenario declines in the long term (Figure 42), this is not reflected in the end-user prices – the end-user price follows an upward trend since electricity price subsidies are removed.

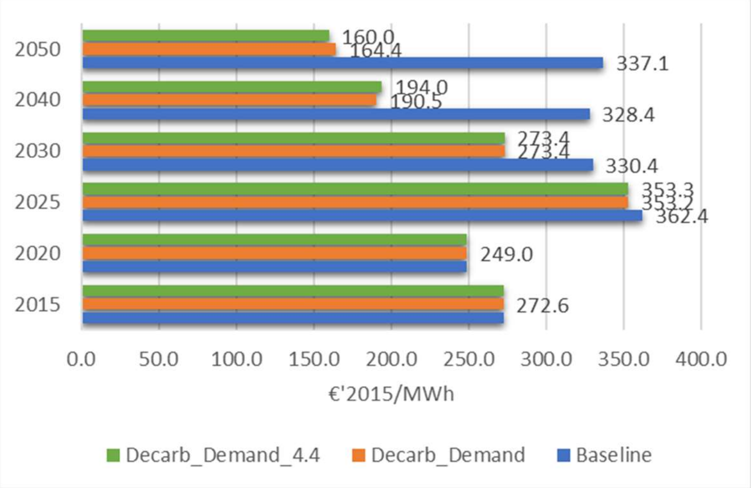
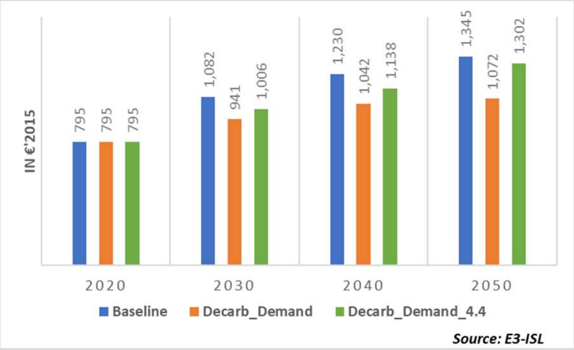


Figure 42: Evolution of average cost of electricity generation by scenario compared to Baseline.

Since electricity is basically the sole energy carrier used and paid by the energy consumers in the residential sector, the energy costs of a household (without accounting for private transportation but only for energy consumption in the buildings) are also rising. Nevertheless, the energy costs of Decarb_Demand_nosub continue being below the Baseline levels even by 2050 as the removal of electricity subsidies is more than counterbalanced by reduced power generation costs driven by the massive uptake of RES that replace the expensive diesel-fired power plants. In 2050, the share of household energy costs (excluding transport) in GDP is 1.66% in the Decarb_Demand_nosub scenario and 1.71% in the Baseline scenario.



*Source: E3-ISL*

Figure 43: Evolution of Household energy costs (w/o transport) by scenario in €'2015 per HH.

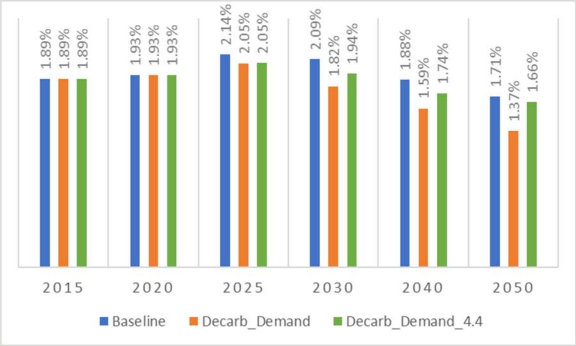


Figure 44: Household energy costs (w/o transport) in % of GDP by scenario.

We approximated the level of the subsidization of the electricity price by year in monetary terms, based on the available data and the model results of different scenarios. It is noteworthy that the cumulative savings for the French public from the removal of subsidies starting from 2030 amount to 758 million Euros. These savings could be more effectively used and redistributed to support vulnerable households to cope with price shocks, e.g., with targeted compensation schemes for the low-income households or with subsidies to install rooftop PV to produce their own electricity.

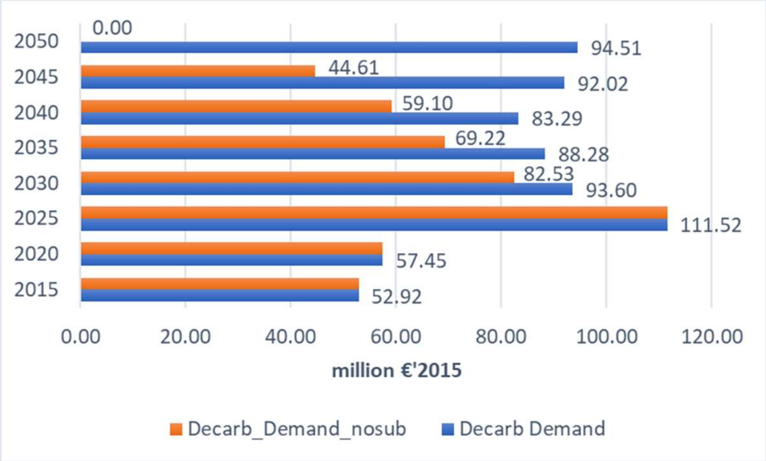


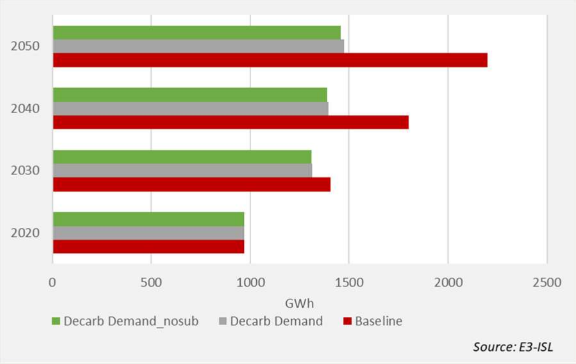
Figure 45: Level of subsidization of power system costs by 2050 in Decarb_Demand variants.

In principle, the E3-ISL model considers the price-elastic behavior of consumers and seeks for an electricity market equilibrium, meaning that the balancing of electricity demand and supply is cleared by prices. Regarding the impacts of the removal of the electricity price subsidies on the final energy consumption, it is observed that:

1. the overall final energy consumption declines driven by rising electricity prices and increased energy efficiency improvements as it was considered more cost efficient to purchase more efficient electric equipment.

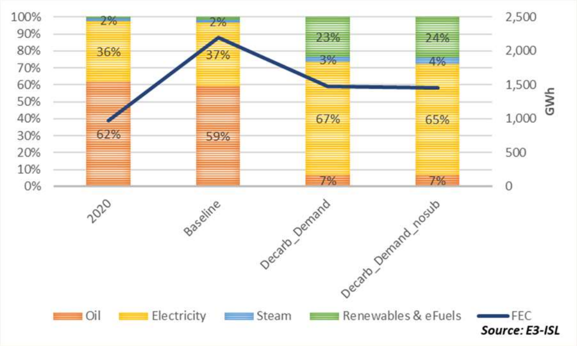
2. electricity was slightly substituted by other fuels (solar, steam, etc.) especially in the industry, and tertiary sectors (the share of electricity in the fuel mix is 65% instead of 67% in the original Decarb_Demand scenario).

Although the end-user electricity price gradually doubles by 2050 compared to current levels, the impact of the high end-user prices on the demand of electricity of Mayotte is relatively limited. The main reason is that there is no leeway for fuel substitution in the case of Mayotte in the residential and industry sector, let alone when it comes to a decarbonization context.



*Source: E3-ISL*

Figure 46: Projection of final energy consumption by scenario.



***Source: E3-ISL***

Figure 47: Fuel mix in final energy consumption by scenario compared to 2020 and Baseline.

# 7. DISCUSSION AND CONCLUSION

The transition to carbon neutrality is a complex process that requires high uptake of clean energy technologies, low-carbon innovation, sufficient financial resources, and coordination of market players. In Mayotte, energy system decarbonization involves the substitution of imported fossil fuels by products and services related to zero-carbon technologies and energy-efficient equipment and appliances. The installation, operation and maintenance of these technologies is an activity that is performed domestically, thus creating jobs and value added in the island, in contrast to imported fossil fuels. The substitution towards low-emission technologies, appliances, and vehicles requires economic restructuring towards a more capital-intensive structure. The large-scale deployment of renewables will reduce the average cost of electricity production in Mayotte, and thus the electricity price, as the currently dominant diesel-fired plants are much more expensive than renewable-based alternatives. This would benefit both domestic demand (as households would face lower energy bills) and production (through reduced production costs and enhanced international competitiveness of firms), and **the transition to carbon neutrality would provide clear socio-economic benefits in the form of increased GDP, consumption, investment, and employment**.

**The scenario focusing on consumer-driven transition (Decarb_Demand) generates more positive economic impacts relative to Decarb_Supply**, due to the high costs in the latter to massively produce or import clean hydrogen and e-fuels. This points to the positive effects of energy efficiency, electrification, and active citizen participation in the transition to carbon neutrality. In the short-term, GDP gains are smaller in the case of early decarbonization, as the rapid energy transformation poses stresses in capital markets influencing economic activity. However, when the transformation is completed, GDP is 4% higher than Baseline levels in 2050, triggered by lower electricity prices, accelerated clean energy investment, and reduced fossil fuel imports. **This would lead to the creation of new job opportunities in Mayotte, with employment increasing by up to 9%-10% from Baseline levels in 2050**. New jobs are created both in sectors directly impacted by the low-carbon transition (e.g., electricity), but also in sectors featuring in supply chains of low-carbon technologies and benefitting indirectly from the transition, with jobs created in the construction sector, market, and non-market services and in the industrial sector, due to increased domestic demand and exports. **The transition to carbon neutrality has clear socio-economic benefits for Mayotte mostly triggered by the phase-out of expensive diesel-fired power plants**, even without quantifying the benefits of decarbonization related to avoided climate impacts and improved air quality.

In the Baseline scenario, an additional total of 56.6 MW of (bio-)diesel generator capacity is installed in 2045 and 2050 to meet energy demand and provide grid stability. Given the high costs of diesel-based power generation, which make it economically unattractive in all scenarios and time periods, this further expansion of diesel capacity should be avoided, and other solutions be pursued instead. This is the case in all decarbonization scenarios, where additional diesel expansion does not take place, and grid stability is achieved through demand-side management, storage and the stable generation of geothermal plants. Still, in all decarbonization scenarios, the currently estimated geothermal potential of 40 MW will be tapped into only at a late stage, and not fully be exploited due to the technology's considerable CAPEX. In the final periods of the Decarb_Demand scenario, a total of 12.1 MW geothermal capacity is installed, the lowest capacity of all decarbonization scenarios. Geothermal thus has an important role to play in the later stages of the energy transition, and today's exploration efforts around this technology can be an important first step for its exploitation in Mayotte in the future. Still, given the current high-cost projections for geothermal and its limited confirmed potential in Mayotte, other options should be considered and supported as well. These include storage and demand-based solutions, which emerge as a cost-efficient and scalable alternative. These solutions are available already today, their small scale allows for a step-by-step integration into the existing energy system, and our results confirm their high economic feasibility and profitability. Thus, to increase the momentum of the energy transition in Mayotte, these decentralized solutions should be stronger supported by awareness raising, financial support measures and regulatory changes.

Our analysis strongly focuses on economic costs and benefits, especially those that can be quantified in monetary terms. An important non-financial benefit of the energy transition is the localization of power production, with reduced (fossil-) fuel imports leading to increased energy independence. This aspect has gained relevance in the wake of the Ukraine crisis, which laid bare the critical dependence of mainland Europe on fuel imports from single regions or states, as well as the socio-political effects of rising fuel prices, resulting in burdens for the industry, consumers and public budgets and political concessions in important arenas, including climate policy. A shift towards a more decentralized energy system as envisaged in the Decarb_Demand scenario with high citizen engagement, energy efficiency and small-scale local power generation and use, could result in a wider distribution of the control and ownership of assets and their associated gains, thereby increasing the economic participation of Mayotte's citizens in the energy transition. It is not clear, however, how this shift would affect the distribution of resources and incomes between different socio-economic groups, and future research should investigate this point.

Further points for future research include a detailed analysis of non-economic barriers, such as social and political factors, path dependencies, and (unfavourable) policies and regulations. On the techno-economic side, a further quantification of the costs of grid extension, balancing, storage, and other services needed for higher RES penetration in Mayotte's energy system, would allow for a more detailed understanding of the economic viability of renewables. Also, a more detailed analysis of environmental impacts through life-cycle assessment can support a multi-faceted understanding of energy transition pathways, beyond financial costs and greenhouse gas emissions.

Our analysis makes clear that the energy transition entails significant shifts, both in the composition of the energy system and the wider economy. While major investments will be needed to finance environmentally friendly assets in all sectors, Mayotte stands much to gain from lower energy expenditures, increased economic activity and competitiveness, new jobs and the wider environmental benefits of the transition.

# 8. REFERENCES

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